DOCUMENT 1

U.S. Department of Energy
Washington, DC

MINOR CHANGE

DOE O 413.3B

Approved: 11-29-2010
Chg 5 (MinChg): 04-12-2018

SUBJECT: MINOR CHANGE TO DOE O 413.3B, *PROGRAM AND PROJECT MANAGEMENT FOR THE ACQUISITION OF CAPITAL ASSETS*

1. EXPLANATION OF CHANGES. This minor change adjusts the time-frame to achieve Critical Decision (CD)-2, *Approve Performance Baseline*, following a Congressional Budget Request for construction funds to two years before requiring Energy Systems Acquisition Advisory Board (ESAAB) review and Deputy Secretary approval. It also aligns the Order with DOE-STD-1189-2016, and changes were made to ESAAB membership to reflect the Department's current organizational structure.

2. LOCATIONS OF CHANGES:

Page	Paragraph	Changed	To
Gen		References to DOE-STD-1189-2008	DOE-STD-1189-2016
Gen		References to DOE-STD-1073-2003	DOE-STD-1073-2016
Gen		References to DOE-STD-3006-2010	Deleted from the Order
Gen		Acronyms for CSVR, PSDR, and PSVR	Deleted from the Order
Gen		References to GAO-15-37	GAO-16-22
Gen		References	Reflect their current version
3	3.c.(4). Second Bullet	An on-going set of active capital asset projects, post CD-2, of over 10 projects at any time during the current Fiscal Year (FY); and	An on-going set of active capital asset projects, post CD- 2, of over 5 projects at any time during the current Fiscal Year (FY); and
5	6.	Language did not previously exist.	INVOKED STANDARDS. The following DOE technical standards and industry standards are invoked as required methods in this Order in accordance with the applicability and conditions

Page	Paragraph	Changed	To
			described within this Order. Any technical standard or industry standard that is mentioned in or referenced by this Order, but is not included in the list below, is not invoked by this Order. Note: DOE O 251.1D, Appendix J, provides a definition for "invoked technical standard." a. DOE-STD-1189-2016, *Integration of Safety into the Design Process*. This DOE technical standard is required to be used for development and integration of safety analysis and supporting design for new nuclear facilities and applicable modifications. See Appendix A and Attachment 1 for specific requirements. b. DOE-STD-1073-2016, *Configuration Management*. This DOE technical standard is required to be used in the establishment of a configuration management process for new nuclear facilities and applicable modifications. See Attachment 1, Section 9 for specific requirements. c. DOE-STD-1104-2016, *Review and Approval of Nuclear Facility Safety Basis and Safety Design Basis Documents*. This DOE technical standard is invoked by DOE O 420.1C, *Facility Safety*, and therefore treated as a requirement in this Order for DOE review and approval of safety basis and safety design basis documents for nuclear facilities.
5	6.-8.	Renumbered	7.-9.

Page	Paragraph	Changed	To
A-5	4.b.	This process uses a systems engineering methodology that integrates requirements analysis, risk identification and analysis, acquisition strategies, and concept exploration….	This process uses a systems engineering methodology that integrates requirements analysis, safety strategies, risk identification and analysis, acquisition strategies, and concept exploration….
A-8	Table 2.1	Conduct a Preliminary Security Vulnerability Assessment from prior to CD-2	Prior to CD-1
A-8	Table 2.1	For Hazard Category 1, 2, and 3 nuclear facilities, prepare a Safety Design Strategy (SDS), with the concurrence of the CNS or with written advice of the CDNS, as appropriate, for projects subject to DOE-STD-1189-2008.	For Hazard Category 1, 2, and 3 nuclear facilities, prepare a Safety Design Strategy (SDS) to guide the development of the conceptual design, with the concurrence of the CNS or with written advice of the CDNS, as appropriate, for projects subject to DOE-STD-1189-2016.
A-8	Table 2.1	Approval authority of the CSDR from SBAA via the CSVR	SBAA via the Safety Review Letter
A-8	Table 2.1	Prepare a Conceptual Safety Validation Report (CSVR), with concurrence from the FPD, on the DOE review of the CSDR for Hazard Category 1, 2, and 3 nuclear facilities. (Refer to DOE-STD-1189-2008.)	Prepare a Safety Review Letter, with concurrence from the FPD, on the DOE review of the CSDR for Hazard Category 1, 2, and 3 nuclear facilities. (Refer to DOE-STD-1189-2016 and DOE-STD-1104-2016.)
A-9	Table 2.1 Note 4	Per 10 CFR 830.206(b), a major modification of an existing Hazard Category 1, 2 or 3 nuclear facility requires DOE approval of the nuclear safety design criteria to be used in the PDSA, unless the contractor uses the design criteria in DOE O 420.1, *Facility Safety*. Per DOE-STD-1189-2008, a SDS must be developed that addresses: (1) the need for a CSDR or Preliminary Safety Design	Per 10 CFR 830.206(b), a major modification of an existing Hazard Category 1, 2 or 3 nuclear facility requires DOE approval of the nuclear safety design criteria to be used in the PDSA, unless the contractor uses the design criteria in DOE O 420.1C, *Facility Safety*. Content requirements and guidance for the SDS are specified in DOE-STD-1189-2016.

Page	Paragraph	Changed	To
		Report (PSDR) as well as the required PDSA, to support project phases; (2) the graded content of the PDSA necessary to support the design and modification; (3) the application of nuclear safety design criteria; and (4) the interface with the existing facility, its operations, and construction activities.	
A-11	Table 2.2	Prepare a Preliminary Safety Design Report (PSDR)[3] that updates the CSDR for Hazard Category 1, 2, and 3 nuclear facilities based on updated hazard analysis and design information. For a project involving a major modification of an existing facility, the SDS must address the need for a PSDR, as well as the required PDSA. (Refer to DOE-STD-1189-2008.) Approval authority from SBAA via the PSVR	Prepare Preliminary Safety and Design Results[3] that update the CSDR for Hazard Category 1, 2, and 3 nuclear facilities based on updated hazard analysis and design information. These results complete the preliminary design phase and allow for DOE review prior to completing the final design phase. (Refer to DOE-STD-1189-2016.) SBAA via the Safety Review Letter
A-11	Table 2.2	Prepare a Preliminary Safety Validation Report (PSVR), with concurrence from the FPD, based on a DOE review of the PSDR for Hazard Category 1, 2, and 3 nuclear facilities. (Refer to DOE-STD-1189-2008.)	Prepare a Safety Review Letter, with concurrence from the FPD, based on a DOE review of the Preliminary Safety and Design Results for Hazard Category 1, 2, and 3 nuclear facilities. This DOE review should be scheduled as early as practicable, after contractor completion of the preliminary design, to minimize project risk. (Refer to DOE-STD-1189-2016 and DOE-STD-1104-2016.)
A-11	Table 2.2	Prepare a Safety Evaluation Report, with concurrence from the FPD, based on review of the PDSA for Hazard Category 1, 2, and 3 nuclear facilities.	Prepare a Safety Evaluation Report, with concurrence from the FPD, based on review of the PDSA for Hazard Category 1, 2, and 3 nuclear facilities. (Refer to

Page	Paragraph	Changed	To
		(Refer to 10 CFR Part 830, Subpart B.)	10 CFR Part 830, Subpart B, and DOE-STD-1104-2016.)
A-12	Table 2.2 Note 4	Per 10 CFR 830.206(b), a major modification of an existing Hazard Category 1, 2 or 3 nuclear facility requires DOE approval of the nuclear safety design criteria to be used in the PDSA, unless the contractor uses the design criteria in DOE O 420.1, *Facility Safety*. Per DOE-STD-1189-2008, a SDS must be developed that addresses: (1) the need for a CSDR or Preliminary Safety Design Report (PSDR) as well as the required PDSA, to support project phases; (2) the graded content of the PDSA necessary to support the design and modification; (3) the application of nuclear safety design criteria; and (4) the interface with the existing facility, its operations, and construction activities.	Per 10 CFR 830.206(b), a major modification of an existing Hazard Category 1, 2 or 3 nuclear facility requires DOE approval of the nuclear safety design criteria to be used in the PDSA, unless the contractor uses the design criteria in DOE O 420.1C, *Facility Safety*. Content requirements and guidance for the SDS are specified in DOE-STD-1189-2016.
A-12	Table 2.2 Note 5	Language did not previously exist.	5. There are some statutory (appropriation and authorization) and/or regulatory provisions that implicate this Order. Solely for purpose of the application of appropriations and authorization laws and regulations and for any approvals under those laws and regulations, CD-3A (or CD-3X) will be treated as separate from and not within the scope of those laws and regulations as they pertain to CD-2 and CD-3. For all other purposes, from a project management perspective, CD-3A (or CD-3X) remains part of the project total scope and remains embedded in the project TPC.

Page	Paragraph	Changed	To
A-12	4.c.(2) Bullet 1 Bullet 3 Bullet 4	Optional budget request process for construction projects. Upon PME approval, a construction project can submit a line item budget request prior to CD-2 approval, provided the PME accepts the following conditions: • Project will document the strategy to request funds prior to CD-2 approval in the AS and preliminary PEP. • CD-2 approval is obtained within one year following OMB budget submission to Congress. Typically, there are no exceptions and subsequent budget requests would not be allowed until CD-2 approval. • If CD-2 approval is not achieved within one year following budget submission, any future budget requests for construction must be approved by the CE through the ESAAB process.	Optional budget request process for construction projects. Normally, funds for construction cannot be requested until CD-2 approval is obtained, or when CD-3A approval is obtained to support CD-3A scope of work. Upon PME approval, a construction project can submit a line item budget request prior to CD 2 approval, provided the PME accepts the following conditions: • Project will document the strategy to request funds (i.e., CD-3A) prior to CD-2 approval in the AS and preliminary PEP. • CD-2 approval is obtained within two years following OMB budget submission to Congress. Typically, there are no exceptions and subsequent budget requests would not be allowed until CD-2 approval. • If CD-2 approval is not achieved within two years following budget submission, any future budget requests for construction must be approved by the CE through the ESAAB process.
A-16	Table 2.4	Prepare a Safety Evaluation Report (SER) based on a review of the Documented Safety Analysis and Technical Safety Requirements for Hazard Category 1, 2, and 3 nuclear facilities. (Refer to 10 CFR Part 830, Subpart B.)	Prepare a Safety Evaluation Report (SER) based on a review of the Documented Safety Analysis and Technical Safety Requirements for Hazard Category 1, 2, and 3 nuclear facilities. (Refer to 10 CFR Part 830, Subpart B, and DOE-STD-1104-2016.)
A-16	Table 2.4	For nuclear facilities, the Code of Record must be included as part of the turnover documentation from a design and construction phase contractor to the operating phase contractor; from an operating phase contractor to	For nuclear facilities, the Code of Record must be included as part of the turnover documentation from a design and construction phase contractor to the operating phase contractor; from an operating phase contractor to the decommissioning phase

Page	Paragraph	Changed	To
		the decommissioning phase contractor; and when a change in contractor occurs during any single life cycle phase and is maintained under configuration control.	contractor; and when a change in contractor occurs during any single life cycle phase and is maintained under configuration control. (Refer to DOE-STD-1189-2016)
A-18	5.c.	Language did not previously exist.	For projects involving construction of new Hazard Category 1, 2, and 3 nuclear facilities, DOE-STD-1189-2016 provides requirements for contractor justification of long-lead procurement items. DOE-STD-1104-2016 establishes the required method for DOE review and approval of long-lead procurement items.
A-22	7.a.(2) and (3)	ESAAB Membership. The members are (including anyone acting in such capacity): (2) Under Secretary for Management and Performance (3) Under Secretary for Science and Energy	ESAAB Membership. The members are (including anyone acting in such capacity): (2) Under Secretary of Energy (3) Under Secretary for Science
A-23	7.a.	The Deputy Secretary will serve as the Chair and the Under Secretary for Management and Performance will serve as the Vice Chair. In the event that the Deputy Secretary position is vacant or the Deputy Secretary is recused from a matter involving the ESAAB or is otherwise unable to attend an ESAAB meeting, the Chair of the ESAAB shall be filled by the Vice Chair. In the event that the Under Secretary for Management and Performance position is vacant, the Secretary shall designate a Vice Chair from among the members. In the event that	The Deputy Secretary will serve as the Chair. In the event that the Deputy Secretary position is vacant, the Secretary shall designate a Chair from among the members. If the Deputy Secretary is recused from a matter involving the ESAAB or is otherwise unable to attend an ESAAB meeting, the Deputy shall designate a Chair from among the members. The Chair may elect to choose a Chair pro tempore, from among the members, to convene an ESAAB meeting to review a CD and to transmit the recommendation of the ESAAB to the Chair.

Page	Paragraph	Changed	To
		both the Deputy Secretary and Under Secretary for Management and Performance positions are vacant, the position of the Chair shall be filled by the Secretary. The Chair may elect for the Vice Chair to convene an ESAAB meeting to review a CD and to transmit the recommendation of the ESAAB to the Chair.	
A-27	7.f.(2) and (3)	Membership. The Secretary shall appoint the members of the committee. All committee members shall be federal employees who are experts in their representative fields or senior leaders with significant decision making authorities. Standing members shall include: (2) Director, Office of Project Management Oversight and Assessments, Office of the Under Secretary for Management and Performance (Secretariat) (3) Director, Office of Project Assessments, Office of the Under Secretary of Management and Performance	Membership. The Secretary shall appoint the members of the committee. All committee members shall be federal employees who are experts in their representative fields or senior leaders with significant decision making authorities. Standing members shall include: (2) Director, Office of Project Management Oversight and Assessments, Office of the Under Secretary of Energy (Secretariat) (3) Director, Office of Project Assessment, Office of Environmental Management, Office of the Under Secretary for Science
C-5	6.a.	Design Management for Nuclear Facilities. Nuclear construction projects are DOE/NNSA projects that build facilities with technologies to manage, store, process or handle nuclear materials, shall comply with DOE-STD-1189-2008 design safety requirements. Projects designated as Hazard Category 1, 2, and 3 nuclear facilities shall achieve at least 90	Design Management for Nuclear Facilities. Projects involving construction of new Hazard Category 1, 2, and 3 nuclear facilities intended to manage, store, process or handle nuclear materials shall comply with DOE-STD-1189-2016 and shall achieve at least 90 percent design completion before CD-2. The objective of this requirement is to ensure systems, structures, and components, the overall design, are sufficiently mature to

Page	Paragraph	Changed	To
		percent design completion before CD-2. The objective is to ensure systems, structures, and components, the overall design, are sufficiently mature to meet project requirements and outcomes and thus fulfilling the mission need.	meet project requirements and outcomes and thus fulfilling the mission need.
C-13	9.a.(2) and (3)	(2) Prior to CD-2, a PSDR is developed from the CSDR to reflect more refined analyses based on the evolving design and safety integration activities during preliminary design. The PSDR should include the results of process hazards analyses and confirm or adjust, as appropriate, the items included in the CSDR. (3) Prior to CD-2, a PDSA is prepared which updates the safety information in the PSDR and identifies and justifies changes from the design approach described in the PSDR.	(2) At completion of the Preliminary Design Phase, Preliminary Safety and Design Results are developed to reflect more refined analyses based on the evolving design and safety integration activities during preliminary design. The Preliminary Safety and Design Results should include the results of process hazards analyses and confirm or adjust, as appropriate, the items included in the CSDR. (3) Prior to CD-2, a PDSA is prepared which updates and expands the safety information in the Preliminary Safety and Design Results and identifies and justifies any changes from the design approach described in the Preliminary Safety and Design Results.
C-14	9.b.(2)	Prior to CD-2, a Hazard Analysis Report is developed by updating the PHAR to include any new or revised information on facility hazards and safety design.	Prior to CD-2, a Hazard Analysis Report is developed by updating the PHAR to include any new or revised information on facility hazards and safety design. If the hazard characterization is below Hazard Category 3 by analysis, the SBAA should approve this analysis before CD-2.
C-23	23.c.(1)	Language did not previously exist.	(1) DOE Review of Preliminary Safety and Design Results. For Hazard Category 1, 2, and 3 nuclear facilities, DOE conducts

Page	Paragraph	Changed	To
			an independent review of the Preliminary Design and Safety Results to determine whether final design should proceed. The review may consist of a single review or a series of reviews, based on when the preliminary design of the facility (or of defined segments of the design) is complete and ready to enter final design. This review is conducted by a DOE-selected team of experts and its results provided to the FPD for review and action as necessary. The size and composition of the team reflects the size and complexity of the project. More than one review may be conducted at the discretion of the FPD; the SDS should define segments when more than one review is planned. The independent review(s) should be scheduled as early as practicable, after completion of preliminary design, to minimize project risk. This review may be handled by the TIPR, as long as the appropriate experts are part of the review team. Refer to DOE-STD-1104-2016 for the required method for DOE personnel to review and approve the Preliminary Design and Safety Results.
C-24	23.c.(2)	Completion of the TIPR is required prior to the start of any subsequent reviews (including EIRs) and is required prior to CD-2 approval. CNS or CDNS concurrence, as appropriate, is required for reviews of projects that must implement DOE-STD-1189-2008.	Completion of the TIPR is required at or near the completion of preliminary design, and prior to the start of any subsequent reviews (including EIRs) and is required prior to CD-2 approval. CNS or CDNS concurrence in CD-2 approval is required for reviews of projects that must implement DOE-STD-1189-2016.

Page	Paragraph	Changed	To
C-32	27.e.	CD-3A may be needed for long lead item procurement. While there is potential risk in procuring equipment before the design is complete, the potential schedule improvement may be significant and more than compensate for the risk. If the long lead item is nuclear safety related or nuclear safety related equipment, safety document maturity must also be considered.	CD-3A may be needed for long lead item procurement. While there is potential risk in procuring equipment before the design is complete, the potential schedule improvement may be significant and more than compensate for the risk. If the long lead item is nuclear safety related or nuclear safety related equipment, safety document maturity must also be considered (refer to DOE-STD-1189-2016 and DOE-STD-1104-2016).
Atch 1 Pg.5	14.	For projects that are Hazard Category 1, 2, and 3 nuclear facilities or include major modifications thereto (as defined in 10 CFR Part 830), the requirements in DOE-STD-1189-2008 shall be fully implemented. The following documents must be submitted: Safety Design Strategy (CD-1), Conceptual Safety Design Report (CD-1), Preliminary Safety Design Report (CD-2), Preliminary Documented Safety Analysis (CD-2), and Documented Safety Analysis with Technical Safety Requirements (CD-4). For major modifications, the Conceptual Safety Design Report (CSDR) and the Preliminary Safety Design Report (PSDR) may either be separate documents or be subsumed within the Preliminary Documented Safety Analysis. The need to maintain the CSDR and PSDR as separate documents shall be based on the design development phases. Projects with conceptual and/or preliminary design phases shall	For projects involving construction of new Hazard Category 1, 2, and 3 nuclear facilities or include major modifications thereto (as defined in 10 CFR Part 830), the requirements in DOE-STD-1189-2016 shall be fully implemented. The following documents must be submitted, as applicable: Safety Design Strategy (CD-1), Conceptual Safety Design Report (CD-1), Preliminary Safety and Design Results (CD-2), Preliminary Documented Safety Analysis (CD-2), and Documented Safety Analysis with Technical Safety Requirements (CD-4).

Page	Paragraph	Changed	To
		develop the corresponding safety documentation.	
Atch 2 Pg.2	15.	Code of Record. A set of requirements, including Federal and state laws, as defined in contracts and Standards or Requirements Identification Documents (or their equivalent), that are in effect at the time a facility or item of equipment was designed and accepted by DOE. It is initiated during the conceptual design phase, and prior to approval of CD-1. It is placed under configuration control to ensure it is updated to include more detailed design requirements as they are developed during preliminary design, and prior to approval of CD-2. It is controlled during final design and construction with a process for reviewing and evaluating new and revised requirements to determine their impact on project safety, cost and schedule before a decision is taken to revise the Code of Record. It is maintained and controlled through facility decommissioning.	Code of Record. A set of design and operational requirements, including Federal and state laws, in effect at the time a facility or item of equipment was designed and accepted by DOE. It is (i) initiated during the conceptual design phase, placed under configuration control to ensure it is updated to include more detailed design requirements as they are developed during preliminary design, (ii) controlled during final design and construction with a process for reviewing and evaluating new and revised requirements to determine their impact on project safety, cost and schedule before a decision is taken to revise the Code of Record, and (iii) maintained and controlled through facility decommissioning. The Code of Record may be defined in contracts, Standards or Requirements Identification Documents (or their equivalent), or project-specific documents. [DOE-STD-1189-2016]
Atch 2 Pg.7	55.	General Plant Project. Miscellaneous minor construction project, of a general nature, for which the total estimated cost may not exceed the congressionally established limit. GPPs are necessary to adapt facilities to new or improved production techniques, to effect economies of operations, and to reduce or eliminate health, fire and security problems.	General Plant Project. Miscellaneous minor construction project, of a general nature, for which the total estimated cost may not exceed the congressionally established limit. GPPs are necessary to adapt facilities to new or improved production techniques, to effect economies of operations, and to reduce or eliminate health, fire and security problems. These projects provide for design, construction, additions,

Page	Paragraph	Changed	To
		These projects provide for design and/or construction, additions, improvements to land, buildings, replacements or additions to roads, and general area improvements. (Refer to DOE O 430.1B and 50 USC 2743)	and/or improvements to land, buildings, replacements or additions to roads, and general area improvements. (Refer to 50 USC 2743)
Atch 2 Pg.12	107.	Technical Independent Project Review. An independent project review conducted prior to obtaining CD-2, for Hazard Category 1, 2, and 3 nuclear facilities. At a minimum, the focus of this review is to determine that the safety documentation is sufficiently conservative and bounding to be relied upon for the next phase of the project.	Technical Independent Project Review. An independent project review conducted at or near the completion of preliminary design, and is required prior to CD-2 approval, for Hazard Category 1, 2, and 3 nuclear facilities. At a minimum, the focus of this review is to determine that the safety documentation is sufficiently conservative and bounding to be relied upon for the next phase of the project.

U.S. Department of Energy
` **Washington, D.C.**

ORDER

DOE O 413.3B

Approved: 11-29-2010
Chg 1 (Admin Chg): 10-22-2015
Chg 2 (PgChg): 05-12-2016
Chg 3 (PgChg): 12-20-2016
Chg 4 (MinChg): 10-13-2017
Chg 5 (MinChg): 04-12-2018

SUBJECT: PROGRAM AND PROJECT MANAGEMENT FOR THE ACQUISITION OF CAPITAL ASSETS

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1. PURPOSE.

   a. To provide the Department of Energy (DOE) Elements, including the National Nuclear Security Administration (NNSA), with program and project management direction for the acquisition of capital assets with the goal of delivering projects within the original performance baseline (PB), cost and schedule, and fully capable of meeting mission performance, safeguards and security, and environmental, safety, and health requirements unless impacted by a directed change.

   b. To implement Office of Management and Budget (OMB) Circulars to include: A-11, and its supplement, *Capital Programming Guide*, which prescribes new requirements and leading practices for project and acquisition management; A-123, *Management's Responsibility for Internal Control*, which defines management's responsibility for internal control in Federal agencies; and A-131, *Value Engineering*, which requires that all Federal agencies use Value Engineering (VE) as a management tool.

2. CANCELLATION. This Order cancels DOE O 413.3A, Chg 1, *Program and Project Management for the Acquisition of Capital Assets*, dated 11-17-08. Cancellation of a directive does not, by itself, modify or otherwise affect any contractual or regulatory obligation to comply with the directive. Contractor Requirements Documents (CRDs) that have been incorporated into a contract remain in effect throughout the term of the contract unless and until the contract is modified to either eliminate requirements that are no longer applicable or substitute a new set of requirements.

3. APPLICABILITY.

   a. Departmental Applicability.

      The requirements identified in this Order are mandatory for all DOE Elements (unless identified in Paragraph 3.c., Equivalencies/Exemptions) for all capital asset projects having a Total Project Cost (TPC) greater than $50M, except that during the project development phase, Under Secretaries may reduce the threshold to $10M for nuclear projects or complex first-of-a-kind projects. Any reference to a Program Secretarial Officer (PSO) in this Order is also applicable to the Deputy Administrator/Associate Administrators for the NNSA.

The principles (see Appendix C, Paragraph 1.a.-l.) as set forth in this Order apply to all capital asset projects. They also apply to General Plant Projects (GPPs) for which the approved total estimated cost does not exceed the minor construction threshold, using a tailored approach.

All projects with a TPC greater than $50M are required to report progress and provide documentation in the Project Assessment and Reporting System (PARS II) at Critical Decision (CD)-0 and thereafter, in accord with Appendix C. After CD-2 is approved for projects with a TPC greater than $50M, earned value reporting shall apply.

Additionally, for all projects with a TPC greater than $50M, all approved CD or equivalent documents and performance baseline changes shall be submitted to the Office of Project Management Oversight and Assessments (PM).

This Order does not apply to Financial Assistance Awards (grants and cooperative agreements) covered under 2 CFR Parts 200 and 910 and 10 CFR Part 600 (legacy awards).

The Administrator of NNSA will assure that NNSA employees and contractors comply with their respective responsibilities under this directive. Nothing in this Order will be construed to interfere with the NNSA Administrator's authority under Section 3212(d) of Public Law (P.L.) 106-65 to establish Administration-specific policies, unless disapproved by the Secretary.

b. DOE Contractors.

Except for the equivalencies/exemptions in paragraph 3.c., the CRD (Attachment 1) sets forth requirements of this Order that will apply to contracts that include the CRD.

The CRD must be included in all contracts that make the contractor responsible for planning, design, construction and execution of capital asset projects subject to this Order.

c. Equivalencies/Exemptions. Equivalencies and exemptions to this Order are processed in accordance with DOE O 251.1D, Departmental Directives Program. Central Technical Authority (CTA) (or designee) concurrence is required for both exemptions and equivalencies to this Order for nuclear facilities. The Deputy Secretary must approve all equivalencies and exemptions to the requirements delineated in this Order except for those stipulated in Paragraphs 3.c.(3)-(4).

(1) Equivalency. In accordance with the responsibilities and authorities assigned by Executive Order (EO) 12344, codified at 50 USC Sections 2406 and 2511 and to ensure consistency through the joint Navy/DOE Naval Nuclear Propulsion Program, the Deputy Administrator for Naval

Reactors (Director) will implement and oversee requirements and practices pertaining to this Directive for activities under the Director's cognizance, as deemed appropriate.

(2) Equivalency. Bonneville Power Administration in accordance with Secretarial Delegation Order 00-033.00B, dated 7-20-09.

(3) Exemption – Specific Capital Asset Project. For PSOs that are not exempt as defined in Paragraph 3.c.(4) of this Order, the Programs may present cases to the Project Management Risk Committee (PMRC) for a specific project to have an exemption from a specific Order requirement. If the consensus of the committee is to endorse the exemption request, approval of the exemption request will be made by the appropriate Under Secretary. However, if consensus cannot be attained, at the discretion of the Program, the exemption request may be forwarded to the Deputy Secretary as the Chief Executive for Project Management (CE) with formal review by the PMRC outlining the advantages and disadvantages of the proposed exemption. In this case, the exemption request will be entered into, and processed through, the Department's formal collaboration process.

(4) Exemption. PSOs that meet all of the following criteria may be excluded from specific requirements of this Order. The intent of this exemption is to shift CD authority to the PSO and place those activities normally carried out by PM in the hands of the Project Management Support Office (PMSO). They must have:

- An established PMSO with adequate project management requirements, processes and procedures defined to enable continued project success. This will be validated by PM and must be consistent with the Acquisition Management System delineated in the Order;

- An on-going set of active capital asset projects, post CD-2, of over 5 projects at any time during the current Fiscal Year (FY); and

- Completed 90% of projects across a three-year rolling average, not to exceed by more than 10% of the original cost baseline for the original approved scope at CD-2 for all capital asset projects with a TPC greater than $50M.

To allow PM to determine Departmental-wide metrics and to permit an independent validation of the PSO eligibility to exercise this exemption, all PSOs are still required to:

- Report all projects into PARS II monthly, including earned value data, when applicable.

- Submit all CD or equivalent documents to PM.

- Submit Performance Baseline Change Proposal approvals to PM.

- PM will lead Independent Cost Reviews and Independent Cost Estimates as delineated in Appendix A, Tables 2.0 through 2.3.

For PSOs that are eligible for the exemption, the Deputy Secretary must take affirmative action and approve the exemption through an action memorandum from the PSO with concurrence from PM. The Deputy Secretary may specify exceptions (e.g., retain high profile projects).

Additionally, the nuclear safety-related requirements of the Order, including DOE-STD-1189-2016, shall not be exempted. Further, this exemption does not apply to defense nuclear facilities.

The Deputy Secretary shall rescind this exemption if the PSOs are unable to maintain the exemption requirements listed previously. The exemption may also be rescinded at any time at the discretion of the Deputy Secretary.

(5) When a PSO is no longer exempt, the requirements of this Order must be implemented within six months. Specifically, projects reaching a particular CD or project closeout within six months of exemption rescission are not required to comply with this Order for approval of that CD. Those reaching a CD after six months of exemption rescission shall comply with this Order to gain approval of that particular CD or for project closeout.

4. REQUIREMENTS.

a. General.

(1) Detailed requirements on capital asset projects are provided in this Order.

(2) Guides are not requirements documents and are not to be construed as requirements in any audit or appraisal for compliance with the parent Policy, Order, Notice, or Manual. The Guides referenced in this Order are meant as suggestions or potential guidelines for content and purpose of documents.

Tailoring is necessary for the efficient delivery of projects and should be applied to all projects considering size, complexity, cost, and risks. Tailoring does not imply the omission of requirements, and requirements must be addressed to the extent necessary and practical. Tailoring may involve consolidation or phasing of CDs, substituting equivalent documents, using a graded approach to document development and content, concurrency of processes, or creating a portfolio of projects to facilitate a single CD or Acquisition Strategy (AS) for the entire group of projects. Tailoring may also include adjusting the scope of Independent Project Reviews (IPRs) and External Independent Reviews (EIRs), delegation of acquisition authority, and other elements. Major tailored elements such as consolidating or phasing CDs or delegation of Project Management Executive (PME) duties must be specified in the Project Execution Plan (PEP) or the Tailoring Strategy and approved by the PME. For Hazard Category 1, 2, and 3 nuclear facilities, the Tailoring Strategy must include the approach to satisfying DOE-STD-1189-2016 safety document development.

b. Implementation. The requirements in this update must be implemented immediately upon issuance of this Order. Programs are not required to revisit previously achieved critical decisions.

5. RESPONSIBILITIES. Key roles and responsibilities of line managers are described in Appendix B.

6. INVOKED STANDARDS. The following DOE technical standards and industry standards are invoked as required methods in this Order in accordance with the applicability and conditions described within this Order. Any technical standard or industry standard that is mentioned in or referenced by this Order, but is not included in the list below, is not invoked by this Order. Note: DOE O 251.1D, Appendix J, provides a definition for "invoked technical standard."

a. DOE-STD-1189-2016, *Integration of Safety into the Design Process*. This DOE technical standard is required to be used for development and integration of safety analysis and supporting design for new nuclear facilities and applicable modifications. See Appendix A and Attachment 1 for specific requirements.

b. DOE-STD-1073-2016, *Configuration Management*. This DOE technical standard is required to be used in the establishment of a configuration management process for new nuclear facilities and applicable modifications. See Attachment 1, Section 9 for specific requirements.

c. DOE-STD-1104-2016, *Review and Approval of Nuclear Facility Safety Basis and Safety Design Basis Documents*. This DOE technical standard is invoked by DOE O 420.1C, *Facility Safety*, and therefore treated as a requirement in this Order for DOE review and approval of safety basis and safety design basis documents for nuclear facilities.

7. DEFINITIONS. See Attachment 2. See Attachment 3 for Acronyms.

8. REFERENCES. See Attachment 4.

9. CONTACT. Questions concerning this Order should be directed to PM, 202-586-3524.

BY ORDER OF THE SECRETARY OF ENERGY:

DAN R. BROUILLETTE
Deputy Secretary

TABLE OF CONTENTS

Topics addressed are accessible through links in the following topic list:

Appendix A: Requirements

Appendix B

Appendix C

List of Attachments:

List of Tables:

List of Figures:

APPENDIX A
REQUIREMENTS

1. Objective.

The Department's ultimate objective is to deliver every project at the original PB, on schedule, within budget, and fully capable of meeting mission performance, safeguards and security, quality assurance (QA), sustainability, and environmental, safety, and health requirements. Consistent with this objective, a project shall be completed at CD-4 within the original approved performance baseline (CD-2), unless otherwise impacted by a directed change.

The authority and accountability for any project, including its costs, must be vested firmly in the hands of the Federal Project Director (FPD).

Some cost estimate, or cost range, should be provided at each CD gateway, but the degree of rigor and detail for a cost estimate should be carefully defined, depending on the degree of confidence in project scale and scope that is reasonable to expect at that stage. Whatever figure or range that is provided should explicitly note relevant caveats concerning uncertainties inherent in estimates at CD-0 and CD-1 stages.

A project owner should never be the sole cost estimator, at any stage (i.e., from CD-0 on), given the inherent conflict of interest.

The second cost estimator should come from outside of the line manager's chain of command, to avoid conflict of interest.

2. DOE Acquisition Management System.

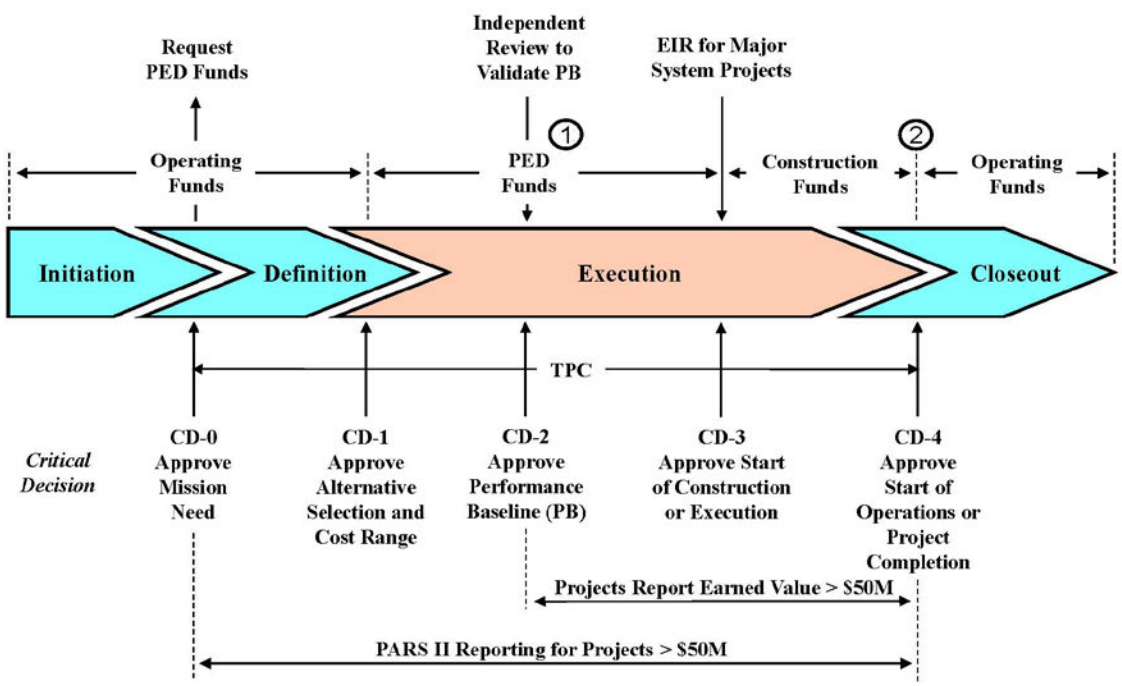
The DOE Acquisition Management System establishes principles and processes that translate user needs and technological opportunities into reliable and sustainable facilities, systems, and assets that provide a required mission capability. The system will be organized by project phases and CDs, progressing from broadly-stated mission needs into well-defined requirements resulting in operationally effective, suitable, and affordable facilities, systems, and other products.

Within DOE, projects typically progress through five CDs, which serve as major milestones approved by the Chief Executive for Project Management (CE) or PME. Each CD marks an authorization to increase the commitment of resources by DOE and requires successful completion of the preceding phase or CD. The amount of time between decisions will vary. The CDs are:

- CD-0, Approve Mission Need. There is a need that cannot be met through other than material means;
- CD-1, Approve Alternative Selection and Cost Range. The selected alternative and approach is the optimum solution;

- CD-2, Approve Performance Baseline. Definitive scope, schedule and cost baselines have been developed;
- CD-3, Approve Start of Construction/Execution. The project is ready for implementation; and
- CD-4, Approve Start of Operations or Project Completion. The project is ready for turnover or transition to operations, if applicable.

Figure 1 illustrates the requirements for the typical implementation of the DOE Acquisition Management System for Line Item Capital Asset Projects. Figure 2 depicts the implementation for Other Capital Asset Projects such as Major Items of Equipment (MIE) and Operating Expense (OE) projects.



NOTES:
1. PED funds can be used after CD-3 for design.
2. Operating Funds may be used prior to CD-4 for transition, startup, and training costs.

Figure 1. Typical DOE Acquisition Management System for Line Item Capital Asset Projects

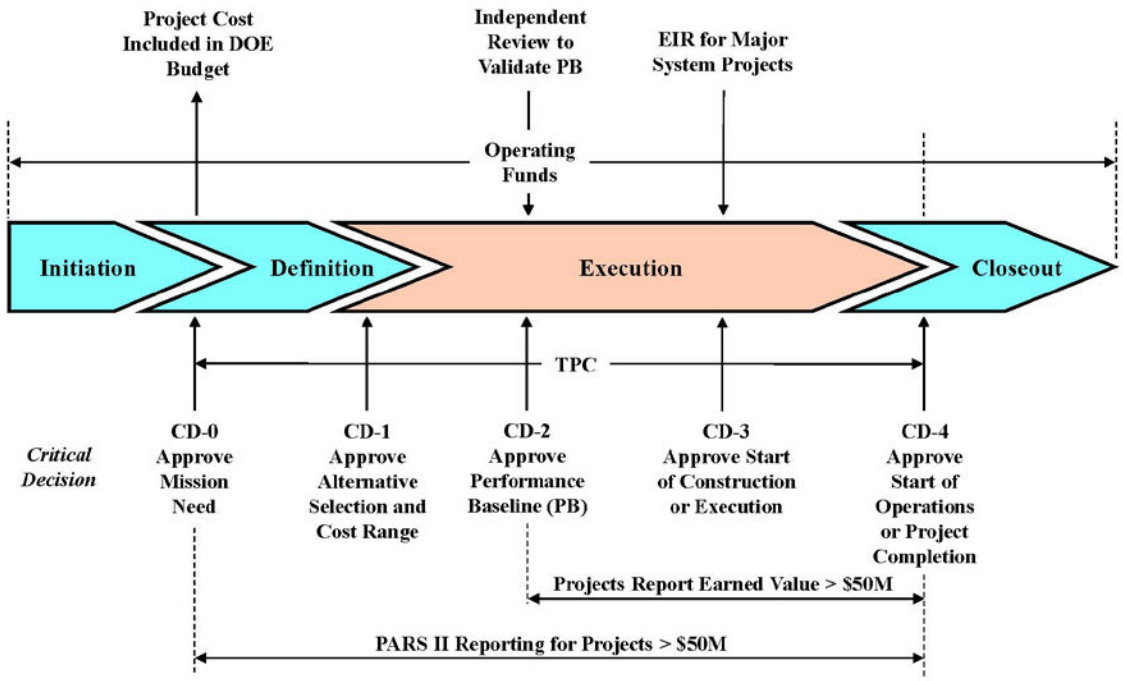


Figure 2. Typical DOE Acquisition Management System for Other Capital Asset Projects (i.e., Major Items of Equipment and Operating Expense Projects)

3. Critical Decision Approval Authority and Thresholds.

The Deputy Secretary serves as the Department's CE and promulgates Department-wide policy and direction. The CD authorities, thresholds and delegations are identified in Table 1.

a. Major System Projects.

Projects with a TPC greater than or equal to $750M are Major System Projects. All Major System Project CDs must be proposed by the appropriate PSO and approved by the Deputy Secretary as DOE's designated CE before proceeding to the next project phase or CD.

b. Non-Major System Projects.

Projects with a TPC less than $750M are Non-Major System Projects. The designated PME must approve all Non-Major System Project CDs, except for CD-0, which cannot be delegated below the PSO.

Table 1. Critical Decision Authority Thresholds

Critical Decision Authority	Total Project Cost Thresholds
Deputy Secretary	≥ $750M (or any project on an exception basis when designated by the Deputy Secretary) **Further delegation is allowed.**
Under Secretaries	≥ $100M and < $750M (or any project on an exception basis when designated by the Under Secretaries) **Further delegation is allowed.**
Program Secretarial Officer	> $50M and < $100M **Further delegation is allowed.**

4. Requirements for Approval of Critical Decisions.

a. CD-0, Approve Mission Need.

The Initiation Phase begins with the identification of a mission-related need. A Program Office will identify a credible performance gap between its current capabilities and capacities and those required to achieve the goals articulated in its strategic plan. The Mission Need Statement (MNS) is the translation of this gap into functional requirements that cannot be met through other than material means. It should describe the general parameters of the solution and why it is critical to the overall accomplishment of the Department's mission, including the benefits to be realized. The mission need is independent of a particular solution, and should not be defined by equipment, facility, technological solution, or physical end-item. This approach allows the Program Office the flexibility to explore a variety of solutions and not limit potential solutions (refer to DOE G 413.3-17). Table 2.0 lists the requirements needed to attain CD-0.

The cost range provided at CD-0 should be Rough-Order of Magnitude (ROM) and is used to determine the PME authority designation. It does not represent the PB, which will be established at CD-2.

Table 2.0 CD-0 Requirements[1]	
Prior to CD-0	**Approval Authority[2]**
Perform Pre-Conceptual Planning activities that focus on the Program Offices' strategic goals and objectives, safety planning, design, development of capability gaps, high-level project parameters, a ROM cost range, and schedule estimates.	
Perform a Mission Validation Independent Review on all Major System Projects. (Refer to DOE G 413.3-9.)	PSO
Approve a Mission Need Statement Document with recommendation from PM for projects with a TPC ≥ \$100M. (Refer to DOE G 413.3-17.)	PSO
For Major System Projects, or for projects as designated by the CE, PM will conduct an Independent Cost Review (ICR).	
For Major System Projects, the Project Management Risk Committee (PMRC) will review and analyze the CD and make recommendations to the ESAAB, CE, or PME, as applicable, before approval.	CE ≥ \$750M
For NNSA only, prepare a Program Requirements Document that defines the ultimate goals which the project must satisfy. (Refer to NNSA Business and Operating Policy.)	PSO
***For Hazard Category 1, 2, and 3 nuclear facilities**, and to the specificity possible, document DOE expectations for Safety-in-Design. (Refer to DOE-STD-1189-2016.)*	*Safety Basis Approval Authority (SBAA)*
Post CD-0 Approval	
Submit all CD documents to PM.	
Develop a Project Data Sheet (PDS) for Line Item Projects to request Project Engineering and Design (PED) funds. Develop funding documents for MIE or OE projects for the design, and OMB A-11 Business Cases. (Refer to DOE CFO Budget Call for PDS and Business Case Template.)	
Initiate monthly PARS II reporting (excluding earned value data). FPD, Program Manager and PM will provide monthly assessments, as appropriate.	
Initiate Quarterly Project Reviews (QPRs) with the PME or their designee.	
Conduct a project peer review of active projects when the top-end range is \$100M or greater.	
Proceed with conceptual planning and design used to develop alternative concepts and functional requirements using operating funds.	
NOTES: 1. Documents and reports are not intended to be stand-alone and may be combined. 2. Where no approval authorities are noted, authorities are established through other directives or the Program Offices (e.g., Functions and Requirements Assignment Matrix). 3. Title 10 CFR Part 830 does not apply to accelerators and their operations.	

b. CD-1, Approve Alternative Selection and Cost Range.

CD-1 approval marks the completion of the project definition phase and the conceptual design. This is an iterative process to define, analyze, and refine project concepts and alternatives. This process uses a systems engineering methodology that integrates requirements analysis, safety strategies, risk identification and analysis, acquisition strategies, and concept exploration in order to evolve a cost-effective, preferred solution to meet a mission need (refer to DOE G 413.3-1 for more information). The recommended alternative should provide the essential functions and capabilities at an optimum life-cycle cost, consistent with required cost, scope, schedule, performance, and risk considerations. It should be reflected in the site's long-range planning documents as well. Approval of CD-1 provides the authorization to begin the project Execution Phase and allows PED funds to be used. Table 2.1 lists the requirements needed to attain CD-1.

For each project, the appropriate Under Secretary will designate a project owner. Each Under Secretary will also establish a clear line of functional responsibility that extends from the Under Secretary to the project owner to the Federal Project Director. This shall be documented in the preliminary project execution plan at CD-1.

The cost range provided at CD-1 is the preliminary estimate for the selected alternative. As CD-1 progresses to CD-2, the TPC will be refined and the TPC established at CD-2 may be higher than the range defined at CD-1, in which case the PME must be notified. The CD-1 cost range is not the PB cost. The PB against which project success is measured will be established at CD-2. The only exception is when a construction budget request is submitted in advance of an approved CD-2. In this circumstance, refer to Appendix A, Paragraph 4.c.(2).

If the top end of the original approved CD-1 cost range grows by more than 50% as the project proceeds toward CD-2, the Program, in coordination with the PME, must reassess the alternative selection process. Upon completing the review, the PME must approve a revised CD-1 identifying the new or reaffirmed selected alternative and an updated CD-1 cost range. This revised CD-1 information, to include the new CD-1 cost range and CD-1 approval date, will be reflected within PARS II and all subsequent PDS and similar project documentation.

Table 2.1 CD-1 Requirements[1]

Prior to CD-1	**Approval Authority[2]**
Approve an Acquisition Strategy (AS) with endorsement from PM for Major System Projects. (Refer to DOE G 413.3-13.)	PSO
Approve a preliminary Project Execution Plan (PEP). The Tailoring Strategy, if required, can be included in the PEP or placed in a separate document. (Refer to DOE G 413.3-15.)	CE or PME
• Approve appointment of the Federal Project Director considering the requirements in DOE O 361.1C.	CE or PME
• Establish and charter an Integrated Project Team to include a responsibility assignment matrix. The Charter may be included in the PEP. (Refer to DOE G 413.3-18A.)	PSO ≥ \$750M FPD < \$750M

Table 2.1 CD-1 Requirements[1]	
Prior to CD-1	**Approval Authority[2]**
• Develop a Risk Management Plan (RMP) and complete an initial risk assessment of a recommended alternative. This may be included in the PEP. For evaluating the Safety-in-Design Strategy, prepare Risk and Opportunity Assessments for input to the RMP. (Refer to DOE G 413.3-7A and DOE-STD-1189-2016.)	
For projects with a TPC ≥ \$100M, PM will develop an Independent Cost Estimate and/or conduct an Independent Cost Review, as they deem appropriate.	
For projects with a TPC ≥ \$100M, the PMRC will review and analyze the CD and make recommendations to the ESAAB, CE, or PME, as applicable, before approval.	CE ≥ \$750M PME < \$750M
Comply with the One-for-One Replacement legislation (excess space/offset requirement) as mandated in House Report 109-86.	
For Major System Projects, develop a Design Management Plan that establishes design maturity targets at critical milestones through final design.	
Complete a Conceptual Design.	
• Document Guiding Principles for Federal Leadership in High Performance and Sustainable Building provisions per EO 13693, Section 3(h), support for the Site or Strategic Sustainability Plan(s) per DOE O 436.1 and/or other sustainability considerations planned in the Conceptual Design Report, Acquisition Strategy, and/or PEP, as appropriate. (Refer to DOE G 413.3-6A.)	
• Conduct a Design Review of the conceptual design with reviewers external to the project.	
• ***For Hazard Category 1, 2, and 3 nuclear facilities,*** *a Code of Record shall be initiated during the conceptual design.*	
• Complete a Conceptual Design Report. Refer to Appendix C, Paragraph 8.	
Conduct an Analysis of Alternatives (AoA) that is independent of the contractor organization responsible for managing the construction or constructing the capital asset project, for projects with an estimated TPC greater than \$50M. (Refer to GAO-16-22.)	PME
For Major System Projects, or first-of-a-kind engineering endeavors, conduct a Technology Readiness Assessment and develop a Technology Maturation Plan, as appropriate. At this stage, each critical technology item or system shall achieve a Technology Readiness Level-4 (TRL-4). (Refer to DOE G 413.3-4A.)	PME
Prepare a Preliminary Hazard Analysis Report (PHAR) for facilities that are below the Hazard Category 3 nuclear facility threshold as defined in 10 CFR Part 830, Subpart B.	Field Organization
Develop and implement an Integrated Safety Management Plan into management and work process planning at all levels per DOE G 450.4-1C.	
Establish a Quality Assurance Program (QAP). (Refer to 10 CFR Part 830, Subpart A, DOE O 414.1D, and DOE G 413.3-2.) ***For nuclear facilities****, the applicable national consensus standard shall be NQA-1-2008 (Edition) and NQA-1a-2009 (Addenda).*	

Table 2.1 CD-1 Requirements[1]	
Prior to CD-1	**Approval Authority[2]**
Identify general Safeguards and Security requirements for the recommended alternative. (Refer to DOE O 470.4B and DOE G 413.3-3A.)	
Complete a National Environmental Policy Act (NEPA) Strategy by issuing a determination (e.g., Environmental Assessment), as required by DOE O 451.1B. Prepare an Environmental Compliance Strategy, to include a schedule for timely acquisition of required permits and licenses.	
Update Project Data Sheet, or other funding documents for MIE and OE projects, and A-11 Business Case, if applicable. This must contain an estimate of the required amount of PED funds to execute the planning and design portion of a project (period from CD-1 to completion of the project's design). (Refer to DOE CFO Budget Call for PDS and Business Case Template.)	
Conduct a Preliminary Security Vulnerability Assessment, if necessary. (Refer to DOE O 470.4B and DOE G 413.3-3A.)	
For Hazard Category 1, 2, and 3 nuclear facilities*, prepare a Safety Design Strategy (SDS) to guide the development of the conceptual design, with the concurrence of the CNS or with written advice of the CDNS, as appropriate, for projects subject to DOE-STD-1189-2016.*	*SBAA and FPD*
For Hazard Category 1, 2, and 3 nuclear facilities*, conduct an Independent Project Review (IPR) to ensure early integration of safety into the design process. (Refer to DOE G 413.3-9 and DOE-STD-1189-2016.)*	*PSO*
Prepare a Conceptual Safety Design Report (CSDR)[4] ***for Hazard Category 1, 2, and 3 nuclear facilities****, including preliminary hazard analysis. For a project involving a major modification of an existing facility, the SDS must address the need for a CSDR, as well as the required PDSA. (Refer to DOE-STD-1189-2016.)*	*SBAA via the Safety Review Letter*
Prepare a Safety Review Letter, with concurrence from the FPD, on the DOE review of the CSDR ***for Hazard Category 1, 2, and 3 nuclear facilities****. (Refer to DOE-STD-1189-2016 and DOE-STD-1104-2016.)*	*SBAA*
Post CD-1 Approval	
Submit all CD documents to PM.	
Begin expenditure of PED, MIE, or OE funds for the project design.	
Develop an Acquisition Plan, if applicable.	
Continue monthly PARS II reporting (excluding earned value). FPD, Program Manager and PM will provide monthly assessments, as appropriate.	
Annually conduct project peer reviews of active projects when the top-end range is $100M or greater.	
Continue QPRs with the PME of their designee.	
For nuclear facilities*, develop a Checkout, Testing and Commissioning Plan in preparation for acceptance and turnover of the structures, systems and components at CD-4. (Refer to DOE-STD-1189-2016.)*	

NOTES:

1. Documents and reports are not intended to be stand-alone and may be combined.
2. Where no approval authorities are noted, authorities are established through other directives or the Program Offices (e.g., Functions and Requirements Assignment Matrix).
3. Title 10 CFR Part 830 does not apply to accelerators and their operations.
4. Per 10 CFR 830.206(b), a major modification of an existing Hazard Category 1, 2 or 3 nuclear facility requires DOE approval of the nuclear safety design criteria to be used in the PDSA, unless the contractor uses the design criteria in DOE O 420.1C, *Facility Safety*. Content requirements and guidance for the SDS are specified in DOE-STD-1189-2016.

c. CD-2, Approve Performance Baseline.

(1) Completion of preliminary design is the first major milestone in the project Execution Phase. The design must be sufficiently mature (refer to Appendix C, Paragraph 7) at the time of CD-2 approval to provide reasonable assurance that the design will be implementable within the approved PB. The document signed by the CE or PME approving CD-2 must clearly specify the project's approved PB, which includes the TPC, CD-4 date (month and year), scope and minimum Key Performance Parameters (KPPs) that must be achieved at CD-4. Table 2.2 lists the requirements needed to attain CD-2.

Table 2.2 CD-2 Requirements[1]

Prior to CD-2	Approval Authority[2]
Approve an updated Acquisition Strategy, if there are any major changes to the acquisition approach. Obtain endorsement from PM for Major System Projects. (Refer to DOE G 413.3-13.)	PSO
Establish a Performance Baseline, reflective of identified and assessed risks and uncertainties, to include scope, TPC, CD-4 date, and minimum KPPs (if applicable). The key project milestones and completion dates shall be stated no less specific than month and year. The scope will be stated in quantity, size and other parameters that give shape and form to the project. The funding assumptions upon which the PB is predicated will be clearly documented and approved. (Refer to DOE G 413.3-5A.)	FPD
Approve updated Project Execution Plan. (Refer to DOE G 413.3-15.)	CE or PME
• Prepare a Funding Profile to support the execution of the PB and reflect in the budget document. The funding profile may be included in the PEP.	CE or PME
• Approve Long-Lead Item Procurements, if necessary. Approval may be concurrent with (or prior to) CD-2 approval. (Long-lead item procurement approval will be designated as CD-3A.)[5]	CE or PME
Develop a Project Management Plan, if applicable. (Refer to Attachment 1.)	

Table 2.2 CD-2 Requirements[1]	
Prior to CD-2	**Approval Authority[2]**
Perform a Performance Baseline External Independent Review (EIR) or an Independent Project Review (IPR). PM will conduct EIRs to validate the PB for projects with a TPC ≥ $100M. PM must issue a Performance Baseline Validation Letter to the PSO that describes the cost, schedule, and scope being validated. PMSO will conduct IPRs to validate the PB for projects with a TPC < $100M. (Refer to DOE G 413.3-9) For projects with a TPC ≥ $100M, PM will develop an Independent Cost Estimate (ICE). The ICE will support validation of the PB.	PM ≥ $100M PMSO < $100M
Complete a Preliminary and/or Final Design. ***Hazard Category 1, 2, and 3 nuclear facilities*** *shall achieve at least 90% design completion prior to CD-2 approval. Non-nuclear project designs shall be sufficiently mature to prepare a project baseline with 80-90% confidence prior to CD-2 approval. (See Appendix C, Paragraph 6a for definition of 90% design complete.)*	
• Incorporate the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings per EO 13693, Section 3(h), sustainability requirements per DOE O 436.1, and/or other sustainability considerations into the preliminary design and design review. (Refer to DOE G 413.3-6A.)	
• Conduct a Design Review of the preliminary and final designs.	
• ***For Hazard Category 1, 2, and 3 nuclear facilities,*** *design reviews should include a focus on safety and security systems. Additionally, the Code of Record shall be placed under configuration control during preliminary design. It is controlled during final design and construction with a process for reviewing and evaluating new and revised requirements. New or modified requirements are implemented if technical evaluations determine that there is a substantial increase in the overall protection of the worker, public or environment, and that the direct and indirect costs of implementation are justified in view of this increased protection.*	
• Complete a Preliminary Design Report.	
For projects with a TPC ≥ $100M, the PMRC will review and analyze the CD and make recommendations to the ESAAB, CE, or PME, as applicable, before approval.	CE ≥ $750M PME < $750M
Conduct a Project Definition Rating Index Analysis, as appropriate, for projects with a TPC ≥ $100M. PM will review as part of the EIR. (Refer to DOE G 413.3-12.)	FPD
For Major System Projects, or first-of-a-kind engineering endeavors, conduct a Technology Readiness Assessment and develop a Technology Maturation Plan, as appropriate. At this stage, each critical technology item or system shall achieve a Technology Readiness Level-7 (TRL-7). (Refer to DOE G 413.3-4A.)	PME
Employ an Earned Value Management System compliant with EIA-748C, or as required by the contract. This is performed by the contractor. (Refer to DOE G 413.3-10A.)	
Prepare a Hazard Analysis Report for facilities that are below the Hazard Category 3 nuclear facility threshold as defined in 10 CFR Part 830, Subpart B by updating the PHAR based on new hazards and design information.	Field Organization
Determine that the Quality Assurance Program is acceptable and continues to apply. (Refer to 10 CFR Part 830, Subpart A, DOE O 414.1D, and DOE G 413.3-2.)	

Table 2.2 CD-2 Requirements[1]

Prior to CD-2	**Approval Authority**[2]
Issue the final Environmental Impact Statement or Environmental Assessment and Finding of No Significant Impact, as required by 10 CFR Part 1021. For an Environmental Impact Statement, the appropriate authority shall issue the Record of Decision after CD-2 is granted, but prior to CD-3 approval. (Refer to DOE P 451.1.)	
Update Project Data Sheet, or other funding documents for MIE and OE projects, and A-11 Business Case, if applicable. (Refer to DOE CFO Budget Call for PDS and Business Case Template.)	
For Hazard Category 1, 2, and 3 nuclear facilities, *conduct a Technical Independent Project Review (TIPR).The TIPR is required at or near the completion of the preliminary design. The TIPR is not required for non-nuclear facilities. (Refer to DOE G 413.3-9).*	*PSO*
For Hazard Category 1, 2, and 3 nuclear facilities*, update the Safety Design Strategy, with the concurrence of CNS or with written advice from CDNS, as appropriate, for projects subject to DOE-STD-1189-2016.*	*SBAA and FPD*
Prepare Preliminary Safety and Design Results[3] *that update the CSDR* ***for Hazard Category 1, 2, and 3 nuclear facilities*** *based on updated hazard analysis and design information. These results complete the preliminary design phase and allow for DOE review prior to completing the final design phase. (Refer to DOE-STD-1189-2016.)*	*SBAA via the Safety Review Letter*
Prepare a Safety Review Letter, with concurrence from the FPD, based on a DOE review of the Preliminary Safety and Design Results ***for Hazard Category 1, 2, and 3 nuclear facilities****. This DOE review should be scheduled as early as practicable, after contractor completion of the preliminary design, to minimize project risk. (Refer to DOE-STD-1189-2016 and DOE-STD-1104-2016.)*	*SBAA*
Prepare the Preliminary Documented Safety Analysis (PDSA)[4] *for newly planned* ***Hazard Category 1, 2, and 3 nuclear facilities*** *based on updated hazard analysis and design information; also for major modifications of existing facilities. (Refer to 10 CFR Part 830, Subpart B, and DOE-STD-1189-2016.)*	*SBAA via the SER*
Prepare a Safety Evaluation Report, with concurrence from the FPD, based on review of the PDSA ***for Hazard Category 1, 2, and 3 nuclear facilities****. (Refer to 10 CFR Part 830, Subpart B, and DOE-STD-1104-2016.)*	*SBAA*
Post CD-2 Approval	
Submit all CD documents, and if there are changes to the PB, submit BCP documents to PM.	
For projects with a TPC ≥ $100M, the PMRC will review and analyze the PB deviation disposition request and make recommendations to the ESAAB, CE, or PME, as applicable, before approval. The resulting BCP must also be presented to the PMRC before convening an ESAAB.	CE ≥ $750M PME < $750M
Obtain PME endorsement on any changes to the approved funding profile that negatively impacts the project.	
Continue monthly PARS II reporting (including earned value data). FPD, Program Manager and PM will provide monthly assessments.	
Continue QPRs with the PME or their designee.	

Table 2.2 CD-2 Requirements[1]	
Post CD-2 Approval	**Post CD-2 Approval**
Annually conduct project peer reviews for projects with a TPC > $100M.	

NOTES:

1. Documents and reports are not intended to be stand-alone and may be combined.
2. Where no approval authorities are noted, authorities are established through other directives or the Program Offices (e.g., Functions and Requirements Assignment Matrix).
3. Title 10 CFR Part 830 does not apply to accelerators and their operations.
4. Per 10 CFR 830.206(b), a major modification of an existing Hazard Category 1, 2 or 3 nuclear facility requires DOE approval of the nuclear safety design criteria to be used in the PDSA, unless the contractor uses the design criteria in DOE O 420.1C, *Facility Safety*. Content requirements and guidance for the SDS are specified in DOE-STD-1189-2016.
5. There are some statutory (appropriation and authorization) and/or regulatory provisions that implicate this Order. Solely for purpose of the application of appropriations and authorization laws and regulations and for any approvals under those laws and regulations, CD-3A (or CD-3X) will be treated as separate from and not within the scope of those laws and regulations as they pertain to CD-2 and CD-3. For all other purposes, from a project management perspective, CD-3A (or CD-3X) remains part of the project total scope and remains embedded in the project TPC.

(2) Optional budget request process for construction projects. Normally, funds for construction cannot be requested until CD-2 approval is obtained, or when CD-3A approval is obtained to support CD-3A scope of work. Upon PME approval, a construction project can submit a line item budget request prior to CD-2 approval, provided the PME accepts the following conditions:

- Project will document the strategy to request funds (i.e., CD-3A) prior to CD-2 approval in the AS and preliminary PEP.
- Construction funds cannot be expensed until the approval of CD-2 and CD-3, with exception of CD-3A, approval for long lead procurement, where applicable.
- CD-2 approval is obtained within two years following OMB budget submission to Congress. Typically, there are no exceptions and subsequent budget requests would not be allowed until CD-2 approval.
- If CD-2 approval is not achieved within two years following budget submission, any future budget requests for construction must be approved by the CE through the ESAAB process.
- A default original performance baseline (or TPC) will be established equivalent to the top-end range at CD-1 with the initial budget submission. At that time, a funding profile will be established and included in the PDS to support this default cost baseline.

- This original PB is refined with formal CD-2 approval and cannot exceed the top-end range established at CD-1. The project funding profile will be modified accordingly to align with the CD-2 cost baseline.

- If long lead procurement is needed upon budget submission, pursue CD-3A with the PME. (The default CD-2 performance baseline [or TPC] is the upper limit of the CD-1 cost range.)

(3) Execution typically comprises the longest and most costly phase of the project, but is only a fraction of the total life-cycle cost of a project. Value Management (VM) and VE techniques, as appropriate, should be used to ensure that the most effective life-cycle solutions are implemented. Refer to OMB Circular A-131.

d. CD-3, Approve Start of Construction/Execution.

CD-3 is a continuation of the execution phase. The project is ready to complete all construction, implementation, procurement, fabrication, acceptance and turnover activities. Table 2.3 lists the requirements needed to attain CD-3.

Table 2.3 CD-3 Requirements[1]

Prior to CD-3	**Approval Authority[2]**
Approve updated CD-2 Project Documentation that reflects major changes from Final Design, the PEP, PB, AS, and PDS/funding documents for MIE and OE funds.	CE or PME
Complete and review the Final Design for non-nuclear facilities and less than Hazard Category 3 nuclear facilities.	
• Incorporate the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings per EO 13693, Section 3(h), sustainability requirements per DOE O 436.1, and/or other sustainability considerations into the Final Design and the EIR. (Refer to DOE G 413.3-6A.)	
Employ a certified Earned Value Management System compliant with EIA-748C, or as required by the contract. (Refer to DOE G 413.3-10A.)	Certified by: PM ≥ \$100M
Perform an External Independent Review by PM for Construction or Execution Readiness on all Major System Projects. (Refer to DOE G 413.3-9.) Perform an Independent Project Review by the appropriate PMSO for Non-Major System Projects unless justification is provided and a waiver is granted by the PME. For projects with a TPC ≥ \$100M, PM will develop an Independent Cost Estimate.	PM ≥ \$750M PMSO < \$750M
For projects with a TPC ≥ \$100M, the PMRC will review and analyze the CD and make recommendations to the ESAAB, CE, or PME, as appropriate, before approval.	CE ≥ \$750M PME < \$750M

Table 2.3 CD-3 Requirements[1]	
Prior to CD-3	**Approval Authority[2]**
For Major System Projects where a significant critical technology element modification occurs subsequent to CD-2, conduct a Technology Readiness Assessment, as appropriate. (Refer to DOE G 413.3-4A.)	PSO
Update the Hazard Analysis Report for facilities that are below the Hazard Category 3 nuclear facility threshold as defined in 10 CFR Part 830, Subpart B, based on new hazards and design information.	Field Organization
Prior to start of construction, prepare a Construction Project Safety and Health Plan[4] in accordance with 10 CFR Part 851, Appendix A, Section 1(d). This plan must be kept current during construction.	Field Organization
Update the Quality Assurance Program for construction, field design changes, and procurement activities. (Refer to 10 CFR Part 830, Subpart A, DOE O 414.1D, and DOE G 413.3-2.)	
Finalize the Security Vulnerability Assessment Report, if necessary. (Refer to DOE O 470.4B and DOE G 413.3-3A.)	
Post CD-3 Approval	
Submit all CD documents to PM.	
Commit all the resources necessary, within the funds provided and within the TPC, to execute the project.	
For projects with a TPC ≥ $100M, the PMRC will review and analyze the PB deviation disposition request and make recommendations to the ESAAB, CE, or PME, as applicable, before approval. The resulting BCP must also be presented to the PMRC before convening an ESAAB.	CE ≥ $750M PME < $750M
Within 90 days, submit Lessons Learned regarding up-front project planning and design to PSO and PM.	
Update PDS, or other funding documents for MIE and OE, and A-11 Business Case, if applicable. (Refer to DOE CFO Budget Call for PDS and Business Case Template.)	
Conduct EVMS surveillance to ensure compliance with EIA-748C, or as defined in the contract. Contractor must conduct the surveillance annually.	Conducted by: PM ≥ $100M
Continue monthly PARS II reporting (including earned value data). FPD, Program Manager and PM will provide monthly assessments.	
Continue QPRs with the PME or their designee.	
Continue annual project peer reviews for projects with a TPC > $100M.	

NOTES:

1. Documents and reports are not intended to be stand-alone and may be combined.
2. Where no approval authorities are noted, authorities are established through other directives or the Program Offices (e.g., Functions and Requirements Assignment Matrix).
3. Title 10 CFR Part 830 does not apply to accelerators and their operations.
4. For Environmental Management Clean-up Projects, refer to 29 CFR 1910.120.

e. CD-4, Approve Start of Operations or Project Completion.

CD-4 is the achievement of the project completion criteria defined in the PEP, the approval of transition to operations, and it marks the completion of the execution phase. The approval of CD-4 is predicated on the readiness to operate and/or maintain the system, facility, or capability. Transition and turnover does not necessarily terminate all project activity. In some cases, it marks a point known as Beneficial Occupancy Date (BOD) at which the operations organizations assume responsibility for starting operations and maintenance. The CE or PME approves CD-4 upon notification from the project team that all project completion criteria defined in the PEP have been met. The document signed by the CE or PME approving CD-4 must clearly specify the scope accomplished, the TPC, KPPs met, and the completion date (month and year) as it relates to the original CD-2 performance baseline and latest approved baseline change. The date the CE or PME signs the document represents the CD-4 completion date. Table 2.4 lists the requirements needed to attain CD-4.

Table 2.4 CD-4 Requirements[1]

Prior to CD-4	**Approval Authority**[2]
Verify that Key Performance Parameters and Project Completion Criteria have been met and that mission requirements have been achieved. The FPD will verify and document the scope accomplished, TPC, KPPs met, and the completion date as it relates to the original CD-2 performance baseline and the latest approved baseline change.	FPD
Issue a Project Transition to Operations Plan[3] that clearly defines the basis for attaining initial operating capability, full operating capability, or project closeout, as applicable. The plan will include documentation, training, interfaces, and draft schedules. (Refer to DOE G 413.3-16A.)	
For non-nuclear projects, conduct a formal assessment of the project's Readiness to Operate, as appropriate. Determine the basis for DOE acceptance of the asset and if the facility or area can be occupied from both a regulatory and a work function standpoint. Establish a beneficial occupancy/utilization date for the facility and/or equipment.	
Finalize the Hazard Analysis Report for facilities that are below the Hazard Category 3 threshold as defined in 10 CFR Part 830, Subpart B.	Field Organization
Revise the Environmental Management System in accordance with DOE O 436.1, as appropriate.	
If applicable, complete and submit Contractor Evaluation Documents to the PME, the appropriate PSO, Federal procurement office, and PM in accordance with FAR 42.15.	
For projects with a TPC ≥ \$100M, the PMRC will review and analyze the CD and make recommendations to the ESAAB, CE, or PME, as applicable, before approval.	CE ≥ \$750M PME < \$750M
Conduct an Operational Readiness Review (ORR) or Readiness Assessment (RA) ***for Hazard Category 1, 2, and 3 nuclear facilities*** *in accordance with DOE O 425.1D.*	
Prepare the Documented Safety Analysis[3] *with Technical Safety Requirements* ***for Hazard Category 1, 2, and 3 nuclear facilities****. (Refer to 10 CFR Part 830, Subpart B.)*	*SBAA via the SER*

Table 2.4 CD-4 Requirements[1]	
Prior to CD-4	**Approval Authority[2]**
Prepare a Safety Evaluation Report (SER) based on a review of the Documented Safety Analysis and Technical Safety Requirements ***for Hazard Category 1, 2, and 3 nuclear facilities****. (Refer to 10 CFR Part 830, Subpart B, and DOE-STD-1104-2016.)*	
For nuclear facilities, *the Code of Record must be included as part of the turnover documentation from a design and construction phase contractor to the operating phase contractor; from an operating phase contractor to the decommissioning phase contractor; and when a change in contractor occurs during any single life-cycle phase and is maintained under configuration control.(Refer to DOE-STD-1189-2016)*	
Post CD-4 Approval	
Submit all CD documents to PM.	
Finalize PARS II reporting (including reporting earned value data through completion of the PMB).	
Within 90 days, submit Lessons Learned regarding project execution and facility start-up to PSO and PM.	
Within 90 days, submit an Initial Project Closeout Report.	
NOTES: 1. Documents and reports are not intended to be stand-alone and may be combined. 2. Where no approval authorities are noted, authorities are established through other directives or the Program Offices (e.g., Functions and Requirements Assignment Matrix). 3. Title 10 CFR Part 830 does not apply to accelerators and their operations. 4. For Environmental Management Clean-up Projects, refer to 29 CFR 1910.120.	

f. Project Closeout.

After the project is complete, the next step is project closeout. Project Closeout provides a determination of the overall closure status of the project, contracts, regulatory drivers, and fiscal condition. After CD-4 approval, the project is required to complete the activities listed in Table 2.5.

Table 2.5 Project Closeout Requirements[1]	
Prior to Project Closeout	**Approval Authority[2]**
Perform final administrative and financial closeout. Prepare the final Project Closeout Report once all project costs are incurred and invoiced and all contracts are closed. The report includes final cost details as required to include claims and claims settlement strategy where appropriate. (Refer to DOE G 413.3-16A.)	
Complete and document achievement of Facility Sustainment goals (e.g., LEED Gold, LEED Silver, etc.), as applicable, via an independent third-party entity within one year of facility occupancy in accordance with EO 13693, Section 3(h), EO 13514, Section 3, and DOE O 436.1.	

Table 2.5 Project Closeout Requirements[1]	
Prior to Project Closeout	**Approval Authority[2]**
Establish and/or update the property record in the Facilities Information Management System (FIMS) for all construction of or modifications to real property. (Refer to DOE O 430.1C.)	

NOTES:
1. Documents and reports are not intended to be stand-alone and may be combined.
2. Where no approval authorities are noted, authorities are established through other directives or the Program Offices (e.g., Functions and Requirements Assignment Matrix).
3. Title 10 CFR Part 830 does not apply to accelerators and their operations.

5. Application of Requirements for Different Circumstances.

Although most DOE projects will follow the requirements outlined in this Order, there are some differing project situations where customizing the process is beneficial:

a. Environmental Management Cleanup Projects.

When the Department, Congress or a regulatory agreement transfers or formally assigns cleanup responsibilities for a parcel of land or facilities to EM for cleanup, this will serve as the basis for a "Mission Need" in support of CD-0 approval by the PME. Characterization and analysis efforts are considered operational activities and shall be conducted prior to selecting scope and performance parameters and establishing a PB. Any project costs that occur after CD-0 and prior to CD-4 approval are considered to be part of the project's TPC. Normally, CD-1/2/3 will be accomplished simultaneously, since project requirements (e.g., baseline development) and associated environmental documents (e.g., regulatory agreements) are finalized in unison.

b. Design-Build Projects.

To address potential mission impacts, aggressive risk mitigation strategies are required for close-coupled or fast-tracked design-build projects. Risk management strategies must be outlined in the RMP and at a minimum must address:

- All technical uncertainties;
- The establishment of design margins to address the unique nature of the design; and
- Increased technical oversight requirements.

The PDS must be submitted for the budget year in which the Design-Build contract is to be awarded and must include the costs of design as part of the TPC. The PSO may budget for PED funds if there is a need to develop significant performance or technical specifications for the project. For Design-Build projects, PED funds may be used for the design of line item projects and may be used to develop a statement of work or a request for proposal; whereas, operating funds are used for MIE or OE projects.

c. Projects Requiring Long-Lead Procurement.

It may be necessary to obtain CD-3 approval early, namely CD-3A, for long-lead item procurement. When exercising long-lead procurement, the FPD must consider design maturity and the associated project risk. If the long-lead item is nuclear safety-related or nuclear safety-related equipment, safety document maturity must also be considered. A budget document, such as a PDS, should be submitted within the budget process requesting construction funds to procure long lead items or indicating the use of PED funds for long-lead procurement. This is the only instance when a CD action may be taken out of sequence (i.e., CD-3A in advance of CD-2). Activities such as site preparation work, site characterization, limited access, safety and security issues (i.e., fences) are often necessary prior to CD-3, and may be pursued as long as project documents such as a PDS requesting construction or PED funds to procure the long-lead items and funding approvals are in place. The default CD-2 performance baseline (or TPC) is the upper limit of the CD-1 cost range. This represents that project execution has started, but only for the procurement of specified long-lead items. For projects involving construction of new Hazard Category 1, 2, and 3 nuclear facilities, DOE-STD-1189-2016 provides requirements for contractor justification of long-lead procurement items. DOE-STD-1104-2016 establishes the required method for DOE review and approval of long-lead procurement items.

d. Commissioning of Capital Asset Projects for Nuclear/Chemical Process Facilities.

For projects involving nuclear/chemical processes, Program Offices shall define a capital asset project as completed (CD-4) in a PEP. The Program Office must determine if hot commissioning (i.e., introduction of radioactive material) is a condition of CD-4. Ultimately, the capital asset must have the capability to meet the end-state capacity requirements approved in the CD-2 decision by the respective PME, but not as a condition of CD-4.

e. Alternative Financing.

In some instances, Alternative Financing may be the most appropriate method to obtain use of capital assets. In these instances, it is required that CD-0 and CD-1 approval be attained so that a full evaluation of the mission need and the alternatives can be accomplished. If alternative financing is selected and approved, further compliance with this Order will not be required. At that time, other policies, laws and regulations will apply. For further details, refer to DOE Acquisition Guide, Subchapter 70.3270 and DOE G 430.1-7.

6. Baseline Management.

a. Performance Baseline Deviation.

A performance baseline deviation occurs when the approved TPC, CD-4 completion date, or performance and scope parameters cannot be met. This includes any disaggregation of scope in an effort to establish a smaller discrete project (or projects) for the immediate or at a later date. The FPD must promptly notify management whenever project performance indicates the likelihood of a PB deviation. When a deviation occurs, the approving authority must make a specific determination whether to terminate the project or establish a new PB by requesting the FPD to submit a BCP.

Additionally, all PB deviation decisions must be reported to the CE and PM. New PBs to be established because of a deviation must be validated by PM for projects with a TPC greater than or equal to $100M and by the PMSO for projects with a TPC less than $100M. In circumstances where a PB deviation is beneficial to the project—such as a lower TPC, earlier completion date, or significant scope enhancements, a validation of the PB deviation or approval by the PSO is not required.

When the Integrated Project Team (IPT), Program Office or independent oversight offices determine the Performance Baseline scope, schedule, or cost thresholds will be breached, the Program Office is required to conduct an independent and objective root cause analysis to determine the underlying contributing causes of cost overruns, schedule delays, and performance shortcomings. The root cause analysis will be provided to the PME as part of the rebaselining process to inform the PME's decision of whether to terminate or proceed with the project. Corrective actions shall be identified and presented to the PME for action approval.

b. Performance Baseline Changes.

A performance baseline change represents an irregular event which should be avoided to the maximum extent. Table 3 identifies when a deviation must be approved by the CE. The approval by the CE does not constitute approval of individual contract changes and modifications. If a contract change is necessary, the contracting officer has exclusive authority to issue changes and modify contracts, but only if the changes or modifications comply with regulatory and statutory requirements. It is critical that the FPD and the contracting officer ensure that changes to the contract are identified, issued, administered, and managed in a timely manner over the life of the project and contract. The performance baseline change process should not be used to circumvent proper change control management (refer to DOE G 413.3-20) and contract management. The document signed by the CE approving the BCP must clearly specify the project's revised PB, which includes the TPC, CD-4 date (month and year), scope and minimum KPPs that must be achieved at CD-4.

Table 3. Performance Baseline Change Authority

Performance Baseline Changes Requiring CE Approval	
Major System and Non-Major System Projects	
Technical	Any change in scope and/or performance that affect the ability to satisfy the mission need or are not in conformance with the current approved PEP and PDS.
OR	
Cost	Increase in excess of the lesser of $100M or 50% (cumulative) of the original CD-2 cost baseline.

In addition, the CE must endorse any reduction in funding that adversely affects the project's approved funding profile for all non-Major System Projects and previously approved CE BCP actions. PM shall be notified of these funding decrements. The CE and PM shall be notified of all:

- Schedule delays that breach the original PB by greater than 12 months; or
- Post-CD-2 projects that get terminated; or
- Capital asset projects, regardless of value, no longer able to meet the Department's objective (see Appendix A, Paragraph 1).

The Under Secretaries are the approval authorities for PB changes below CE approval level. These approval authorities may not be delegated below the PSOs. New PB or PMB approval thresholds and authorities should be documented in the PEP for project changes below the thresholds identified above. These approval levels must be incorporated into the change control process for each project. Decrements to approved PB funding profiles must be endorsed by the PME. In circumstances where a PB change is beneficial to the project, such as a lower TPC, earlier completion date, or significant scope enhancements, PB changes can be approved at lower levels as designated in the PEP.

c. <u>Directed Changes</u>.

Directed changes are caused by DOE policy directives (such as those that have the force and effect of law and regulation), regulatory, or statutory actions and are initiated by entities external to the Department, to include external funding reductions. Directed change decisions are reviewed and verified by PM and OMB and follow the appropriate baseline management process.

d. Change Control.

Change control, as defined in the PEP, ensures that project changes are identified, evaluated, coordinated, controlled, reviewed, approved/disapproved, and documented in a manner that best serves the project. One key goal of change control is to ensure that PB thresholds are not exceeded. Approval authority for changes depends upon the estimated impact(s) of the change and can range from the contractor to the CE, usually with the involvement and support of a Change Control Board (CCB). The CCB membership, authorities, thresholds, and procedures should be detailed or referenced within the PEP.

e. Contract Modifications for New Performance Baseline, if Applicable.

Prior to approval of a baseline change by the PME, the FPD shall coordinate with the Contracting Officer to identify the specific contract changes that may be required, develop an Independent Government Cost Estimate (refer to FAR 36.203 and FAR 15.406-1), establish a schedule for receipt of a contractor's proposal(s), obtain audit support, and ensure the timely analysis, negotiation, and execution of contract modification(s) that comply with regulatory and statutory requirements.

f. Cancellations of Projects.

If a project is to be cancelled at any point after CD-0, the respective PME shall approve a cancellation decision and PARS II will be updated to reflect the cancellation of the project. For all post CD-2 cancellations, a formal written notification shall be issued to the Under Secretary and the Office of the Chief Financial Officer (CFO) via PM. The formal written notification shall outline the reasons for the cancellation, how the mission need will be impacted, and a disclosure of all funds expended prior to the cancellation and the costs associated with the cancellation. The CE shall be similarly notified of all post CD-2 cancellations.

7. Energy Systems Acquisition Advisory Board.

The purpose of the Energy Systems Acquisition Advisory Board (ESAAB) is to support the Department of Energy’s strategic objective of achieving and maintaining excellence in project management. The ESAAB advises the Secretary, Chief Executive for Project Management, and Departmental Project Management Executives on enterprise-wide project management policy and issues and assists the CE on critical on CD milestones for Major System Projects and PB deviation dispositions with a TPC of $750M or greater. The ESAAB will be supported by the Project Management Risk Committee (PMRC), which provides enterprise-wide project management risk assessment and expert advice.

The ESAAB will not be responsible for project implementation and execution, which remains with the CE, PME, project owner, and FPD. The authority for approving CDs for Major System Projects will continue to reside with the CE and for non-Major System Projects will continue to reside with the appropriate PME. The ESAAB's role is to provide recommendations to the CE at those CD points and to the CE and PME at any other times as needed.

The ESAAB will convene at least quarterly to review all capital asset projects with a TPC of $100M or greater, focusing in particular on projects at risk of not meeting their PBs; discuss project management and project execution across the Department; and, if applicable, provide recommendations to the CE on CD milestones for Major System Projects. The ESAAB shall meet as often as deemed necessary for the execution of the ESAAB's functions. A call for a special ESAAB can also be made when an unforeseen review of a capital asset project is required. During these quarterly meetings, the ESAAB will meet with the PMRC and be briefed by the Chair of the PMRC or others as designated by the Chair.

Based on analysis provided by the program and other project management organizations, and any additional input from the committee, the ESAAB will evaluate project scope, cost and schedule estimates, management oversight processes, technical readiness, and other issues (including organization and staffing) that may have a material bearing on a project's successful delivery. In addition to the PMRC, the ESAAB may also identify and advise on uncertainties and risk factors affecting successful project execution as well as on compliance with applicable project management policies and procedures. To support the ESAAB's efforts, the ESAAB will have access to all relevant project-related information and data, including any PMRC analyses.

The ESAAB shall advise the CE on decisions related to CD milestones, including baseline change proposals and other matters as appropriate. The ESAAB shall review Major System Projects before all CDs and baseline change proposals are presented to the CE using information and data provided by the program and other project management organizations, including the PMRC. The PMRC, the cognizant FPD, and/or others, as appropriate, will brief the ESAAB as part of each ESAAB's review of projects for CDs. The ESAAB may request additional information and analyses from other individuals and organizations with project responsibilities, including Departmental staff.

a. ESAAB Membership. The members are (including anyone acting in such capacity):

(1) Deputy Secretary, Chair

(2) Under Secretary of Energy

(3) Under Secretary for Science

(4) Under Secretary for Nuclear Security

(5) General Counsel

(6) Chief Financial Officer

(7) Chief Information Officer

(8) Senior Procurement Executive, as appropriate

(9) Executive Director, Loan Program Office

(10) Director, Office of Project Management Oversight and Assessments, Office of the Under Secretary of Energy (Secretariat)

(11) Chair of the Project Management Risk Committee

(12) The Secretary or Deputy Secretary may designate other PSOs or functional staff as ESAAB members (temporary or permanent) as needed.

The Deputy Secretary will serve as the Chair. In the event that the Deputy Secretary position is vacant, the Secretary shall designate a Chair from among the members. If the Deputy Secretary is recused from a matter involving the ESAAB or is otherwise unable to attend an ESAAB meeting, the Deputy shall designate a Chair from among the members. The Chair may elect to choose a Chair pro tempore, from among the members, to convene an ESAAB meeting to review a CD and to transmit the recommendation of the ESAAB to the Chair.

In the case of all members of the ESAAB (except the Chair), if the individual is recused from matters involving the ESAAB or is otherwise unable to attend an ESAAB meeting, or if the position is vacant, their deputy (or if applicable, their principal deputy) shall serve as an ESAAB member.

A simple majority of the ESAAB shall constitute a quorum. The ESAAB may invite other federal Departmental officials or employees to participate in meetings or supply information.

The ESAAB will document its recommendations and provide analysis prepared in support of recommendations to the CE, PME, and other officials, as appropriate. The ESAAB members will vote on all recommendations to the CE, PME, and other officials. Recommendations by the ESAAB shall be made by majority vote and the votes will be recorded in the minutes of the ESAAB meetings.

b. <u>“Paper” ESAAB: Streamlined ESAAB Process</u>.

In circumstances where the acquisition action is of relatively low monetary value, low risk, and requires non-controversial decisions (i.e., baseline deviation and CD approvals) that need CE or PME approval, a streamlined ESAAB achieves the required staff coordination and approval without convening a formal meeting of all ESAAB members. This process should be considered, when the following parameters are met:

(1) A Program Office requests PM to consider a streamlined ESAAB in lieu of a formal ESAAB meeting;

(2) PM will determine: (1) if a streamlined ESAAB is appropriate; (2) level of inter-office coordination required; and

(3) At a minimum, all streamlined ESAABs will be coordinated with PM, CIO, CFO, and the Office of the General Counsel with the expectation of expeditious review. If issues cannot be resolved within 15 days of document submission to ESAAB members, PM will forward the issues to the Deputy Secretary for final decision.

c. ESAAB Issue Resolution.

To ensure timely decision making, if open issues cannot be resolved in 15 calendar days following an ESAAB, PM will forward the issues to the Deputy Secretary for final decision.

d. ESAAB Secretariat.

The ESAAB Secretariat resides in PM and provides administrative and analytical support and recommendations to the ESAAB. When performing the Executive Secretariat duties, the Director of PM is accountable to the Deputy Secretary. The Executive Secretariat will prepare and coordinate all briefing materials in collaboration with appropriate programs, and record and maintain all minutes of the ESAAB meetings.

e. Non-Major System Project Advisory Boards.

The designated PME will appoint an Advisory Board to provide advice and recommendations on actions for projects that are not designated as Major System Projects. The designated PME is the Chair of the Advisory Board. The Advisory Board replicates and conducts identical functions to those performed by the ESAAB. Members may be selected from within the PME's organization. However, at least one member from an office not under the PME will be designated as a contributing representative. PM will not be a Board member for projects with a TPC less than $750M, but must be invited to attend the Advisory Board meetings. The implementing documentation (including CD and BCP approval memoranda) and composition of each Advisory Board along with meeting agendas and minutes will be provided to PM.

f. Project Management Risk Committee.

The purpose of the PMRC is to support the Department of Energy's strategic objective of excellence in project management. The Committee will leverage existing capabilities to provide enterprise-wide project management risk assessment and expert advice to the Secretary, CE, PME and the ESAAB on cost, schedule and technical issues regarding capital asset projects with a TPC of $100M or greater. Upon request of the CE, PME, or ESAAB, the Committee will also address projects with a TPC less than $100M that are at risk of not meeting their performance baseline.

The Committee will not be responsible for project implementation and execution, which remains with the CE, PME, project owner, and FPD. The authority for approving CDs for Major System Projects will continue to reside with the CE and for non-Major System Projects will continue to reside with the appropriate PME. The Committee's role is to provide recommendations to the CE, PME and ESAAB at those CD points and at any other time as needed.

The Committee shall be an integral part of the ESAAB and shall advise the CE, PME and ESAAB on decisions related to CD milestones, baseline change proposals, and other matters as appropriate. They will also provide on-going monitoring and assessments of projects throughout the CD process. In addition, the Committee will review project management policies and procedures, including the implementation of this Order, for Department-wide application and provide the Secretary, CE, PME and ESAAB with expert advice. This includes assuring that clear, strong Departmental functional responsibility extends from the PME to the project owner to the FPD, and ensuring that issues are appropriately flagged and elevated early so that they may be appropriately addressed. Finally, the committee will enable the sharing of best practices and lessons learned information on a routine basis. To support the Committee's efforts, access to all project-related information and data will be made available from project assessment and data collections frameworks.

To support the committee's efforts, access to all project-related information and data will be made available from project assessment and data collections frameworks.

Project Assessments. The committee will assess, on a periodic basis, reviews that have been conducted at the Under Secretarial level, and advise the CE, PME, ESAAB and other program officials on project performance. These assessments will complement, but not duplicate or replace, the ongoing peer review processes within the Under Secretaries' organizations. The committee shall conduct more frequent and detailed assessments of higher risk projects, and provide advice and assistance to the CE, PME and ESAAB on a regular basis.

The committee will utilize project analyses conducted by the programs and other project management organizations to assess projects and advise the senior leadership on appropriate actions to address and mitigate risks associated with project scope, cost and schedule estimates, management oversight processes, technical readiness, and other issues (including organization and staffing) that may have a material bearing on the project's successful implementation. The committee will also identify and advise on uncertainties and risk factors affecting successful project implementation as well as on compliance with applicable project management policies and procedures.

Assessment of CD proposals and Baseline Change Proposals. The committee will use information and data provided by the program and other project management organizations to review and analyze projects before all CDs and BCP are presented to the CE, PME, or ESAAB. As appropriate, the respective FPD or designated program representative (prior to CD-1) will brief the committee as part of the assessment process. The committee may request additional information and analyses from the CE, PME and other individuals with project responsibilities, including both Departmental staff and contractor managers. The committee, the respective FPD, and/or others, as appropriate, will brief the ESAAB as part of the ESAAB's review process for CDs. The committee will perform its assessments to support the CD milestone schedule established by the project owners such that the committee does not unnecessarily delay CDs if there are no issues.

The assessments may address, but are not limited to:

- Alternatives analysis to ensure that all viable options are thoroughly considered and the best alternative is recommended (CD-1)
- Scope, schedule, cost, design maturity level, and technology readiness level to ensure they are appropriate prior to establishing a project baseline (CD-2)
- Construction readiness to ensure the project is prepared to begin construction (CD-3)
- Operational readiness to make certain a project is ready to start operations (e.g., evaluating Operational Readiness Reviews) (CD-4)

Strengthening Peer Reviews. To enhance the peer review process, each Under Secretary's Office of Project Assessments will provide sufficient notice to the committee regarding upcoming peer reviews. The committee will advise on planned peer reviews, as needed, to ensure review groups are focused on pressing issues, and recommend review team members, as appropriate. The committee will evaluate results of the reviews as well as related corrective actions.

Independent Assessments. The committee may recommend to the CE, PME or ESAAB that an independent assessment of a project be conducted.

Advising Senior Leadership. The Committee will meet at least quarterly with the ESAAB to review all capital asset projects with a TPC of $100M or greater with a focus on projects at risk of not meeting their performance baselines, discuss project management across the Department, and, if applicable, provide recommendations to the ESAAB on CD milestones for projects under the Committee's purview. The Chair of the Committee or others as designated by the Chair will brief the ESAAB at the quarterly meetings. The Committee may also recommend to the Secretary, CE or ESAAB that the ESAAB review and advise on matters brought to its attention by the Committee.

Membership. The Secretary shall appoint the members of the committee. All committee members shall be federal employees who are experts in their representative fields or senior leaders with significant decision-making authorities. Standing members shall include:

(1) Associate Deputy Secretary (or other Senior Advisor designated by the Secretary)

(2) Director, Office of Project Management Oversight and Assessments, Office of the Under Secretary of Energy (Executive Secretariat)

(3) Director, Office of Project Assessment, Office of Environmental Management, Office of the Under Secretary for Science

(4) Deputy Assistant Secretary for Acquisition and Project Management, Office of Environmental Management

(5) Director, Office of Project Assessment, Office of Science

(6) Deputy Director for Science Programs, Office of Science

(7) Director, Office of Project Assessment, Office of the Under Secretary for Nuclear Security

(8) Associate Administrator for Acquisition and Project Management, Office of the Under Secretary for Nuclear Security

(9) Chief Operating Officer, Loan Programs Office or Chief Engineer, Director of Technical and Project Management, Loan Programs Office

The Secretary will appoint a Chair from among the members. The Chair may designate a Vice Chair. The Director of PM will serve as the Executive Secretariat of the PMRC. When performing those duties, the Secretariat will be accountable to the Deputy Secretary. The Executive Secretariat will prepare and coordinate all briefing materials, in collaboration with appropriate programs, and record and maintain all minutes of the committee meetings.

In the case of all members of the Committee (except the Chair), if the individual is recused from matters involving the Committee or is otherwise unable to attend a Committee meeting, or if the position is vacant, their deputy (or if applicable, their principal deputy) shall serve as a Committee member.

A simple majority shall constitute a quorum. The committee may invite other Departmental federal officials or employees to participate in meetings or supply information.

To the extent reasonable and practicable, recommendations by the Committee shall be made by consensus, although they may also be made by majority vote or, in the event there are less than three sitting member, by unanimous vote. Any dissenting votes will be noted in the minutes of the meetings. The Committee will document its recommendations and provide analysis prepared in support of its recommendations to the CE, PME, and ESAAB, as appropriate.

APPENDIX B
RESPONSIBILITIES

Three objectives regarding roles and responsibilities that are necessary to achieve defined project objectives as well as the objectives of this Order are:

- Strengthening line management accountability for successful project management results;
- Clearly defining the roles, responsibilities, authority, and accountability of the Federal Project Management Team relative to the contractor Project Management Team; and
- Developing effective IPTs to assist the FPD in planning, programming, budgeting, and successfully acquiring capital assets.

Line managers are responsible for successfully developing, executing, and managing projects within the approved PB. Delegation of authority from one line manager to a lower-level line manager must be documented and consistent with DOE delegation authorities and the qualifications of the lower-level line manager. Although the authority and responsibility for decision-making may be delegated to a lower-level manager, the senior manager remains accountable for the decisions made by subordinate managers.

Clear roles, responsibilities and accountabilities among the project's owner, line management organizational elements, and support staff organizations shall be documented in the preliminary project execution plan at CD-1 and updated during subsequent changes to the PEP.

Key roles and responsibilities of line managers are described in the following sections:

1. Deputy Secretary (Chief Executive for Project Management).

    a. Serve as the Chief Executive responsible and accountable for all project acquisitions.

    b. Exercise decision-making authority, including CDs for all Major System Projects.

    c. Ensure that the FPDs appointed for Major System Projects are qualified, experienced, and have appropriate communication skills and leadership characteristics prior to designation.

    d. Identify special interest projects and ensure senior executive-level quarterly reviews are provided for those projects.

    e. Approve disposition of projects and PB changes at the CE approval level upon PB deviations.

f. Serve as Chair for the ESAAB.

g. Approve site selection for facilities at new sites to include real estate purchases outside of the current DOE footprint.

h. Conduct quarterly project reviews for Major System Projects, which may be delegated to the Under Secretaries.

i. Approve exemptions as defined in Paragraph 3.c.(3) and (4).

2. Under Secretaries.

a. Receive PME authority from the CE, as appropriate.

b. Designate a project owner before CD-1.

c. Ensure that the FPDs appointed to Non-Major System Projects are qualified and have appropriate communication skills and leadership characteristics prior to designation.

d. Delegate PME authority, as appropriate (refer to Appendix A, Table 1).

e. Exercise decision-making authority, including CDs, functioning as the PME.

f. Hold line accountability for applicable program and capital asset project execution and implementation of policy.

g. Hold accountability for project-related site environment, safety and health, and safeguards and security.

h. Serve as Chair and appoint members for Acquisition Advisory Boards.

i. Approve disposition of projects and PB changes below CE approval level upon PB deviations (may not be delegated below Program Secretarial Officers).

j. Maintain a list of special interest projects and ensure that senior executive-level quarterly reviews are provided for those projects.

k. Establish PMSO or delegate this responsibility to the Program Secretarial Officer.

l. Address and resolve issues on projects which report to them.

m. Conduct quarterly project reviews when serving as the PME. These reviews may be delegated to the Program Secretarial Officer.

3. Program Secretarial Officers and Deputy Administrators/Associate Administrators for the NNSA.

a. Hold line accountability for applicable capital asset project execution and implementation of policy.

b. Hold accountability for project-related site environment, safety and health, and safeguards and security.

c. Approve MNS documents and AS documents for all capital asset projects (cannot be delegated).

d. Approve disposition of projects and PB changes below the CE approval level following PB deviations. If delegated, this authority cannot be further delegated.

e. Exercise decision-making authority, including CDs, when functioning as PME.

f. Ensure that the FPDs appointed to Non-Major System Projects are qualified and have the appropriate communication skills and leadership characteristics prior to designation.

g. Delegate PME functions, as appropriate (refer to Appendix A, Table 1).

h. Nominate FPDs, when the PME is above the Program Secretarial Officer, no later than CD-1 (can be delegated). The FPD appointment is subject to the approval of the PME.

i. Approve the IPT charter for Major System Projects.

j. Serve as Chair and appoint members for Acquisition Advisory Boards.

k. Establish PMSO when responsibility is delegated or directed by the Under Secretaries.

l. Explicitly address integration of safety into design and construction for Hazard Category 1, 2, and 3 nuclear facilities as a key consideration in approval of project documentation and when functioning as PME.

m. Appoint a Safety Basis Approval Authority no later than CD-0 for projects including the design and construction of Hazard Category 1, 2, and 3 nuclear facilities or for projects including major modifications thereto.

4. Project Owner.

a. Ensure the identification of requirements and request the necessary budget to support the mission need.

b. Visit the project site and review the progress against key milestones that were approved as part of the performance baseline.

5. Project Management Support Offices (when established).

a. Provide independent oversight and report directly to the Under Secretaries, or Program Secretarial Officer, as appropriate.

b. Serve as the Secretariat for the Program Secretarial Officer/NNSA-level Advisory Board functions.

c. Coordinate quarterly project reports.

d. Perform IPRs, TIPRs, and Project Peer Reviews as requested by the PME or Program Offices.

e. Develop Program-specific guidance, policies, and procedures.

f. Collect, analyze and disseminate lessons learned and "best practices."

g. Coordinate with other DOE organizations and offices, including PM, to ensure the effective and consistent implementation of project management policies and directives.

h. Provide assistance and oversight to line project management organizations.

i. Analyze project management execution issues.

j. Actively assist senior management on issues related to project management performance, including implementation of corrective actions.

k. Provide support to the FPDs.

l. Validate the PB for capital asset projects with a TPC less than $100M.

6. Program Managers and Heads of Field Organizations.

a. Direct initial project planning and execution roles for projects assigned by the PME.

b. Initiate definition of mission need based on input from Sites, Laboratories and Program Offices.

c. Establish the initial IPT in advance of the designation of a FPD.

d. Oversee development of project definition, technical scope and budget to support mission need.

e. Initiate development of the AS before CD-1 (during the period preceding designation of the FPD).

f. Perform functions as a PME when so delegated.

g. Develop project performance measures and monitor and evaluate project performance throughout the project.

h. Allocate resources throughout the program.

i. Oversee the project line management organization and ensure the line project teams have the necessary experience, expertise, and training in design engineering, safety and security analysis, construction, and testing.

j. Serve as the FPD until the FPD is appointed.

k. Ensure that performance measures, resource allocations, and project oversight, as applicable, address integration of safety into design and construction for Hazard Category 1, 2, and 3 nuclear facilities.

l. Review prerequisite documents (as listed in Appendix A, Tables 2.0-2.5) before each CD submission.

m. Identify which contracts should incorporate the CRD and notify the Contracting Officer to include the CRD in the contract.

7. Project Management Executives.

The following roles and responsibilities are for illustrative purposes and each designated PME is guided by the specific limits of their delegated authority (see DOE/NNSA Senior Procurement Executive for contract award and modification execution authority). There can only be one designated PME per project.

a. Approve CDs for capital asset projects including CD-2, performance baseline approval and its associated funding profile.

b. Appoint and chair Acquisition Advisory Boards to provide advice and recommendations on key project decisions.

c. Approve the appointment of the FPD. Ensure that the FPD has the appropriate qualifications, competencies, and communication and leadership skills prior to designation by interviewing the proposed FPD for each project. When the FPD is not a designated career federal civil servant (i.e., contracted project manager) or is under an Intergovernmental Personnel Act (IPA) Agreement, the CE must endorse their appointment.

d. For nuclear facilities, designate the Design Authority at CD-1.

e. Monitor the effectiveness of FPDs and their support staff.

f. Approve project changes in compliance with change control levels identified in PEPs, to include all BCPs and funding profile changes that impact the PB.

g. Conduct quarterly project reviews.

h. Explicitly address integration of safety into design and construction for Hazard Category 1, 2, and 3 nuclear facilities as a key consideration in QPRs and approval of project CDs.

i. Direct IPRs be conducted.

j. Ensure the FPD has a contracting, construction and design organization(s) that is prepared to execute the project planned.

k. Ensure the contractor has a competent manager supported by a qualified project team.

l. Ensure there is adequate skilled staff for federal oversight of the contractor.

m. Visit the project site and review the progress against key milestones that were approved as part of the performance baseline.

8. Federal Project Director.

Successful performance of DOE projects depends on professional and effective project management by the FPD. The FPD is accountable to the PME, Program Secretarial Officer or delegated authority, as appropriate, for the successful execution of the project within a PB.

The FPD's assigned project must meet cost, schedule and performance targets unless circumstances beyond the control of the project directly result in cost overruns and/or delays. FPDs must demonstrate initiative in incorporating and managing an appropriate level of risk to ensure best value for the government. In cases where significant cost overruns and/or delays may occur, the FPD must alert senior management in a timely manner and take appropriate steps to mitigate them.

Roles and responsibilities of the FPD's team must be clearly defined relative to the contractor management team. DOE Guides provide further information. These roles and responsibilities include:

a. Attain and maintain certification in concert with the requirements outlined in DOE O 361.1C before they are delegated the authority to serve as FPD and/or within one year of appointment, achieve the appropriate level of certification.

b. Serve as the single point of contact between Federal and contractor staff for all matters relating to a project and its performance.

c. Prepare and maintain the IPT Charter and operating guidance with IPT support and ensure that the IPT is properly staffed. Define and oversee the roles and responsibilities of each IPT member.

d. Appointed as the Contracting Officer's Representative, as delegated by the Contracting Officer.

e. Lead the IPT and provide broad project guidance. Delegate appropriate decision-making authority to the IPT members.

f. Approve the IPT charter for non-Major System Projects.

g. Ensure the development and implementation of key project documentation (e.g., the PEP).

h. Define project cost, schedule, performance, and scope baselines.

i. Ensure that design, construction, environmental, sustainability, safety, security, health and quality efforts performed comply with the contract, public law, regulations and EOs.

j. Ensure timely, reliable and accurate integration of contractor performance data into the project's scheduling, accounting, and performance measurement systems, to include PARS II.

k. Evaluate and verify reported progress; make projections of progress and identify trends.

l. Approve (in coordination with the Contracting Officer) changes in compliance with the approved change control process documented or referenced in the PEP.

m. Ensure that safety is fully integrated into design and construction for Hazard Category 1, 2, and 3 nuclear facilities.

n. Ensure early warning systems (triggered by thresholds) and communication channels are in place, so senior leadership is informed of potential project issues in time to make productive changes.

9. Departmental Staff and Support Offices.

Departmental Staff and Support Offices develop policy and related implementing guidance, perform review functions, and provide advice and recommendations to Department leadership. Key roles and responsibilities of these offices regarding the acquisition of capital assets follow.

10. DOE/NNSA Senior Procurement Executives.

The Senior Procurement Executive (SPE) will:

a. Execute the procurement functions and responsibilities in accordance with the Office of Federal Procurement Policy and EO 12931.

b. Serve as the principal procurement advisor to the CE, PME and the Chief Acquisition Officer.

c. Execute certain decisional authorities reserved for the SPE.

d. Exercise general procurement authority.

e. Delegate procurement authority to the Heads of Contracting Activity and Contracting Officers.

11. Contracting Officer.

The Contracting Officer is the only member of the IPT delegated authority to enter into, administer, modify, change, and/or terminate contracts. Significant responsibilities are:

a. Serve as the principal procurement advisor to the FPD.

b. Participate in the formulation of the DOE and NNSA Acquisition Strategy and Acquisition Plan.

c. Work with the IPT to develop solicitations and evaluate and award mission-oriented contracts.

d. Serve as a standing member of the CCB with sole authority to modify the contract.

e. Work with the IPT to ensure alignment between the PEP and the Contract Management Plan.

f. Assist in the development of contract cost, schedule and performance incentives.

g. Incorporate the applicable clauses, and terms and conditions in the solicitation and the contract. Ensure that the prime contractor complies with the requirements to include subcontractor flow down requirements of this Order, FAR clauses and EVMS-related terms and conditions as identified by the FPD.

12. Office of the Associate Under Secretary for Environment, Health, Safety and Security.

    a. Advise the Deputy Secretary in his/her role as the CE on environmental, safety, and security matters related to all CD approvals.

    b. Serve as a member of the IPR team at the request of the CE, PSO, Program Manager, Operations/Field Office Manager or FPD.

    c. Participate on EIRs, as an observer, at the request of PM.

    d. Participate in safety and security documentation and QA reviews for acquisition projects at the request of PM and/or the PME when considered appropriate.

    e. Participate in ORRs or RAs at the request of the line organizations.

    f. Support the CTAs as requested.

13. Office of Enterprise Assessments.

    Perform targeted reviews of technical processes and products associated with the design and construction of nuclear facilities.

14. Office of Project Management Oversight and Assessments.

    a. Serve as DOE's principal point of contact and advisor relating to project management.

    b. Develop policy, requirements and guidance for the planning and management of capital asset projects.

    c. Assist in the planning, programming, budgeting and execution process for the acquisition of capital assets in coordination with the Program Secretarial Officer and PMSO.

    d. Support the Office of the Secretary, Deputy Secretary, Under Secretaries and Program Secretarial Officer in the CD process; and oversee the acquisition management process.

    e. Serve as a member and Executive Secretariat for the ESAAB and the PMRC. When performing the Executive Secretariat duties, the Director of PM-1 is accountable to the Deputy Secretary.

    f. Manage the Project Management Career Development Program (PMCDP).

g. Establish, maintain and execute the EVMS Certification and Surveillance Review processes in accordance with established levels to ensure full compliance with applicable FAR and OMB requirements.

h. Perform EVMS Certification and Surveillance Reviews of contractors with projects that have a TPC of $100M or greater and, on an exception basis, or at the request of the PMSO, of contractors with projects that have a TPC between $50M and $100M.

i. Review MNS documents for projects with a TPC of $100M or greater.

j. Review the AS for Major System Projects.

k. Maintain a corporate project reporting capability.

l. Establish, maintain and execute a corporate EIR capability to provide an independent assessment and analysis of project planning, execution and performance.

m. Validate the PB for all capital asset projects with a TPC greater than or equal to $100M to permit inclusion in the DOE annual budget.

n. For Major System Projects, conduct an ICR prior to CD-0. For projects with a TPC of $100M or greater, develop an ICE and/or conduct an ICR prior to CD-1, develop an ICE prior to CD-2 and CD-3.

15. Integrated Project Team.

a. Support the FPD.

b. Work with the Contracting Officer to develop a project AS and AP, as applicable.

c. Ensure that project interfaces are identified, defined and managed to completion.

d. Identify, define and manage to completion the project environmental, safety, health, security, risk and QA requirements.

e. Identify and define appropriate and adequate project technical scope, schedule and cost parameters.

f. Perform periodic reviews and assessments of project performance and status against established performance parameters, baselines, milestones and deliverables.

g. Plan and participate in project reviews, audits, and appraisals as necessary.

h. Review all CD packages and recommend approval/disapproval.

i. Review and comment on project deliverables (e.g., drawings, specifications, procurement, and construction packages).

j. Review change requests, as appropriate, and support CCBs as requested.

k. Participate, as required, in ORRs or RAs.

l. Support preparation, review and approval of project completion and closeout documentation.

m. Ensure safety is effectively integrated into design and construction as applicable to each team member's respective functional area for design and construction of Hazard Category 1, 2, and 3 nuclear facilities.

16. Central Technical Authorities.

The CTAs are responsible for maintaining operational awareness, especially with respect to complex, high-hazard nuclear operations and ensuring that the Department's nuclear safety policies and requirements are implemented adequately and properly (see DOE O 410.1 for further discussion). In this context, it is important to recognize that the CTAs have responsibilities related to nuclear safety directives that apply to projects. The overall roles and responsibilities of the CTAs include:

a. Concur with the determination of the applicability of DOE directives involving nuclear safety included in contracts pursuant to 48 CFR 970.5204-2(b).

b. Concur with nuclear safety requirements included in contracts pursuant to 48 CFR 970.5204-2.

c. Concur with all exemptions to nuclear safety requirements in contracts that were added to the contract pursuant to 48 CFR 970.5204-2.

d. Recommend to the Associate Under Secretary for Environment, Health, Safety and Security issues and proposed resolutions concerning DOE safety requirements, concur in the adoption or revision of nuclear safety requirements (including supplemental requirements) and provide expectations and guidance for implementing nuclear safety requirements for use by DOE employees and contractors.

e. For DOE nuclear facilities, CTA concurrence is required on the directives included in requests for proposals for new prime contracts prior to its release and in revisions to existing prime contracts as per DOE O 410.1.

17. Chief of Defense Nuclear Safety and Chief of Nuclear Safety.

The Chiefs (and staff) are responsible for evaluating nuclear safety issues and providing expert advice to the CTAs and other senior officials (see DOE O 410.1 for further discussion). For Hazard Category 1, 2, and 3 nuclear facilities that are not regulated by the Nuclear Regulatory Commission (NRC), or as requested by the CTA or other senior officials for facilities regulated by the NRC, the Chief shall:

a. Provide support to both the CTA and PME regarding the effectiveness of efforts to integrate safety into design at each of the CDs and as requested during other project reviews.

b. Ensure that TIPRs and IPRs, as appropriate, evaluate: 1) the qualifications of IPT members having nuclear safety-related responsibilities, and 2) the effective implementation of DOE-STD-1189-2016 as applicable for design and construction of nuclear facilities.

c. For nuclear facilities, concur on the nuclear safety scope and breadth of TIPRs and IPRs. Ensure that TIPRs and IPRs evaluate the status of project planning to achieve operational readiness.

d. Advise Safety Basis Approval Authorities and concur with (CNS) or provide written advice (CDNS) prior to the approval of Safety Design Strategies and revisions thereto.

18. Project Management Governance Board.

The governance board (and staff) is responsible for evaluating project management issues and providing resolution to PMSOs and Program Managers. The responsibilities will be an additional duty to the existing PMCDP certification review board whose primary function is to certify FPDs.

a. Responsibilities:

(1) Identify issues through PM as the Secretariat.

(2) Provide interpretation or clarification of Order requirements and resolve 413-series Guide issues.

b. Membership:

(1) PM Director and NNSA Associate Administrator for Acquisition and Project Management, or designees, co-chair the board.

(2) One senior representative from each of the PMSOs to include EM, NNSA, and SC.

(3) PM Deputy Director for Project Management Oversight and Assessments.

(4) PM serves as Secretariat.

APPENDIX C
TOPICAL AREAS

1. Project Management Principles. This is the Department's framework for successful project execution:

   a. Line management accountability.

   b. Sound, disciplined, up-front project planning.

   c. Well-defined and documented project requirements.

   d. Development and implementation of sound acquisition strategies that incorporate effective risk handling mechanisms.

   e. Well-defined and managed project scope and risk-based PBs and stable funding profiles that support original cost baseline execution.

   f. Development of reliable and accurate cost estimates using appropriate cost methodologies and databases.

   g. Properly resourced and appropriately skilled project staffs.

   h. Effective implementation of all management systems supporting the project (e.g., quality assurance, integrated safety management, risk management, change control, performance management and contract management).

   i. Early integration of safety into the design process.

   j. Effective communication among all project stakeholders.

   k. Utilization of peer reviews throughout the life of a project to appropriately assess and make course corrections.

   l. Process to achieve operational readiness is defined early in the project for Hazard Category 1, 2, and 3 nuclear facilities.

   A project is a unique effort having defined start and end points which is undertaken to create a product, facility or system. Built on interdependent activities that are planned to meet a common objective, a project focuses on attaining or completing a deliverable within a predetermined cost, schedule and technical scope baseline.

   All projects entail risk. Generally, the larger and more complex the project, the higher the probability that the PB may be breached. By dividing larger projects into multiple smaller projects, the probability of success is generally increased as the duration, complexity and attendant risks for each project have been reduced. Where appropriate, Program Offices in coordination with the PME should consider breaking large projects into multiple, smaller, discrete usable projects (mindful of project interfaces) that collectively meet the mission need. However, the benefits of reduced risk exposure should be balanced with the potential for increased overhead costs.

Some things to consider when breaking larger projects into multiple smaller projects prior to establishing PBs (at CD-2):

- Time Horizon: Minimize the time horizon and risk to the maximum extent possible. Ideally, execution should take no more than four (4) years starting from CD-3.

- Funding Profile: Develop each project's funding profile to support the optimum project schedule and deliver projects quickly.

- Segregate by Building or Group Similar Types of Facilities: Segregate nuclear from non-nuclear work; utility systems/buildings from general use facilities; fixed price work from cost reimbursable work.

- Phase Projects: Execute well-defined, lower-risk, complete and usable projects first, allowing additional time to advance designs on more complex and/or technical projects. Project phases should not impede one another. Refer to Appendix C, Paragraph 27.b.

- Span of Control: Ensure that the planned scope and pace of work is matched to the capacity and capabilities of the management team.

- Segregate Projects by Geographic Area: Occasionally, projects involve separate geographic locations with different site conditions, construction workforce environments, and regulatory and political pressures.

- Workforce Phasing: Phase construction and environmental remediation projects within the program to take advantage of “leap-frogging” trades (i.e., concrete workers moving from one project to the next).

A capital asset project can range from the construction of a simple facility, such as a warehouse, to a group of closely-related projects managed in a coordinated way. This effort is known as program management.

Selection and designation of a Program Manager (see Appendix B, Paragraph 6) is critical as they ensure that all their projects are properly phased, funded over time and that each project manager is meeting their key milestones. Program managers are the advocate; they ensure proper resourcing and they facilitate the execution process. A program manager is responsible for managing programmatic risks and putting mitigation strategies in place to minimize risks to projects. Programmatic risks should be identified and quantified in terms of cost and/or schedule contingency and accounted for within one or more of the projects.

With multiple smaller projects, there may be a need for additional FPDs, perhaps at lower certification levels. However, each project, regardless of size, must be led by a certified FPD. Depending on the project size, an FPD can be assigned to direct one large project and/or multiple small projects. In addition, the project organizational structure, roles and responsibilities, and chain of command should be delineated in the PEP.

2. Acquisition Strategy.

An AS is a key activity formulated by the IPT leading up to CD-1. The AS is the FPD's overall plan for satisfying the mission need in the most effective, economical and timely manner. For more details, see FAR 34.004, DOE Acquisition Guide, Chapter 7, and DOE G 413.3-13.

Supporting the execution of the AS is the procurement strategy that must be documented in writing as prescribed by FAR 7.1 and for major systems acquisition, FAR 34.004. While the AS represents a high level plan which is approved through the CD review and approval process, the information and analysis required as part of an AP, if applicable, provides greater focus on the analysis and strategies needed to appropriately execute procurements in accordance with sound business practices, statutory, regulatory and policy requirements. Typically, the AP will not be formulated until after the CD authority has selected the programmatic approach as part of CD-1. The review and approval of the AP resides within the contracting authority of the Senior Procurement Executive or their designee. Therefore, approval of the AS by the PSO cannot be presumed to constitute approval of the AP.

While the approval of the AS and the acquisition planning processes may be bifurcated, it is critical that the planning and formulation are aligned. The early formulation of an IPT (including the assignment of a contracting officer), the balance in its composition, and continuity in the membership is critical to the integration and alignment of the AS and acquisition planning processes.

If an AS includes the acquisition of real property, it must be reviewed by a certified Real Estate Specialist for regional land use impact and a real property alternative analysis must be conducted.

3. Analysis of Alternatives.

The responsible program office is required to conduct an analysis of alternatives (AoA) that is independent of the contractor organization responsible for managing the construction or constructing the capital asset project. The AoA will be conducted for projects with an estimated TPC greater than $50M prior to the approval of CD-1 and may also be conducted when a performance baseline deviation occurs or if new technologies or solutions become available. This determination will be made by the PME. The AoA will be consistent with published GAO best practices. Refer to GAO-16-22, DOE and

NNSA Project Management: Analysis of Alternatives Could Be Improved by Incorporating Best Practices.

4. Baseline Clarity.

There is only one original PB and it is documented at CD-2 approval. The PB represents the Department's commitment to Congress to deliver the project's defined scope by a particular date at a specific cost. Cost estimates in advance of CD-2 do not represent such commitments. Also, there should be clarity over the terms PB and Performance Measurement Baseline (PMB) as they are different. The former is the project's baseline and the latter is for use by the EVMS. Refer to DOE G 413.3-10A for further clarification.

FPDs, contracting officers and program managers are accountable for ensuring contract and project documentation is complete, up-to-date, and auditable. Project baseline documentation must clearly define scope, key performance parameters, and the desired product, capability, and/or result. At project completion, there should be no question whether the objectives were achieved. Contracts and M&O work authorizations must clearly reflect project objectives and scope. Changes, especially to project objectives, need to be executed through a timely, disciplined change control process. Significant changes should be the exception, rather than the norm.

5. Cost Estimating.

The authority and accountability for any project, including its costs, must be vested firmly in the hands of the FPD. Some cost estimate, or cost range, should be provided at each CD gateway, but the degree of rigor and detail for a cost estimate should be carefully defined, depending on the degree of confidence in project scale and scope that is reasonable to expect at that stage. Whatever figure or range that is provided should explicitly note relevant caveats concerning risks and uncertainties inherent in early estimates at CD-0 and CD-1 stages given the immature requirements definition at this juncture. A project owner should never be the sole cost estimator, at any stage (i.e., from CD-0 on), given the inherent conflict of interest. The second cost estimator should come from outside of the line manager's chain of command, to avoid conflict of interest.

Established methods and best practices will be used to develop, maintain, monitor, and communicate comprehensive, well-documented, accurate, credible, and defensible cost estimates. Cost estimates shall be developed, maintained, and documented in a manner consistent with methods and the best practices identified in DOE G 413.3-21, GAO Cost Estimating and Assessment Guide (GAO-09-3SP), and, as applicable, with the Federal Acquisition Regulation (e.g., FAR Subpart 15.4 – Contract Pricing; FAR Subpart 17.6 – Management and Operating Contracts), Office of Management and Budget Circular A-11, Preparation, Submission, and Execution of the Budget, and Department of Energy Acquisition Regulation (DEAR) Subpart 915-4 – Contract Pricing.

6. Design Management.

a. Design Management for Nuclear Facilities.

Projects involving construction of new Hazard Category 1, 2, and 3 nuclear facilities intended to manage, store, process or handle nuclear materials shall comply with DOE-STD-1189-2016 and shall achieve at least 90 percent design completion before CD-2.

The objective of this requirement is to ensure systems, structures, and components, the overall design, are sufficiently mature to meet project requirements and outcomes and thus fulfilling the mission need. Design maturity at 90 percent completion will ensure that a performance baseline is based on a credible cost estimate and achievable schedule for project completion.

As a minimum, 90 percent design complete includes:

- Complete final drawings and specifications that may be released for bid and/or construction
- A current and detailed cost estimate
- A current construction schedule
- Clearly defined testing requirements and acceptance criteria for the safety and functionality of all subsystems
- Independent technical, construction, operation and environmental reviews of the final drawings and specifications
- A quality control review that evaluates both technical accuracy and discipline coordination
- A final design that meets all the requirements stipulated in the Code of Record
- A final design review that should be a final validation of comment resolution from previous reviews and a review of any additional developments since the last review
- The checking and verification of any required waivers or exemptions

The following design and safety basis documents would also need to be prepared prior to CD-2:

- Final design report

- Final design review report
- Preliminary documented safety analysis
- Safety evaluation report

b. Design Management for Non-Nuclear Construction.

Non-nuclear project designs shall be sufficiently mature to allow the PME to ensure achieving a complete, accurate project baseline with 80-90 percent confidence. At CD-1, a design plan shall establish anticipated levels of design maturity at each CD through final design. Independent project reviews should evaluate progress against the design plans established at CD-1.

In addition, for all capital asset projects greater than $100M, the Project Management Risk Committee (PMRC) will review all project design plans at CD-1 to ensure design maturity targets at critical milestones are reasonable based on numerous factors including technology readiness, complexity, total project cost, and any other relevant factor for the project. Ideally, at CD-2, the objective is to achieve a design maturity that would be used as a reliable indicator of a contractor's actual total costs at completion that would not exceed the original cost baseline.

c. Design Management Plans for Major System Projects.

To enhance fiscal insight and discipline for major system projects, an estimate of the required amount of PED funds to execute the planning and design portion of a project (period from CD-1 to completion of the project's design) shall be included in the CD-1 documentation.

As part of the development and approval process for CD-1 for major system projects, design management plans shall be developed and included in the approval package. If at any time, through forecasting or actual costs, it becomes apparent the design cost target will be breached, then the PMRC shall be notified.

7. Design Maturity.

All aspects of a project should be carefully studied to employ an economic and functional design that is closely tailored to the requirements. Particular attention shall be directed to advancing design maturity to a sufficient level prior to establishing the PB. The project design will be considered sufficiently mature when the project has developed a cost estimate and all relevant organizations have a high degree of confidence that it will endure to project completion. In determining the sufficiency of the design level, factors such as project size, duration and complexity will be considered.

In conducting EIRs, PM will evaluate the sufficiency of the project's design maturity. This analysis will serve as a key evaluation factor in formulating its recommendation to validate a project PB. In addition, when approving a CD, the PME should consider the sufficiency of the design maturity.

Project design is a process of preparing design and construction documents that result in fully integrated solutions. For a design to succeed, the entire project team must be involved in the process from project inception through delivery. The Pre-Conceptual Design stage denotes the development and documentation of the functional parameters or capabilities that the potential project must meet. The development of criteria, which are complete and specifically related to the project requirements, allows for orderly development of the design. However, care shall be taken to avoid citing superfluous codes and standards; the primary purpose of functional criteria is to narrow the criteria to only those applicable to specific alternatives or options. These functional criteria are further developed, validated, and expanded during the conceptual design stage.

The conceptual design process must ensure that a solution or alternatives are not only responsive to an approved need, but also technically achievable, affordable and will provide the best value to the Department. Research, development, testing and other efforts may be required to finalize a concept. The conceptual design process may also require negotiation with outside organizations, stakeholders or other legal entities on functional, technical, operational and performance requirements or standards. VM is a key process that supports reaching the best cost and benefit life-cycle cost alternative. VM should be employed as early as possible so that recommendations can be included in the planning and implemented without delaying the project or causing significant rework of designs. VM conducted during the early phases of a project yield the greatest cost reductions. At a minimum, the Conceptual Design shall develop the following:

- Scope required to satisfy the Program mission requirements;
- Project feasibility;
- Attainment of specified performance levels;
- Assessment of project risks and identification of appropriate risk handling strategies;
- Reliable cost and schedule range estimates for the alternatives considered;
- Project criteria and design parameters;
- Impact on the site Sustainability Plan; and

- Identification of requirements and features.

A Conceptual Design Report (CDR) shall be developed that includes a clear and concise description of the alternatives analyzed, the basis for the alternative selected, how the alternative meets the approved mission need, the functions and requirements that define the alternative and demonstrate the capability for success, and the facility performance requirements, planning standards and life-cycle cost assumptions. The CDR should also clearly and concisely describe the KPPs that will form the basis of the PB at CD-2. When the purpose of the project is remediation, restoration, or demolition, other forms of documenting the requirements and alternative(s) may be used.

The following are requirements for projects authorized by the annual National Defense Authorization Act (refer to 50 USC 2744 and 2746 and PL 113-66, Section 3120). These statutory requirements apply only to projects in support of a national security program of the Department.

- The Secretary shall submit a request for funds for a conceptual design for a project if the estimated cost of the conceptual design exceeds $3M.

- The conceptual design for a project shall be completed before requesting funds for a construction project.

- If the TEC for construction design for a project exceeds $1,000,000, funds for that design must be specifically authorized by law.

- Construction on a project may not be started, if the current TEC of the project exceeds by more than 25% the amount shown in the most recent PDS submitted to Congress.

The Preliminary Design stage initiates the process of converting concepts to a more detailed design whereby more detailed and reliable cost and schedule estimates are developed. This stage of the design is complete when it provides sufficient information to support development of the PB. The appropriate completion percentage is dependent upon the type of project. For basic facilities, such as administrative buildings, general purpose laboratories, and utilities, the design does not have to be as mature as for a complex chemical or nuclear processing facility (as depicted in Figure 3). The design is mature when a point estimate can be developed and is ready for an independent review. The determination of a design completion percentage for reporting purposes will be made by the Architect-Engineer as well as by subsystem designers contracted to do the work, and/or other IPT members.

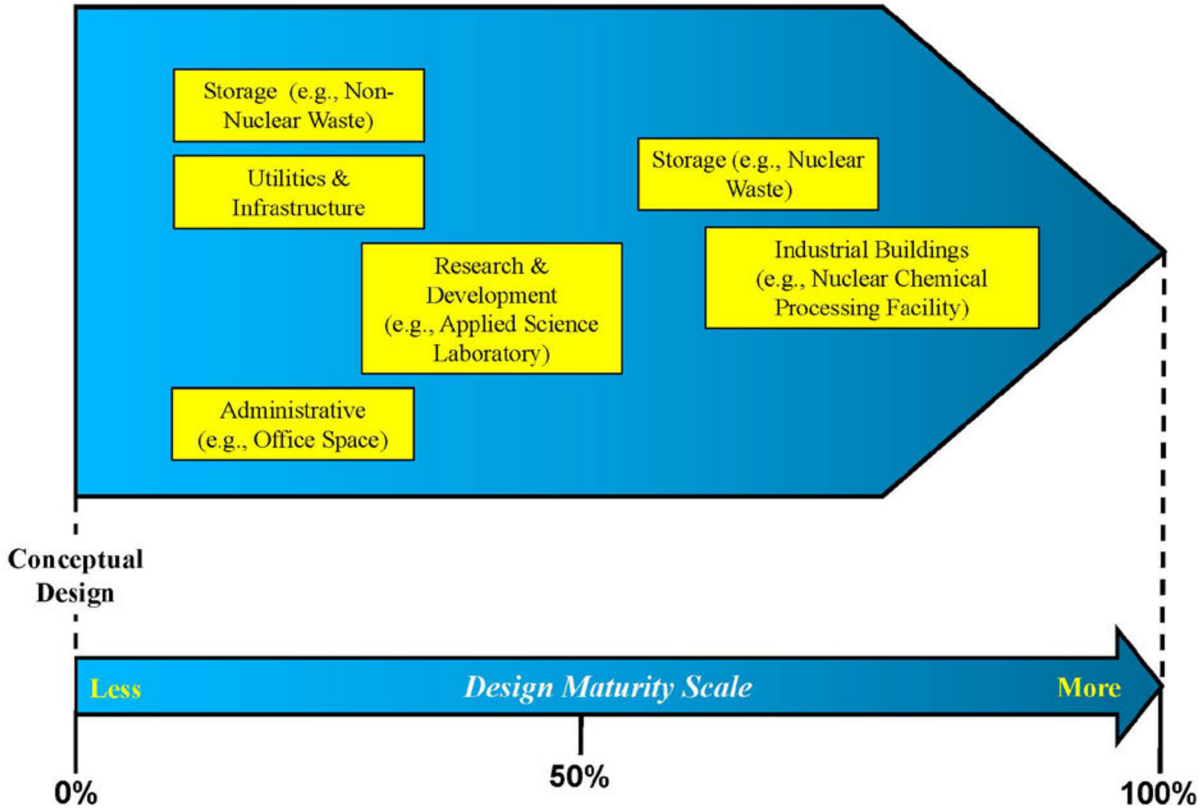


Figure 3. Facility Design Maturity General Guidelines for CD-2.

Final Design is the last stage of development prior to implementation. The purpose of the Final Design stage is to prepare final drawings, technical specifications and contract documents required to obtain bids and quotes for procurement and construction. The Final Design should include clear statements of testing requirements and acceptance criteria for the safety and functionality of all subsystems. The project scope should be finalized and changes (coordinated through a documented and approved change control process and CCBs) should be permitted only for compelling reasons (i.e., substantial economies achieved through VE, accommodation of changed conditions in construction, or reduction in funds or changes in requirements). In any case, construction should not be allowed to proceed until the design is sufficiently mature to minimize change orders.

Scientific systems, such as accelerators, detectors, and production and manufacturing facilities, may not follow a linear design process in which all subsystems reach the same maturity at the same time. Concurrency in these types of projects increases the risk because each subsystem design is dependent upon the design maturity of other subsystems. Projects that have several subsystems may have separate preliminary and final design stages. Consequently, final designs may be completed at various points in time in the system development process. Regardless, design reviews should be conducted for all projects and should involve a formalized, structured approach to ensure the reviews are comprehensive, objective, professional and documented.

Design reviews (including constructability reviews, where appropriate) are a vital component of the entire process and should be explicitly included in the schedule for the design effort. Design reviews shall be conducted by reviewers external to the project to document the completion of conceptual design, preliminary design and final design. The fundamental purpose of the design review is to ensure the following:

- Quality of the design.
- Operational and functional objectives are met.
- Maintenance of costs within the budget.
- Design is sufficient for the stage of the project, e.g., for final design, the design is biddable, constructible, and cost-effective.
- Interface compatibility.
- Final contract documents comply with the design criteria.
- A detailed, unbiased, analytical approach is given to all of the above items.

Complete design submittals are required at completion of established design stages; design and technical reviews shall then be performed. There shall also be a back-check review at design completion to verify that all comments made during the Final Design review stage have been addressed.

8. Earned Value Management System.

The Department will adopt project management control best practices equivalent to those implemented by the Department of Defense (DoD). This includes a DOE version of the DoD Integrated Program Management Report (IPMR) on projects not associated with a firm fixed-price contract.

An EVMS is required for all projects with a TPC greater than $50M. In accordance with FAR Subpart 52.234-4, a contractor's EVMS will be reviewed for compliance with EIA-748C, or as required by the contract. (Further details on establishing, employing, and maintaining a compliant EVMS are found in DOE G 413.3-10A, EIA-748C, and DOE Integrated Program Management Report (IPMR) Data Item Description (DID)).

For projects with a TPC less than $100M, the contractor may request an exemption from the PMSO from using EVMS. For firm fixed-price contracts, a contractor EVMS is not required. For projects with a TPC between $50M and $100M, if an EIA-748C compliant EVMS is not used, an alternative project control method must be approved by the PMSO.

The alternate system requirement must be described in the PEP and provided to the contracting officer to be included as a contract requirement. Alternative project control methods to be used must include at a minimum a(n) work breakdown structure, integrated master schedule showing critical path, schedule of values, account of planned versus actual work and cost, and EAC.

Only the facility construction and facility improvement activities of High Performance Computing (HPC) projects will be subject to the Earned Value Management (EVM) requirements of this Order. "Non-construction activities," which are programmatic elements of HPC activities including research and development, leases, and software development, will be subjected to the following components:

- EVM Compliance – Non-construction activities will be tracked with level of effort activities and milestone achievement and EVM compliance should be eliminated.

- PARS II Reporting – Non-construction activities will be entered with narrative information only.

Project control information will be provided monthly, including upload of the baseline and status schedules, and data from the schedule of values and planned versus actual work and cost accounts, into the Department's PARS II system in accordance with the PARS II Contractor Project Performance (CPP) Upload Requirements document.

For projects using EVMS and reporting EVMS data, the contracting officer, or the Contracting Officers' Representative (COR), normally the FPD, will ensure that contractors upload in PARS II the required project performance data at the lowest element of cost level in the specified format.

a. EVMS Certification. This is the initial determination by PM that a Contractor's EVMS is in full compliance with EIA-748C, or as required by the contract, on all applicable projects. Documentation of the certification shall be provided to the Contracting Officer and the PMSO. The Contracting Officer must provide copies of transmittal memoranda or related documents to PM. All relevant documentation shall be maintained in PARS II.

   - For contractors where there are applicable projects with a TPC between $50M and $100M, the contractor shall maintain EVMS compliant with EIA-748C.

   - For contractors where there are applicable projects having a TPC of $100M or greater, PM must conduct the certification review process and certify the contractor's EVMS compliance with EIA-748C, or as required by the contract.

b. EVMS Surveillance. This is meant to ensure that a contractor's certified EVMS remains in full compliance with EIA-748C, or as required by the contract, on all applicable projects. A surveillance review may include an assessment against some or all of the EIA-748C requirements. The extent of the surveillance review will be tailored based on current conditions.

For contractors where there are applicable projects having a TPC of $100M or greater, PM will conduct a risk-based, data driven surveillance during the tenure of the contract, during contract extensions, or as requested by the FPD, the Program, or the PME). Documentation of the surveillance will be provided to the Contracting Officer documenting the compliance status of the contractor's EVMS with EIA-748C, or as required by the contract.

(1) Notification of Non-Compliance. If following a PM surveillance review, the contractor has not fully corrected the noted deficiencies despite offers of assistance from PM, has ignored contractual direction to take corrective action, or the results of the surveillance review indicate non-compliance with EIA-748C, PM may issue a Notice of Non-Compliance with EIA-748C, or as required by the contract, to the Contracting Officer and will note whether the contractor's EVMS certification has been withdrawn.

(2) Implementation Review. An implementation review is a special type of surveillance performed at PM’s discretion in lieu of a certification review when EVMS compliance is a requirement. This type of review extends the certification of a contractor’s previously certified system. The implementation review must be conducted prior to CD-3 or at the latest within three months of construction mobilization. A contractor’s certified system may be extended in the following situations:

- When a contractor adopts one of their existing certified EVMS for application under a new contract at the same or different site (sometimes referred to as Corporate Certification).

- From one project to another project after a period of system non-use.

- A previously certified system description to a significantly revised system description.

- From one certifying entity to another (meaning other Civilian Federal Agency or DoD to DOE) provided the contracting entity remains the same.

- When a new contractor adopts the previous contractor's existing certified system with minimal to no change in the system description, processes, or tools.

9. Environment, Safety and Health Documentation Development.

a. For projects involving Hazard Category 1, 2, or 3 nuclear facilities as defined in 10 CFR Part 830, Subpart B:

(1) Prior to CD-1, a CSDR is developed to:

- Document and establish a preliminary inventory of hazardous materials, including radioactive materials and chemicals;
- Document and establish the preliminary hazard categorization of the facility;
- Identify and analyze primary facility hazards and facility Design Basis Accidents;
- Provide an initial determination, based on preliminary hazard analysis, of safety class and safety significant structures, systems, and components;
- Include a preliminary assessment of the appropriate seismic design category for the facility itself as well as safety significant structures, systems, and components;
- Evaluate the security hazards that can impact the facility safety basis (if applicable); and
- Include a commitment to the nuclear safety design criteria of DOE O 420.1C (or proposed alternative criteria).

(2) At completion of the Preliminary Design Phase, Preliminary Safety and Design Results are developed to reflect more refined analyses based on the evolving design and safety integration activities during preliminary design. The Preliminary Safety and Design Results should include the results of process hazards analyses and confirm or adjust, as appropriate, the items included in the CSDR.

(3) Prior to CD-2, a PDSA is prepared which updates and expands the safety information in the Preliminary Safety and Design Results and identifies and justifies any changes from the design approach described in the Preliminary Safety and Design Results. A plan to achieve operational readiness is prepared using the core requirements of DOE O 425.1D.

(4) Prior to CD-4, a Documented Safety Analysis is developed based on information from the PDSA and the SER. Technical safety requirements are developed to document and establish specific parameters and requisite actions for safe facility operation.

(5) An ORR or RA will be conducted in accordance with DOE O 425.1D.

b. For projects involving facilities that are below the Hazard Category 3 threshold as defined in 10 CFR Part 830, Subpart B:

(1) Prior to CD-1, prepare a PHAR to identify and evaluate all potential hazards and establish a preliminary set of safety controls. Hazardous chemicals are analyzed in accordance with Integrated Safety Management (ISM) requirements in DOE P 450.4A, 29 CFR 1910.119, and 40 CFR Part 68.

(2) Prior to CD-2, a Hazard Analysis Report is developed by updating the PHAR to include any new or revised information on facility hazards and safety design. If the hazard characterization is below Hazard Category 3 by analysis, the SBAA should approve this analysis before CD-2.

(3) Prior to CD-3 and CD-4, hazard analysis and controls are updated in the Hazard Analysis Report.

(4) The PSO will determine what level of readiness review will be conducted.

c. All projects must comply with environmental protection requirements including NEPA documentation, anticipated permitting requirements and cost-effective environmental stewardship, advance regional and local integrated planning goals and sustainable sites, and high performance and sustainable building principles.

d. A Construction Project Safety and Health Plan is prepared prior to construction activities per 10 CFR Part 851, Appendix A, Section 1(d).

e. EO 13514 requires that all projects divert at least 50 percent of construction and demolition materials and debris (by weight) from the non-hazardous solid waste stream.

10. <u>Integrated Project Team</u>.

The FPD shall organize and lead the IPT. The IPT is an essential element in DOE's acquisition process and is involved in all phases of a project. This team consists of professionals representing diverse disciplines with the specific knowledge, skills and abilities to support the FPD in successfully executing a project. The team size and membership may change as a project progresses from CD-0 to CD-4 to ensure that the necessary skills are always represented to meet project needs. Team membership may be full or part time, depending upon the scope and complexity of a project and the activities underway. However, the identified personnel must be available to dedicate an amount of time sufficient to contribute to the IPT's success. Refer to DOE G 413.3-18A for further clarification.

Qualified staff (including contractors) must be available in sufficient numbers to accomplish all contract and project management functions. Project staffing requirements should be based on a variety of factors, including project size and complexity, as well as the management experience and expertise of the project staff. Programs must use a methodology to determine the appropriate project team size and required skill sets. One such algorithm is detailed in DOE G 413.3-19. Regardless of the methodology used, once the appropriate staff size has been determined, programs should plan and budget accordingly.

The FPD and the team will prepare and maintain an IPT Charter that describes:

- Membership (must include the Contracting Officer);
- Responsibilities and authority;
- Leads (as appropriate);
- Meetings;
- Reporting; and
- Operating guidance.

Nuclear safety experts on a nuclear facility project should include personnel in functional areas which relate to nuclear safety aspects of the facility. Disciplines within these functional areas can include: design disciplines (civil, structural, mechanical, electrical, instrumentation); health physics and radiological protection; safety, accident, hazard, or risk analysis; criticality safety; process chemistry; fire protection; configuration management; startup testing; conduct of operations; maintenance; operational readiness; commissioning; quality assurance. This does not preclude personnel from other disciplines providing that they have relevant and appropriate nuclear safety experience for the functional area for which they are responsible.

11. Integrated Safety Management System.

An Integrated Safety Management System (ISMS) must be in place to ensure that potential hazards are identified and appropriately addressed throughout the project (refer to DOE P 450.4A). It will be used to systematically integrate safety into management and work processes at all levels. The project management team will implement the following seven guiding principles:

a. Line management responsibility for safety;

b. Clear roles and responsibilities;

c. Competence commensurate with responsibilities;

d. Balanced priorities;

e. For Hazard Category 1, 2, and 3 nuclear facilities, the CSDR must identify safety standards and requirements to include preliminary seismic design category for the facility itself as well as safety class and significant structures, systems, and components;

f. Engineered controls tailored to the functions being designed or performed; and

g. Tailoring should be applied to a project's ISMS to enable tasks to be managed at the appropriate levels enabling those closest to the task plan to assume responsibility for planning and performance. Refer to DOE P 470.1A for more information.

12. Key Performance Parameters.

A KPP is defined by CD-2 and is a characteristic, function, requirement or design basis that if changed would have a major impact on the system or facility performance, schedule, cost and/or risk. In some cases, a minimum KPP or threshold value should be highlighted for CD-4 (project completion) realizing in many instances full operational capabilities may take years to achieve. The minimum KPPs and facility mission must stay intact for the duration of the project since they represent a foundational element within the original PB. For NNSA projects, KPPs are also identified in the PRD. Additional details concerning the application of KPPs are provided in DOE G 413.3-5A.

13. Lessons Learned Process.

Lessons Learned and best practices should be captured throughout the continuum of a project. Within 90 days of CD-3 approval, up-front project planning and design lessons learned shall be submitted to PM. Likewise, project execution and facility start-up lessons learned shall be submitted within 90 days of CD-4 approval. Lessons learned reporting allows the exchange of information among DOE users in the context of project management.

14. Nuclear Facilities: Safety Design Strategy and Code of Record.

Early in the conceptual design phase, a SDS should be developed for Hazard Category 1, 2, and 3 nuclear projects. The SDS provides preliminary information on the scope of anticipated significant hazards and the general strategy for addressing those hazards. The SDS is updated throughout subsequent project phases and should contain enough detail to guide design on overarching design criteria, establish major safety structures, systems, and components, and identify significant project risks associated with the proposed facility relative to safety.

Consistent with this Order, DOE O 420.1C, and DOE-STD-1189-2016 for nuclear facilities, adequate resources shall be provided to develop a SDS and a Code of Record early in the design phase. The Code of Record shall be maintained throughout the CD process and for the remainder of the nuclear facility's life-cycle. The Code of Record shall serve as the management tool and source for the set of requirements that are used to design, construct, operate and decommission nuclear facilities over their lifespan.

15. Performance Baseline.

The PB, as established in the PEP, defines the TPC, CD-4 completion date, performance and scope commitment to which the Department must execute a project and is based on an approved funding profile. The PB includes the entire project budget (total cost of the project that includes contingency) and represents DOE's commitment to Congress and the OMB. The approved PB must be controlled, tracked and reported from the beginning to the end of a project to ensure consistency between the PEP, the PDS, and the Business Case (a requirement of OMB Circular A-11).

16. Planning and Scheduling.

Projects shall develop and maintain an Integrated Master Schedule (IMS). The IMS shall be developed, maintained, and documented in a manner consistent with methods and the best practices identified in the Planning and Scheduling Excellence Guide, published by the National Defense Industrial Association, and the GAO’s Schedule Assessment Guide (GAO-16-89C).

17. Project Definition Rating Index.

The project team will perform comprehensive front-end project planning to an appropriate level before establishing a PB at CD-2. The PDRI model assists the IPT in identifying key engineering and design elements critical to project scope definition. PDRI is to be implemented and used for projects with a TPC of $100M or greater, as appropriate. This will be accomplished by the FPD. While not mandated, it is strongly encouraged for use by Programs for projects with a TPC less than $100M. See DOE G 413.3-12 for additional information.

18. Project Execution Plan.

The PEP is the core document for the management of a project. The FPD is responsible for the preparation of this document. It establishes the policies and procedures to be followed in order to manage and control project planning, initiation, definition, execution and transition/closeout, and uses the outcomes and outputs from all project planning processes, integrating them into a formally approved document. It includes an accurate reflection of how the project is to be accomplished, the minimum KPPs for CD-4, resource requirements, technical considerations, risk management, configuration management, and roles and responsibilities. A preliminary PEP is required to support CD-1. This document continues to be refined throughout the duration of a project and revisions are documented through the configuration management process. Key elements of a PEP are provided in DOE G 413.3-15.

19. Project Funding.

a. Incremental Funding. Project budget requests should consider mitigating risks such as continuing resolutions (particularly for new starts), higher than anticipated project burn rate and affordability within the program's capital and operations budget portfolio.

b. Funding Profiles. In approving the funding profile for completing the project, PMEs must determine that the proposed funding stream is affordable and executable within the program's capital and operations budget portfolio. Any changes to the approved funding profile that negatively impacts the project after CD-2 must be endorsed by the project's PME, who may not be the Program Budget Officer. Prior to endorsement by the PME, the CFO and PM will be notified of any proposed project funding profile changes so that the CFO can verify that the funding profile is covered within the President's budget.

c. Funding Documents. All projects, except for MIE, will provide to the CFO and the PM a project funding document (inclusive of the PDS for line item projects) that clearly delineates the budget year funding request, prior year budget requests and appropriations, and future planned budget requests. Consistent with current budget submission requirements, the PDS for line item projects will be included in the Department’s Congressional budget submission.

The project funding document (similar to PDS) for operating expense projects will be considered internal information for the CFO, PM, and appropriate senior leaders during the budget preparation process to document that project funds are being requested consistent with the funding profile established at CD-2, or the latest BCP that was approved.

d. Project Engineering and Design (PED) Funds. To enhance fiscal insight and discipline for major system projects, an estimate of the required amount of PED funds to execute the planning and design portion of a project (period from CD-1 to completion of the project’s design) shall be included in the CD-1 documentation.

For projects where the top-end range is less than $100M, the use of PED funds shall be limited to a two-year duration, unless approved by the PME. The PMRC shall be notified of granted time extensions or waivers. The estimate will be subject to applicable independent reviews.

e. Align Priorities to Program Appropriations. Each program office shall develop an integrated capital asset project priority list as a corporate tool to enable DOE leadership to optimize limited budget resources. The priority list shall be updated at least annually and should rank mission needs that are achieved by each capital asset project and identify project drivers, internal and external factors for ranking the projects. The prioritization should be reflected in the annual fiscal guidance.

20. Project Reporting, Assessments and Progress Reviews.

a. Project Reporting. PARS II is the central repository for key Departmental-level project information. PARS II enables receipt of cost and schedule data in the format specified in the DOE version of the IPMR to ensure consistency across the federal government and deploy improved cost and schedule analysis tools. Contractor will upload in PARS II the required project performance data at the lowest element of cost level in the specified format.

The Program Offices and FPDs will ensure that project data is uploaded monthly into PARS II (including EVMS data provided directly into PARS II from contractor's systems after CD-2). Approval of CD-0 initiates a requirement for project status reporting. This reporting continues through completion of the PMB for all projects with a TPC greater than $50M. The PSO will submit key project documentation such as CD and BCP approval memoranda to PM within five business days of document approval.

At CD-2 and continuing through completion of the PMB, projects with a TPC greater than $50M must report project performance in PARS II no later than the last workday of every month. The data must be current as of the closing of the previous month’s accounting period.

The information and earned value data in PARS II must accurately reflect current project status and provide acceptable forecasts to facilitate project management and decision-making processes. Accordingly:

- The FPD must assure project cost and schedule performance reflects reality. Early warning indicators are essential. Monthly estimates at completion (EACs) are a must, including a separate EAC, or forecasted TPC, provided by the FPD.

- The contractor must be held accountable for providing timely, accurate, reliable and actionable project and contractor cost, schedule, performance, risk, and forecast data, reports and information. The IPT must be accountable for its oversight and validation of the data.

- Contracts should be structured so as to minimize cost overrun exposure. When significant PB cost BCPs occur that generate a new TPC, the FPD and contracting officer shall work together to consider a revised cost share proposition moving forward. In addition, the FPD and contracting officer shall work together to ensure the contracts include appropriate requirements for complete, accurate and timely reporting with appropriate requirements analysis to support the contractor's monthly estimates of project completion cost and schedule.

b. Project Assessments. Following the upload of a contractor's monthly performance data, the FPDs have until the third business day of the following month to accomplish their assessment. The Program Managers have until the sixth business day and PM until the ninth business day to provide their assessment and to compile the monthly project status report. PM will coordinate the report with the Programs and on the 25th business day, forward the report to the Deputy Secretary.

Project performance assessments shall be determined through quantitative and qualitative methods. Elements to be reviewed include, but are not limited to EVMS data, contractor's monthly reports, acquisition management practices, risk management status, EIR/IPR/TIPR/Project Peer Reviews, site visits, staffing assessments, budget submittals, as well as discussions with the IPT members. PM will provide project assessments for all capital asset projects in its monthly reports to the Deputy Secretary. Ratings shall be assessed against the current approved PB:

- Green – Project is expected to meet its current PB.
- Yellow – Project is potentially at risk of not meeting an element of the current PB.
- Red – Project is highly at risk of requiring a change to the PB by the PME or is not being executed within the AS and PEP.

c. Project Progress Reviews. QPRs must be conducted with the applicable PME or their designee. Participation by the PME is strongly encouraged at all QPRs. However, when it is not possible, the PME can delegate the review. In no case should it be delegated beyond two consecutive quarters for projects post CD-2. The CE may delegate QPRs for Major System Projects to the Under Secretaries. PM must be provided all QPR reports and invited to participate in QPRs for all projects with a TPC greater than or equal to $100M. Also, PM will serve as Secretariat for CE QPRs.

21. Project Scope.

Capital asset project scope determinations shall adhere to Federal statutes, regulations, policy, and guidance. Specifically, determinations shall comply with the Office of Management and Budget's Circular A-11 and associated Capital Programming Guide. Capital asset project decisions shall be made based on clearly defined scope and the nature and type of work to be completed and shall include all the project-specific work scope needed to achieve a complete and usable asset and accomplish the defined mission need using proper project segmentation or project phasing. The cost of operational activities that occur solely to support accomplishment of the capital asset project between CD-0 and CD-4 are to be included in the project's TPC. Refer to DOE WBS Handbook.

22. Quality Assurance.

Quality Assurance begins at project inception and continues through all phases of the project. The FPD is responsible for a Quality Assurance Program (QAP) for the project and all applicable QA requirements must be addressed. Apply ASME NQA-1-2008 (Edition) and NQA-1a-2009 (Addenda) for Hazard Category 1, 2, or 3 nuclear facilities. The key elements of a QAP are provided in DOE O 414.1D and 10 CFR Part 830, Subpart A. (See also DOE G 413.3-2.)

23. Reviews.

Reviews are an important project activity and must be planned as an integral part of the project and tailored appropriately to project risk, complexity, duration and CD or phase. Refer to DOE G 413.3-9 for more information. The following is a summary of key reviews organized by CD.

a. Prior to CD-0.

(1) Mission Validation Independent Review.

A Mission Validation Independent Review, performed by the PSO, is a limited review prior to CD-0 for Major System Projects. It validates the mission need and the ROM cost range that is provided, in part, to properly designate the appropriate PME. A Value Study may also be conducted, as appropriate, to assist in CD-0. Refer to DOE G 413.3-17.

(2) Mission Need Statement Document Review.

PM will review the MNS Document and provide a recommendation to the PSO for projects with a TPC greater than or equal to $100M. The review shall be completed within 10 days after the submission for Non-Major System Projects and within 25 days for Major System Projects.

(3) Independent Cost Review.

For Major System Projects, or for projects as designated by the CE, PM will conduct an ICR. This review validates the basis of the ROM cost range and provides an assessment of whether the range reasonably bounds the alternatives to be analyzed in the next project phase. It also determines the PME authority designation.

b. Prior to CD-1.

(1) Acquisition Strategy Review.

Acquisition Strategies for Major System Projects must be sent to the ESAAB Secretariat for review by PM prior to scheduling CD-1 decisional briefings. The FPD and CO must concur with the AS prior to the PM review. Within 10 days upon receipt, PM will provide a recommendation to the appropriate PSO who holds approval authority. Approval of the AS does not constitute approval of the AP. The AP must be submitted for review and approval in accordance with established procurement procedures including DOE Acquisition Guide, Chapter 7.1.

(2) Independent Project Review.

For Hazard Category 1, 2, and 3 nuclear facilities, the PSO will conduct an IPR to ensure early integration of safety into the design process. The review must: 1) ensure that safety documentation is complete, accurate and reliable for entry into the next phase of the project; 2) evaluate whether the preferred alternative process and facility design, and corresponding safety analyses, are sufficiently detailed to identify any safety controls that, because of cost, maintainability, complexity or other limiting characteristics, could significantly impact the decision to select the preferred alternative; and 3) validate that the IPT charter has identified appropriate functions, roles and responsibilities for members needed to support nuclear safety, and that the IPT members supporting nuclear safety are appropriately qualified, and have the availability to meet their responsibilities. The PSO approval of IPRs, specified in Appendix A, Table 2.1 means that the Program Office and FPD jointly request the review, establish the review scope and schedule, and select a team leader.

CNS or CDNS concurrence, as appropriate, is required for reviews of projects that must implement DOE-STD-1189-2016. The team leader is the approval authority for the review plan (including the Criteria and Review Approach Documents) and for the final review report.

(3) Conceptual Design Review.

Conceptual Design Review must be conducted for all projects and involve reviewers external to the project using a formalized, structured approach to ensure that the reviews are comprehensive, objective and documented.

(4) Technology Readiness Assessment.

For Major System Projects or first-of-a-kind engineering endeavors, the IPT shall complete a TRA and Technology Maturation Plan, as appropriate. These assessments are also encouraged for lower cost projects where new technologies may exist.

(5) Independent Cost Estimate and/or Independent Cost Review.

For projects with a TPC greater than or equal to $100M, PM will develop an ICE and/or conduct an ICR, as they deem appropriate. This review validates the basis of the preliminary cost range for reasonableness and executability. It also includes a full accounting of life cycle costs to support the alternative selection process and budgetary decisions.

c. Prior to CD-2.

(1) DOE Review of Preliminary Safety and Design Results.

For Hazard Category 1, 2, and 3 nuclear facilities, DOE conducts an independent review of the Preliminary Design and Safety Results to determine whether final design should proceed. The review may consist of a single review or a series of reviews, based on when the preliminary design of the facility (or of defined segments of the design) is complete and ready to enter final design. This review is conducted by a DOE-selected team of experts and its results provided to the FPD for review and action as necessary. The size and composition of the team reflects the size and complexity of the project. More than one review may be conducted at the discretion of the FPD; the SDS should define segments when more than one review is planned. The independent review(s) should be scheduled as early as practicable, after completion of preliminary design, to minimize project risk. This review may be handled by the TIPR, as long as the appropriate experts are part of the review team. Refer to DOE-STD-1104-2016 for the required method for DOE personnel to review and approve the Preliminary Design and Safety Results.

(2) Technical Independent Project Review.

For Hazard Category 1, 2, and 3 nuclear facilities, a TIPR will be performed to ensure that safety is effectively integrated into design and construction. The TIPR must: 1) ensure that safety documentation is complete, accurate and reliable for entry into the next phase of the project; and 2) evaluate the IPT to ensure that appropriate team member functions to support nuclear safety during final design have been established, and appropriately qualified team members have been selected and have needed availability to address nuclear safety-related matters during final design. Completion of the TIPR is required at or near the completion of preliminary design, and prior to the start of any subsequent reviews (including EIRs) and is required prior to CD-2 approval. The PSO approval of TIPRs, specified in Appendix A, Table 2.2 means that the Program Office and FPD jointly request the review, establish the review scope and schedule, and select a team leader.

CNS or CDNS concurrence in CD-2 approval is required for reviews of projects that must implement DOE-STD-1189-2016. The team leader is the approval authority for the review plan (including the Criteria and Review Approach Documents) and for the final review report.

(3) Performance Baseline Validation Review.

A Performance Baseline Validation Review is required to provide reasonable assurance that the project can be successfully executed. IPRs are required to validate the PB for projects with a TPC less than $100M. The PME may request an EIR in lieu of an IPR through PM, and shall do so if the PME has no PMSO to perform the review. For all projects with a TPC greater than or equal to $100M, PM will conduct an EIR and develop an ICE in support of the PB validation. Findings resulting from project reviews must be addressed by the IPT in their corrective action plan and expeditiously resolved. Follow-up reviews to validate finding resolution may be required at the discretion of the reviewing entity.

(4) Project Definition Rating Index Analysis.

For projects with a TPC greater than $100M, the FPD shall conduct a PDRI Analysis. Such analyses are also encouraged for projects with a TPC less than $100M.

(5) Technology Readiness Assessment.

For Major System Projects or first-of-a-kind engineering endeavors, the IPT shall complete a TRA and Technology Maturation Plan, as appropriate. These assessments are also encouraged for lower cost projects where new technologies may exist.

(6) Preliminary Design Review.

Preliminary Design Review must be conducted for all projects and involve reviewers external to the project using a formalized, structured approach to ensure that the reviews are comprehensive, objective and documented.

(7) Final Design Review.

Final design review must be conducted for all Hazard Category 1, 2, and 3 nuclear facilities and involve reviewers external to the project using a formalized, structured approach to ensure that the reviews are comprehensive, objective and documented.

d. Prior to CD-3.

(1) Construction or Execution Readiness Review.

An EIR must be performed by PM on Major System Projects to verify construction or execution readiness.

(2) Independent Cost Estimate.

For projects with a TPC greater than or equal to $100M, PM will develop an ICE.

(3) EVMS Certification Review.

For contracts where there are applicable projects with a TPC greater than $100M, PM must conduct the certification review.

(4) Technology Readiness Assessment.

For Major System Projects where a significant critical technology element modification occurs subsequent to CD-2, conduct a TRA, as appropriate.

(5) Final Design Review.

Final Design Review must be conducted for all non-nuclear facilities and less than Hazard Category 3 nuclear facilities and involve reviewers external to the project using a formalized, structured approach to ensure that the reviews are comprehensive, objective and documented.

e. Prior to CD-4.

(1) Operational Readiness Review or Readiness Assessment.

Conduct an ORR or RA for Hazard Category 1, 2, and 3 nuclear facilities in accordance with DOE O 425.1D.

(2) Readiness to Operate Assessment.

For non-nuclear projects, conduct a formal assessment of the project's readiness to operate, as appropriate. Determine the basis for DOE acceptance of the asset and if the facility or area can be occupied from both a regulatory and work function standpoint. Establish a beneficial occupancy/utilization date for the facility and/or equipment.

f. Project Peer Reviews.

These focused, in-depth reviews are conducted by non-advocates (Federal and M&O or other contractor experts) and support the design and development of a project. For projects $100M or greater (or lower as deemed appropriate by the Under Secretaries), Project Assessment Offices that have direct line of responsibility to the appropriate Under Secretary shall conduct a Project Peer Review between CD-0 and CD-1, annually between CD-1 and CD-2, at least annually between CD-2 and CD-4 and more frequently for the most complex projects or those experiencing performance challenges. The reviews should be performed by peers (with relevant experience and expertise) independent of the project, to evaluate technical, managerial, cost, scope and other aspects of the project, as appropriate. Each Under Secretary shall ensure that the peer reviews have independence from line management and, to the greatest extent possible, use experts who are familiar with the projects to ensure continuity for future reviews.

The review teams will be established with the Department's most talented project, contract and technical staff from across the complex. This includes both Federal and contractor personnel from within and across Program Offices, which will benefit from this cross-fertilization by learning from each other.

There should be no contractual or budgetary impediments to accomplishing these reviews, which are fundamental to the professional development of each and every member of both the project team and the review team. The knowledge and lessons learned that our project management professional's gain with each review is invaluable. Project management professional development and departmental knowledge management is the ultimate result; enhancements to project execution performance over time is the by-product. Indirect accounts at the contributing sites should cover these allowable costs.

24. Risk Management.

Risk Management is an essential element of every project and must be analytical, forward looking, structured and continuous. Risk assessments are started as early in the project life-cycle as possible and should identify critical technical, performance, schedule and cost risks. Once risks are identified and prioritized, sound risk mitigation strategies and actions are developed and documented in the Risk Register. Post CD-1, the risk register (including new risks) should be evaluated at least quarterly.

Risks and their associated confidence levels are dependent on multiple factors such as complexity, technology readiness and strength of the IPT. Risks for all capital asset projects should be analyzed using a range of 70-90% confidence level upon baselining at CD-2 and reflected in funded contingency, budgetary requests and funding profiles. If a project has a PB change, FPDs should consider reanalyzing the risks at a higher confidence level and then reflecting this in budgetary requests and funding profiles. Additional risk management information is provided in DOE G 413.3-7A.

25. Safeguards and Security.

Prior to CD-1, general safeguards and security requirements for the recommended alternative and preliminary identification of alternatives (including facility design and the incorporation of safeguards and security technologies) must be made and these alternatives evaluated with respect to their impact on mission needs, satisfaction of other requirements (such as safety requirements) and other cost considerations. This input becomes part of the conceptual design requirements for further development.

Prior to CD-1, a Preliminary Security Vulnerability Assessment must be conducted that accounts for the set of applicable safeguards and security requirements, evaluates the methods selected to satisfy those requirements and addresses any potential risk acceptance issues. The PEP and the PB must be reviewed to ensure that cost, schedule, and integration aspects of safeguards and security are appropriately addressed, all feasible risk mitigation has been identified and concerns for which explicit line management risk acceptance will be required are appropriately supported.

Prior to CD-3, a final Security Vulnerability Assessment Report should be issued addressing all the safeguards and security requirements of the project. The project requirements should be satisfied by the facility design or the proposed operational features.

26. Site Development Planning.

Projects including new construction or modifications to real property assets shall be included in the site's Ten Year Site Plan and must provide the necessary documentation to establish a property record in the Department's Facilities Information Management System in accordance with DOE O 430.1C.

27. Tailoring.

a. General.

Tailoring is an element of the acquisition process and must be appropriate considering the risk, complexity, visibility, cost, safety, security and schedule of the project. Tailoring must be identified as early as possible prior to the impacted CD and must be approved by the PME. In the Tailoring Strategy or the PEP, the FPD will identify those areas in which a project is planned to be tailored as well as an explanation and discussion of each tailored area.

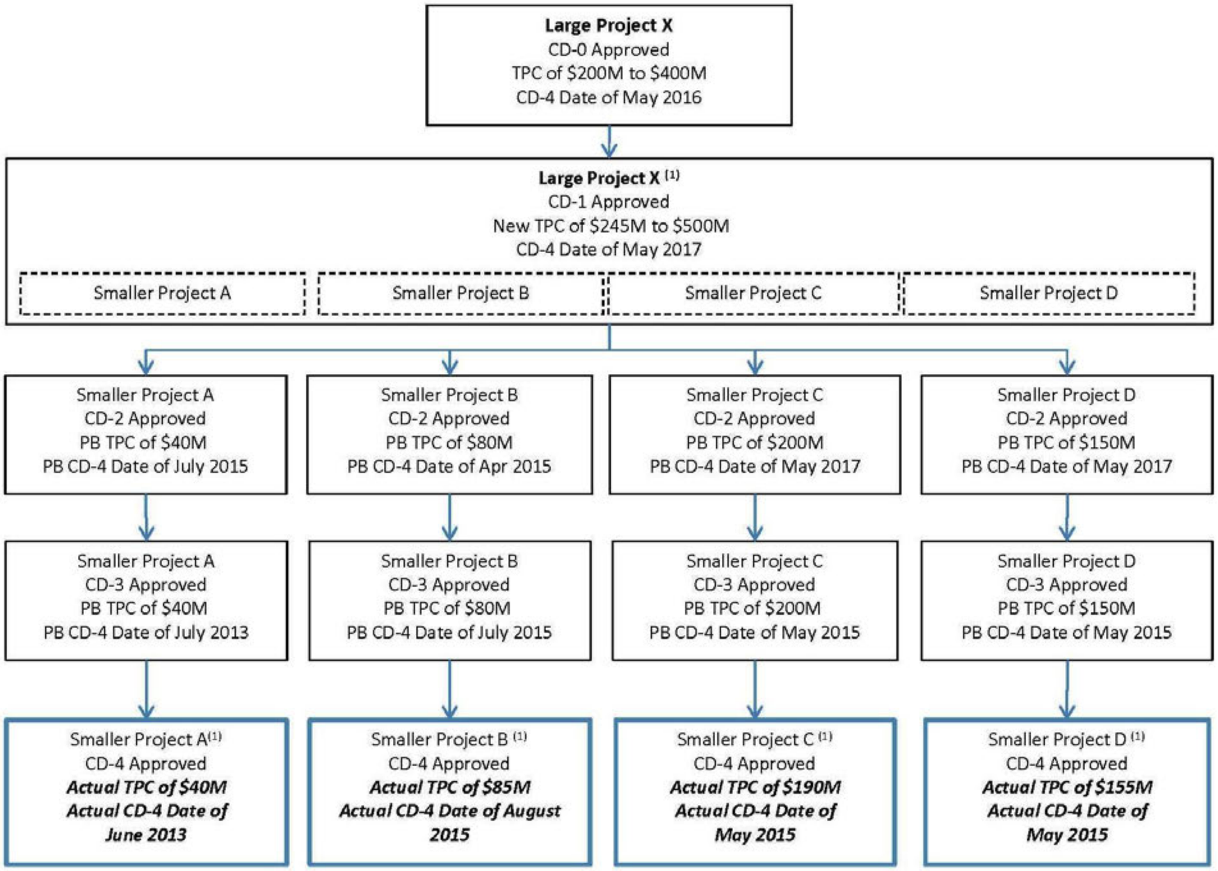
Tailoring does not imply the omission of requirements in the acquisition process or other processes that are appropriate to a specific project's requirements or conditions.

Tailoring may involve consolidation or phasing of CDs, substituting equivalent documents, graded approach to document development and content, concurrency of processes, or creating a portfolio of projects to facilitate a single CD or AS for an entire group of projects. Tailoring may also include adjusting the scope of IPRs and EIRs, delegation of acquisition authority and other elements. Major tailored elements such as consolidating or phasing CDs or delegation of PMEs should be specified in the PEP or the Tailoring Strategy.

Tailoring does not apply to nuclear safety requirements, which use a "graded approach" as prescribed in 10 CFR Part 830, *Nuclear Safety Management*. Details on developing a tailoring approach that could be applied are provided in DOE G 413.3-15.

b. Phasing.

Generally, a CD would not be split and CD-2 is never split. For some projects, it may be appropriate to phase the work (into smaller, related, complete and useable projects) and split or phase the CD. In those instances, it may be appropriate to garner CD-0 and CD-1 approvals for all the smaller projects collectively and simultaneously. Subsequently, each smaller project must have its own distinct performance baseline (CD-2) with clearly defined and documented technical scope, cost, schedule and funding profile including consideration for all applicable contingencies. See Figure 4.



(1) Projects notated will be those tallied for project success metric.

Figure 4. Phasing of a Large Project

As each smaller project achieves CD-2, its cost baseline (or TPC) gets reflected as point estimates but the TPC of the large project is a collective total of the smaller projects with the expectation that it is less than the CD-1 high end range. After each phased CD-2 is approved, the earned value for each smaller project individually must be reported into PARS II monthly if greater than $50M. When a smaller project is developed, the subsequent CDs will be approved by a PME commensurate with that project's TPC.

Although funded contingency is included as part of each smaller project's TPC, during execution, it may be held at the large project level and utilized as risks are realized. Contingency becomes part of the smaller project or an activity after the approval of the baseline change request to utilize contingency. Cost savings from one small project can be returned to the contingency pool for other small projects covered by the same PDS. These additional contingency funds can be applied toward another small project, if necessary. The large project (aggregated) CD-2 value is finally established when the last small project achieves CD-2 approval. At that time, the large project's CD-2 value equals the total value of each of the original CD-2 values for each of the smaller projects combined. The project success metrics are based on the execution of each of the small projects.

For construction projects that collectively support one mission need, it would be advisable to include each project on one PDS to achieve maximum funding flexibility. Examples #1 through #4 outline how a time-phased, multiple-project PDS can be developed.

Example #1: Initial Budget Request for PED funds:

	Construction Cost ($M)		PED Cost ($M)				
	CD-0 or CD-1 (TPC Cost Range)	TPC	FY11	FY12	FY13	FY14	FY15
Project A	20-50	-	5	-	-	-	-
Project B	50-100	-	10	-	-	-	-
Project C	100-200	-	10	10	-	-	-
Project D	75-150	-	-	15	-	-	-
TOTAL	245-500	-	25	25	-	-	-

Example #2: Initial Budget Request for Construction, Project A (with CD-2 approval) and Project B (absent of CD-2):

	Construction Cost ($M)						
	CD-0 or CD-1 (TPC Cost Range)	TPC	FY11	FY12	FY13	FY14	FY15
Project A	-	40	-	-	40	-	-
Project B	50-100	100	-	-	10	50	40
Project C	100-200	-	-	-	-	-	-
Project D	75-150	-	-	-	-	-	-
TOTAL	-	140	0	0	50	50	40

Example #3: Initial Budget Request for Construction, Project A & B (with CD-2 approval) and Project C & D (absent of CD-2):

	Construction Cost ($M)						
	CD-0 or CD-1 (TPC Cost Range)	TPC	FY11	FY12	FY13	FY14	FY15
Project A	-	40	-	-	40	-	-
Project B	-	80	-	-	10	50	20
Project C	100-200	200	-	-	-	100	100
Project D	75-150	150	-	-	-	25	125
TOTAL	-	470	0	0	50	175	245

Example #4: Initial Budget Request for Construction (all projects with CD-2 approval):

	Construction Cost ($M)						
	CD-0 or CD-1 (TPC Cost Range)	TPC	FY11	FY12	FY13	FY14	FY15
Project A	-	40	-	-	40	-	-
Project B	-	80	-	-	10	50	20
Project C	-	200	-	-	-	100	100
Project D	-	140	-	-	-	25	115
TOTAL	-	460	0	0	50	175	235

Likewise, it may be appropriate to split CD-4. For example, "CD-4A" to designate beneficial occupancy of a facility in advance of operations start-up, particularly if there is a significant time lapse.

c. Environmental Management Cleanup Projects.

Environmental Management (EM) Cleanup Projects are frequently the antithesis of construction projects in that EM is deactivating, decommissioning, remediating, stabilizing and disposing (also known as Environmental Restoration) versus constructing. These projects are conducted under a variety of regulatory processes and site-specific cleanup agreements which are legally binding and specify the process, end states, decision points and approvals required. The TRAs plays an important role in determining the solution. For these projects, the performance and scope parameters and start/end dates are based on negotiated terms with Federal and/or State regulatory agencies. As a result of this variability, it is not possible to draw a single crosswalk to the traditional construction project that would be applicable to all EM Cleanup Projects. Hence, a tailored approach is necessary for each project. As such, the FPD will submit a Tailoring Strategy, which may be included in the PEP, to the PME for approval. See DOE G 413.3-15 for additional guidance.

d. Design-Build.

Design-Build is a project delivery method whereby a single contract is awarded for both design and construction. Design-Build is normally used most successfully with projects that have well-defined requirements with limited complexity and risks. Example projects include road building, administrative facilities and/or replication of previously accomplished projects. The nuclear safety requirements of this Order will be fully implemented for defense nuclear facilities.

(1) The Design-Build approach requires the development of a functional design and clearly stated operating requirements that provide sufficient information to allow prospective contractors to prepare bids or proposals. It also allows the flexibility to implement innovative design and

construction approaches, VE, and other cost and time savings initiatives. The overall objective of the Design-Build approach is to:

- Enhance efficiencies in project design integration into construction execution;
- Reduce the total cost to the Department; and
- Deliver projects faster than by using the traditional Design-Bid-Build approach.

(2) Since the requirements are well-defined early in the process and much of the cost and schedule information and key design criteria are known, CD-1, CD-2 and/or even CD-3 may be accomplished simultaneously. Essentially, in requesting a simultaneous approval, CD-1/2, CD-1/2/3 or CD-2/3, the IPT is asserting that:

- There is no advantage to the Department of further evaluation of alternatives;
- The project functions and requirements are well known; and
- A cost and schedule baseline can be established.

e. Long-Lead Procurement.

CD-3A may be needed for long-lead item procurement. While there is potential risk in procuring equipment before the design is complete, the potential schedule improvement may be significant and more than compensate for the risk. If the long-lead item is nuclear safety-related or nuclear safety-related equipment, safety document maturity must also be considered (refer to DOE-STD-1189-2016 and DOE-STD-1104-2016). Procurement of vendor engineering designs, for example, greatly reduces the risk of incomplete or incorrect final designs that would otherwise require rework and potentially impact cost and schedule. The need to phase CD-3 should not be confused with minor, early activities that are necessary and generally performed prior to CD-3. Activities such as site preparation work, site characterization, limited access, and safety and security issues (i.e., fences) are often necessary prior to CD-3, and may be pursued as long as project documents such as a PDS requesting construction or PED funds to procure the long-lead items and funding approvals are in place. If CD-3A is anticipated, the need for this decision and the process should be documented in the PEP or Tailoring Strategy.

28. Technology Readiness Assessment.

The TRA model evaluates technology maturity using the Technology Readiness Level (TRL) scale. TRAs and associated Technology Maturation Plans are used as a project management tool to reduce the technical and cost risks associated with the introduction of new technologies. Where technological readiness is a significant concern, TRAs should be considered for alternatives under consideration.

Major System Projects, or first-of-a-kind engineering endeavors, must be assessed prior to each CD using the Technology Readiness Assessment and should achieve the following minimum Technology Readiness Level (TRL) scores for each critical technology item or system as determined by an independent review team outside of the project team before that CD can be approved. The higher the TRL at CD-2, the lower the risk to the project. The PME must provide justification to the ESAAB, if pursuing a TRL less than 7, at CD-2, which in turn will notify the CE. The following represents the minimum TRL at each CD:

- CD-1: TRL 4
- CD-2: TRL 7

For Major System Projects where new critical technologies are being deployed, the TRA shall be conducted and the associated Technology Maturation Plan developed prior to CD-2. On those projects where a significant critical technology element modification occurs subsequent to CD-2, conduct another TRA prior to CD-3. It is strongly encouraged for use by the PME for projects with a TPC less than $750M. See DOE G 413.3-4A for additional information.

CONTRACTOR REQUIREMENTS DOCUMENT
DOE O 413.3B, PROGRAM AND PROJECT MANAGEMENT
FOR THE ACQUISITION OF CAPITAL ASSETS

This Contractor Requirements Document (CRD) sets forth requirements applicable to the contract to which this CRD is inserted. The Contractor is responsible for performing program and project management of Department-owned or -leased facilities as determined by the Federal Project Director and Contracting Officer, in conjunction with the Federally-assigned Integrated Project Team members. The Contractor shall: (1) comply with the requirements of this CRD to include subcontractor(s), and (2) flow down the appropriate requirements of the CRD to a subcontractor, when the total project cost to the prime contractor are greater than $50 million.

The Contractor's project management system shall satisfy the following requirements:

1. Except for firm fixed-price contracts, the Contractor shall:

   - Employ an Earned Value Management System (EVMS) prior to Critical Decision (CD)-2, or upon contract award, for projects greater than $50 million, unless granted an exemption from the PMSO. The system shall be compliant with EIA-748C (or as required by the contract) in accordance with contract clause FAR Subpart 52.234-4, EVMS.

   - Maintain an EVMS compliant with EIA-748C when there are applicable projects with a TPC between $50M and $100M.

   - Receive certification of EVMS compliance with EIA-748C from PM when there are applicable projects having a TPC of $100M or greater. PM must conduct the certification review process and certify the contractor's EVMS compliance with EIA-748C, or as required by the contract.

   - Receive continued surveillance of EVMS compliance with EIA-748C when there are applicable projects having a TPC of $100M or greater. PM will conduct a risk-based, data-driven surveillance during the tenure of the contract, during contract extensions, or as requested by the FPD, the Program, or the PME. Documentation of the surveillance will be provided to the Contracting Officer documenting the compliance status of the contractor's EVMS with EIA-748C, or as required by the contract.

   - Provide access to all pertinent records and data requested by the contracting officer, PM, or other duly authorized representative as necessary to permit Government surveillance to insure EVMS complies, and continues to comply, with EIA-748C.

   - Submit a request for an Over-Target Baseline (OTB) or Over-Target Schedule (OTS) to the contracting officer, when indicated by performance. The request shall include a top-level projection of cost (known as an estimate at completion) and/or schedule growth (known as an Integrated Master Schedule), a determination of whether or not performance variances will be retained, and the schedule for the implementation of the rebaselining. Refer to DOE G 413.3-20.

2. For projects with a TPC less than $100M, the contractor may request an exemption from using EVMS. For firm fixed-price contracts, a contractor EVMS is not required. If contractor requests and an EVMS waiver is approved by the PMSO, the contractor will:

- Use an alternative project control method approved by the PMSO.
- Describe the alternate project control system in detail to the contracting officer.
- Ensure the system provides adequate insight to potential risks to DOE relating to achievement of cost, schedule, and technical performance objectives.
- Ensure the alternate project control methods include at a minimum a(n) work breakdown structure, integrated master schedule showing critical path, schedule of values, account of planned versus actual work and cost, and EAC.
- Beginning no later than three months following CD-2, upload project control information monthly, including upload of the baseline and status schedules, and data from the schedule of values and planned versus actual work and cost accounts, into the Department's PARS II system in accordance with the PARS II Contractor Project Performance (CPP) Upload Requirements document.

3. The Contractor shall submit monthly project performance data beginning no later than three months following CD-2 for projects having a total project cost greater than $50 million.

   a. For projects executed under a cost reimbursement contract and required to use an EVMS compliant with EIA-748C, or as specified in the contract, the required project performance data must be uploaded into PARS II at the lowest element of cost level in the specified format. This includes:

      - Earned value data consistent with EIA-748C (or as required by the contract);
      - Time-phased incremental budget, and performance in cost and quantity;
      - Management reserve;
      - Integrated Master Schedule (both baseline and status);
      - Variance analysis;
      - Risk management data; and
      - Formal submission of all DOE Integrated Program Management Report (IPMR) formats to the contracting officer and uploaded in PARS II.

b. For a project or a portion of a project being accomplished under a cost reimbursement contract where EVMS requirements have been waived and an alternate project control system adopted, project performance data will be provided monthly into PARS II in accord with PARS II Contractor Project Performance (CPP) Upload Requirements document, and will include:

- Baseline and status schedules;
- Schedule of values data;
- Planned versus actual work and control account data;
- Variance analysis;
- Risk management data; and
- Estimate at Completion (EAC) data.

c. Under a firm fixed-price construction contract, EVM is not mandated by the Government. However, it is not discouraged, if used by a contractor to manage its projects as a standard business practice. Unlike a cost reimbursement contract, firm fixed-price contracts are not subject to adjustment on the basis of the contractor's cost experience in performing the contract. Management of firm fixed-price construction projects are accomplished through establishment of performance milestones, schedules, and percentage of project completion. For construction contracts, FAR Subpart 52.232-5, Payment[s] Under Fixed-Price Construction Contracts, governs payment and the data that the contractor must provide to support its estimate of work accomplished. Substantiation includes an itemization of the amounts requested, related to the various elements of work required by the contract covered by the payment requested and a listing of the amount included for work performed by each subcontractor under the contract, the total amount of each subcontract under the contract, and amounts previously paid to each subcontractor under the contract. While firm fixed-price construction projects cannot require the regular submission of cost data as with a cost reimbursement contract, successful project and contract execution is highly dependent on well-defined requirements that serve as the foundation upon which performance milestones are developed, accomplished, and evaluated.

d. Except for firm fixed-price contracts, the data shall be submitted by the prime contractor electronically by uploading the required project performance data at the lowest element of cost level in the specified format into the Project Assessment and Reporting System (PARS II) in accordance with the "Contractor Project Performance Upload Requirements" document maintained by the Office of Project Management Oversight and Assessments (PM). Unless PM has granted a temporary exemption, all requested data shall be submitted timely and accurately. Data shall be loaded into PARS II no later than the last workday of every month. This data shall be current as of the close of the previous month's accounting period. Ad hoc or periodic reporting by the contractor may be required earlier than CD-2 as specified in the contract.

4. For project contracts to be awarded as subcontracts by the Contractor, the Contractor shall develop a written Acquisition Plan, if applicable. The Acquisition Plan shall receive the Contracting Officer's concurrence.

5. Technical performance analyses and corrective action plans shall be reported to DOE for variances to the project baseline objectives resulting from design reviews, component and system tests and simulations.

6. An Integrated Master Schedule (both resource loaded and with critical path) must be developed and maintained for the project. As a minimum, a resource-loaded IMS must contain labor, material and equipment costs to include unit prices and quantities. For firm fixed-price contracts, the total contract cost must be included in the integrated master schedule.

7. Project technical, cost and schedule risks must be identified, quantified and mitigated throughout the life of the project. A Risk Management Plan (RMP) will be developed to cover processes and procedures that will be implemented to address risk assessment (qualitative and quantitative), risk monitoring, risk reporting and lessons learned. The contractor's RMP must receive concurrence from DOE in accordance with contract requirements.

8. The approved integrated contractor technical, cost and schedule baseline shall be maintained using appropriate change control processes (e.g., Change Control Board) as defined in the Project Execution Plan (PEP).

9. A configuration management process must be established that controls changes to the physical configuration of project facilities, structures, systems and components in compliance with ANSI/EIA-649B and DOE-STD-1073-2016. This process must also ensure that the configuration is in agreement with the performance objectives identified in the technical baseline and the approved quality assurance plan.

10. A Value Management/Engineering (VM/VE) process shall be used. Annually, contractors shall submit a progress report identifying VE accomplishments to the Program Offices. Refer to OMB Circular A-131, 48 CFR 52.248-1, ASTM E1699-10, and 41 USC 1711.

11. A Quality Assurance Program must be developed and implemented for the contract scope of work in accordance with DOE O 414.1D, Attachment 2 (CRD), as applicable, and 10 CFR Part 830, Subpart A. For nuclear-related activities, the applicable national consensus standard shall be ASME NQA-1-2008 (Edition) and NQA-1a-2009 (Addenda).

12. An Integrated Safety Management System must be developed and implemented for the contract scope of work when the contractor is complying with the requirements of

48 CFR 970.5223-1, *Integration of Environment, Safety and Health into Work Planning and Execution*.

13. Contractors performing design for projects shall, at a minimum, conduct a Conceptual, Preliminary and Final Design Review, in accordance with the PEP. For nuclear projects, the design review will include a focus on safety and security systems. A Code of Record shall be maintained under configuration control throughout the CD process and for the remainder of the nuclear facility's life-cycle.

14. For projects involving construction of new Hazard Category 1, 2, and 3 nuclear facilities, or include major modifications thereto (as defined in 10 CFR Part 830), the requirements in DOE-STD-1189-2016 shall be fully implemented. The following documents must be submitted, as applicable: Safety Design Strategy (CD-1), Conceptual Safety Design Report (CD-1), Preliminary Safety and Design Results (CD-2), Preliminary Documented Safety Analysis (CD-2), and Documented Safety Analysis with Technical Safety Requirements (CD-4).

15. The Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings cited in EO 13693, Section 3(h), must be applied to the siting, design, construction, and commissioning of new facilities and major renovations of existing facilities.

16. At a minimum, all new construction and major building renovations must meet U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Gold certification absent an approved waiver from the PME. Refer to DOE Order 436.1.

17. For non-M&O contracts, the Contractor shall develop a Project Management Plan (PMP) that supports and complements the Federal PEP and its contract. The PMP shall describe the management methods, organization, control systems and documentation for the project. The PMP shall receive the concurrences of the FPD and the DOE Contracting Officer. If significant changes occur during the project, the PMP shall be revised by the Contractor at the direction of the Contracting Officer.

DEFINITIONS

1. Acquisition Plan. The document that facilitates attainment of the acquisition objectives. The plan must identify: those milestones at which decisions should be made; all the technical, business, management; and other significant considerations that will control the acquisition including, but not limited to, market research, competition, contract type, source selection procedures and socio-economic considerations.

2. Acquisition Strategy. A high-level business and technical management approach designed to achieve project objectives within specified resource constraints with recognition of key project risks and the strategies identified to handle those risks. It is the framework for planning, organizing, staffing, controlling, and leading a project. It provides a master schedule for activities essential for project success, and for formulating functional strategies and plans.

3. Baseline. A quantitative definition of cost, schedule and technical performance that serves as a base or standard for measurement and control during the performance of an effort; the established plan against which the status of resources and the effort of the overall program, field program(s), project(s), task(s), or subtask(s) are measured, assessed and controlled. Once established, baselines are subject to change control discipline.

4. Baseline Change Proposal. A document that provides a complete description of a proposed change to an approved performance baseline, including the resulting impacts on the project scope, schedule, design, methods, and cost baselines.

5. Beneficial Occupancy. Stage of construction of a building or facility, before final completion, at which its user can occupy it for the purpose it was constructed. Beneficial occupancy does not imply that a project has reached CD-4.

6. Best Practices. An activity or procedure that has produced outstanding results in another situation and could be adapted to improve effectiveness and efficiency in a current situation.

7. Capital Assets. Capital assets are land, structures, equipment and intellectual property, which are used by the Federal Government and have an estimated useful life of two years or more. Capital assets exclude items acquired for resale in the ordinary course of operations or held for the purpose of physical consumption such as operating materials and supplies. Capital assets may be acquired in different ways: through purchase, construction, or manufacture; through a lease-purchase or other capital lease, regardless of whether title has passed to the Federal Government; or through exchange. Capital assets include the environmental remediation of land to make it useful, leasehold improvements and land rights; assets owned by the Federal Government but located in a foreign country or held by others (such as federal contractors, state and local governments, or colleges and universities); and assets whose ownership is shared by the Federal Government with other entities.

8. <u>Capital Asset Project</u>. A project with defined start and end points required in the acquisition of capital assets. The project acquisition cost of a capital asset includes both its purchase price and all other costs incurred to bring it to a form and location suitable for its intended use. It is independent of funding type. It excludes operating expense funded activities such as repair, maintenance or alterations that are part of routine operations and maintenance functions.

9. <u>CD-0, Approve Mission Need</u>. Approval of CD-0 formally establishes a project and begins the process of conceptual planning and design used to develop alternative concepts and functional requirements. Additionally, CD-0 approval allows the Program to request PED funds for use in preliminary design, final design and baseline development.

10. <u>CD-1, Approve Alternative Selection and Cost Range</u>. CD-1 approval marks the completion of the project Definition Phase and the conceptual design. Approval of CD-1 provides the authorization to begin the project Execution Phase and allows PED funds to be used.

11. <u>CD-2, Approve Performance Baseline</u>. CD-2 approval marks the approval of the performance baseline and requires the completion of preliminary design for all projects. It also requires the completion of final design for Hazard Category 1, 2, and 3 nuclear facilities. It is the first major milestone in the project Execution Phase. Approval of CD-2 authorizes submission of a budget request for the TPC.

12. <u>CD-3, Approve Start of Construction</u>. CD-3 provides authorization to complete all procurement and construction and/or implementation activities and initiate all acceptance and turnover activities. Approval of CD-3 authorizes the project to commit all the resources necessary, within the funds provided, to execute the project.

13. <u>CD-4, Approve Start of Operations or Project Completion</u>. CD-4 approval marks the achievement of the completion criteria (i.e., KPPs) defined in the PEP (or in the PRD, for NNSA projects), and if applicable, subsequent approval of transition to operations.

14. <u>Change Control</u>. A process that ensures changes to the approved baseline are properly identified, reviewed, approved, implemented and tested and documented.

15. <u>Code of Record</u>. A set of design and operational requirements, including Federal and state laws in effect at the time a facility or item of equipment was designed and accepted by DOE. It is (i) initiated during the conceptual design phase, placed under configuration control to ensure it is updated to include more detailed design requirements as they are developed during preliminary design, (ii) controlled during final design and construction with a process for reviewing and evaluating new and revised requirements to determine their impact on project safety, cost and schedule before a decision is taken to revise the Code of Record, and (iii) maintained and controlled through facility decommissioning. The Code of Record may be defined in contracts, Standards or Requirements

Identification Documents (or their equivalent), or project-specific documents. [DOE-STD-1189-2016]

16. Conceptual Design. The Conceptual Design process requires a mission need as an input. It is the exploration of concepts, specifications and designs for meeting the mission needs, and the development of alternatives that are technically viable, affordable and sustainable. The conceptual design provides sufficient detail to produce a more refined cost estimate range and to evaluate the merits of the project.

17. Confidence Level. The likelihood – expressed as a percentage – that an occurrence will be realized. The higher the confidence level, the higher the probability of success.

18. Configuration Management. The technical and administrative direction and surveillance actions taken to identify and document the functional and physical characteristics of a configuration item; to control changes to a configuration item and its characteristics; and to record and report change processing and implementation status.

19. Constructability Review. A technical review to determine the extent to which the design of a structure facilitates ease of construction, subject to the overall requirements for the completed form.

20. Contractor Requirements Document. The DOE document that identifies the requirements that the prime contractor's project management system must satisfy (Attachment 1).

21. Contingency. The portion of the project budget that is available for risk uncertainty within the project scope, but outside the scope of the contract. Contingency is budget that is not placed on the contract and is included in the TPC. Contingency is controlled by Federal personnel as delineated in the PEP.

22. Corporate Certification. A corporate certification exists when a contractor adopts one of their existing certified EVMS in its entirety for application under a new contract, regardless of location. The EVMS under the corporate certification must remain intact in all aspects to that originally certified and will be validated by an EVMS Surveillance.

23. Critical Decision. A formal determination made by the CE or PME at a specific point during the project that allows the project to proceed to the next phase or CD.

24. Critical Path. Those series of tasks that define the longest durations of the project. Each task on the critical path is a critical task and must finish on time for the entire project to finish on time.

25. Deactivation. The process of placing a facility in a stable and known condition including the removal of hazardous and radioactive materials to ensure adequate protection of the worker, public health and safety, and the environment, thereby limiting the long-term cost of surveillance and maintenance. Actions include the removal of fuel, draining and/or de-energizing nonessential systems, removal of stored radioactive and hazardous

materials, and related actions. Deactivation does not include all decontamination necessary for the dismantlement and demolition phase of decommissioning, e.g., removal of contamination remaining in the fixed structures and equipment after deactivation.

26. Decommissioning. Takes place after deactivation and includes surveillance and maintenance, decontamination and/or dismantlement. These actions are taken at the end of the life of a facility to retire it from service with adequate regard for the health and safety of workers and the public and for the protection of the environment. The ultimate goal of decommissioning is unrestricted release or restricted use of the site.

27. Decontamination. The removal or reduction of residual chemical, biological, or radiological contaminants and hazardous materials by mechanical, chemical or other techniques to achieve a stated objective or end condition.

28. Demolition. Destruction and removal of physical facilities or systems.

29. Design Authority (for nuclear facilities only). The engineer designated by the PME to be responsible for establishing the design requirements and ensuring that design output documentation appropriately and accurately reflect the design basis. The Design Authority is responsible for design control and ultimate technical adequacy of the design process. These responsibilities are applicable whether the process is conducted fully in-house, partially contracted to outside organizations, or fully contracted to outside organizations. The Design Authority may delegate design work, but not its responsibilities.

30. Design-Bid-Build. A project delivery method whereby design and construction are separate contracts.

31. Design-Build. A project delivery method whereby design and construction contracts are combined. It is important that specific flow down requirements specified in requests for proposals to subcontractors, especially for firm fixed-price subcontracts, to insure implementation of the principles from this Order for effective performance measurement of the subcontractors' scope of work.

32. Design Review. A formal and documented management technique used primarily to conduct a thorough evaluation of a proposed design in order to determine whether or not the proposed design meets the project requirements set forth by the customer, as well as to determine whether the proposed design will be fully functional.

33. Deviation. Occurs when the TPC, CD-4 completion date, or performance and scope parameters, defined by the approved PB at CD-2, cannot be met.

34. Directed Change. A change caused by some DOE policy directives (such as those that have force and effect of law and regulation), regulatory, or statutory action and is initiated by entities external to the Department, to include external funding reductions.

35. Dismantlement. The disassembly or demolition and removal of any structure, system or component during decommissioning and satisfactory interim or long-term disposal of the residue from all or portions of a facility.

36. Disposal. Final placement or destruction of toxic, radioactive, or other waste, surplus or banned pesticides or other chemicals, polluted soils and drums containing hazardous materials from removal actions or accidental releases. Disposal may be accomplished through use of approved, secure, regulated landfills, surface impoundments, land farming, deep well injection or incineration.

37. Disposition. Those activities that follow completion of program missions, including but not limited to, preparation for reuse, surveillance, maintenance, deactivation, decommissioning, and long-term stewardship. DOE O 430.1C provides implementation guidance for requirements specific to the disposition and long-term stewardship of contaminated, excess facilities.

38. Earned Value. The budgeted value of work actually accomplished in a given time. Simply defined, Earned Value represents the value of work accomplished during the period.

39. Earned Value Management. A project performance method that utilizes an integrated set of performance measurements (e.g., scope, cost and schedule) to assess and measure project performance and progress, and estimate cost and schedule impacts at completion.

40. Earned Value Management System. An integrated set of policies, procedures and practices to objectively track true performance on a project or program. EVMS represents an integration methodology that is able to provide an early warning of performance problems while enhancing leadership decisions for successful corrective action.

41. Environmental Remedial Action Plan. Summarizes the remedial alternatives presented in the analysis of the feasibility study and identifies the preferred alternative and the rationale for selecting the preferred alternative.

42. EVMS Certification. The determination that a Contractor's EVMS, on all applicable projects, is in full compliance with EIA-748C, or as required by the contract, and in accordance with FAR Subpart 52.234-4, EVMS.

43. EVMS Surveillance. The process of reviewing a Contractor's certified EVMS, on all applicable projects, to establish continuing compliance with EIA-748C, or as required by the contract, and in accordance with FAR Subpart 52.234-4, EVMS. Surveillance may also verify that EVMS use is properly implemented by the contractor.

44. Energy Systems Acquisition Advisory Board. Advises the CE on CDs related to Major System Projects, site selection and PB deviation dispositions.

45. Equivalencies. Alternatives to how a requirement in a directive is fulfilled in cases where the "how" is specified. These represent an acceptable alternative approach to achieving the goal of the directive. Unless specified otherwise in the directive, Equivalencies are granted, in consultation with the OPI, by the Program Secretarial Officer or their designee, or in the case of the NNSA, by the Administrator or designee, and documented for the OPI in a memorandum. For those directives listed in Attachment 1 of DOE O 410.1, CTA concurrences are required prior to the granting of equivalencies.

46. Estimate-At-Completion. Actual cost of work completed to date plus the predicted costs and schedule for finishing the remaining work.

47. Estimate-To-Complete. The value expressed in either dollars or hours developed to represent the cost of the work required to complete a task.

48. Exemptions. The release from one or more requirements in a directive. Unless specified otherwise in the directive, Exemptions are granted, in consultation with the OPI, by the Program Secretarial Officer or their designee, or in the case of the NNSA, by the Administrator or designee, and documented for the OPI in a memorandum. For those directives listed in Attachment 1 of DOE O 410.1, CTA concurrences are required prior to the granting of exemptions.

49. External Independent Review. A project review performed by personnel from PM and augmented by individuals outside DOE, primarily to support validation of either the Performance Baseline (CD-2) or Construction/Execution Readiness (CD-3). PM selects an appropriate group of subject matter experts in a contracted capacity to assist with these reviews.

50. Facilities Information Management System. The Department's corporate database for real property. The system provides the Department with an accurate inventory and management tool that assists with planning and managing all real property assets. See DOE O 430.1C for additional information.

51. Federal Program Manager. An individual in the headquarters organizational element responsible for managing a program and, until designation of the FPD, its assigned projects. They ensure that all the projects are properly phased, funded over time, and that each project manager is meeting their key milestones. They are the project manager's advocate, ensure proper resourcing and facilitate the execution process. They predict programmatic risks and put mitigation strategies in place so that projects are not affected.

52. Federal Project Director. The individual certified under the Department's PMCDP as responsible and accountable to the PME or Program Secretarial Officer for project execution. Responsibilities include developing and maintaining the PEP; managing project resources; establishing and implementing management systems, including

performance measurement systems; and approving and implementing changes to project baselines.

53. Funding Profile. A representation of the project funding over the life of the project. It is part of the PME decision and any decremental change requires PME approval.

54. Final Design. Completion of the design effort and production of all the approved design documentation necessary to permit procurement, construction, testing, checkout and turnover to proceed.

55. General Plant Project. Miscellaneous minor construction project, of a general nature, for which the total estimated cost may not exceed the congressionally established limit. GPPs are necessary to adapt facilities to new or improved production techniques, to effect economies of operations, and to reduce or eliminate health, fire and security problems. These projects provide for design, construction, additions, and/or improvements to land, buildings, replacements or additions to roads, and general area improvements. (Refer to 50 USC 2743)

56. Hot Commissioning. The processing of a minimal acceptable sample of an actual material to obtain the desired performance output during the startup and testing phase of a chemical or nuclear processing facility.

57. Independent. An office or entity that is not under the supervision, direction, or control of the sponsor responsible for carrying out the project's development or acquisition.

58. Independent Cost Estimate. A cost estimate, prepared by an organization independent of the project sponsor, using the same detailed technical and procurement information to make the project estimate. It is used to validate the project estimate to determine whether it is accurate and reasonable.

59. Independent Cost Review. An independent evaluation of a project's cost estimate that examines its quality and accuracy, with emphasis on specific cost and technical risks. It involves the analysis of the existing estimate's approach and assumptions.

60. Independent Government Cost Estimate. The government's estimate of the resources and its projected costs that a contractor would incur in the performance of a contract. These costs include direct costs such as labor, supplies, equipment, or transportation and indirect costs such as labor overhead, material overhead, as well as general and administrative expenses, profit or fee. (Refer to FAR 36.203 and FAR 15.404-1.)

61. Independent Project Review. A project management tool that serves to verify the project's mission, organization, development, processes, technical requirements, baselines, progress and/or readiness to proceed to the next successive phase in DOE's Acquisition Management System.

62. Integrated Project Team. A cross-functional group of individuals organized for the specific purpose of delivering a project to an external or internal customer. It is led by a Federal Project Director.

63. Integrated Safety Management System. The application of the integrated safety management system to a project or activity. The fundamental premise of Integrated Safety Management is that accidents are preventable through early and close attention to safety, design, and operation, and with substantial stakeholder involvement in teams that plan and execute the project, based on appropriate standards.

64. Key Performance Parameters. A vital characteristic, function, requirement or design basis, that if changed, would have a major impact on the facility or system performance, scope, schedule, cost and/or risk, or the ability of an interfacing project to meet its mission requirements. A parameter may be a performance, design, or interface requirement. Appropriate parameters are those that express performance in terms of accuracy, capacity, throughput, quantity, processing rate, purity, reliability, sustainability, or others that define how well a system, facility or other project will perform. In aggregate, KPPs comprise the scope of the project.

65. Lessons Learned. The project management related input and output device that represents the knowledge, information or instructional knowledge that have been garnered through the process of actually completing the ultimate performance of the respective project. Lessons learned are valuable because they will benefit future endeavors and ideally prevent any negative happenings from taking place in the future.

66. Life-Cycle Costs. The sum total of all direct, indirect, recurring, nonrecurring and other related costs incurred or estimated to be incurred in the planning, design, development, procurement, production, operations and maintenance, support, recapitalization and final disposition of real property over its anticipated life span for every aspect of the program, regardless of funding source.

67. Line Item. A distinct design, construction, betterment and/or fabrication of real property for which Congress will be requested to authorize and appropriate specific funds. A full-scale test asset or other pilot/prototype asset primarily constructed for experimental or demonstration purposes, but planned to become DOE property and continue to operate beyond the experimental or demonstration phase is included in this definition.

68. Long-Lead Procurement. Equipment, services and/or materials that must be procured well in advance of the need because of long delivery times. If long-lead procurements are executed prior to CD-3 approval for the project, this will be designated as CD-3A and require a stand-alone decision by the PME, outside of the CD process.

69. Major Item of Equipment. Capital equipment with a cost that exceeds $2M. In most cases, capital equipment is installed with no construction cost. However, in cases where the equipment requires provision of supporting construction such as

foundations, utilities, structural modifications, and/or additions to a building, the associated construction activities must be acquired through a line item construction project or a minor construction project if the cost is below the minor construction threshold established by Congress.

70. Major System Project. A project with a TPC of greater than or equal to $750M or as designated by the Deputy Secretary.

71. Management Reserve. An amount of the total contract budget withheld for management control purposes by the contractor. Management reserve is not part of the Performance Measurement Baseline.

72. Milestone. Any significant or substantive point, time or event of the project. Milestones typically refer to points at which large schedule events or series of events have been completed, and a new phase or phases are set to begin.

73. Mission Need Statement. The primary document supporting the PME's decision to initiate exploration of options to fulfill a capability gap including but not limited to acquisition of a new capital asset.

74. Mitigation. Technique to eliminate or lessen the likelihood and/or consequence of a risk.

75. Non-Major System. Any project with a TPC less than $750M.

76. Operational Readiness Review. A disciplined, systematic, documented, performance-based examination of facilities, equipment, personnel, procedures and management control systems for ensuring that a facility can be operated safely within its approved safety envelope as defined by the facility safety basis plan. The ORR provides the basis for the Department to direct startup or restart of the facility, activity or operation.

77. Other Project Costs. All other costs related to a project that are not included in the TEC. OPCs will include, but are not limited to: research and development; conceptual design and conceptual design report; startup and commissioning costs; NEPA documentation; PDS preparation; siting; and permitting requirements.

78. Performance Baseline. The collective key performance, scope, cost, and schedule parameters, which are defined for all projects at CD-2. The PB includes the entire project budget (TPC including fee and contingency) and represents DOE's commitment to Congress.

79. Performance Measurement Baseline. The baseline cost that encompasses all contractor project work packages and planning packages, derived from summing all the costs from the Work Breakdown Structure. Undistributed management reserve, contingency, profit,

fee and DOE direct costs are not part of the Performance Measurement Baseline. The PMB is the benchmark used within EVM systems to monitor project (and contract) execution performance.

80. Preliminary Design. This is the design that is prepared following CD-1 approval. Preliminary design initiates the process of converting concepts to a design appropriate for procurement or construction. All KPPs and project scope are sufficiently defined to prepare a budget estimate. This stage of the design is complete when it provides sufficient information to support development of the PB.

81. Program. An organized set of activities directed toward a common purpose or goal undertaken or proposed in support of an assigned mission area. It is characterized by a strategy for accomplishing a definite objective(s) that identifies the means of accomplishment, particularly in qualitative terms, with respect to work force, material and facility requirements. Programs are typically made up of technology-based activities, projects and supporting operations.

82. Program Management. A group of closely-related projects managed in a coordinated way.

83. Project. A unique effort having defined start and end points undertaken to create a product, facility, or system. Built on interdependent activities planned to meet a common objective, a project focuses on attaining or completing a deliverable within a predetermined cost, schedule and technical scope baseline. Projects include planning and execution of construction, assembly, renovation, modification, environmental restoration, decontamination and decommissioning, large capital equipment, and technology development activities. A project is not constrained to any specific element of the budget structure (e.g., operating expense).

84. Project Assessment and Reporting System. A reporting process to connect field project status with headquarters to report and compare budgeted or scheduled project forecasts.

85. Project Closeout. Occurs after CD-4, Project Completion, and involves activities such as performing financial and administrative closeout, developing project closeout and lessons learned reports, and other activities as appropriate for the project.

86. Project Data Sheet. A document that contains summary project data and the justification required to include the entire project effort as a part of the Departmental budget.

87. Project Definition Rating Index. This is a project management tool which is used for assessing how well the project scope is defined. The tool uses a numeric assessment which rates a wide range of project elements to determine how well the project is defined.

88. Project Engineering and Design. Design funds established for use on preliminary design. Typically, PED funds are used for preliminary and final design and related activities for

design-bid-build strategies, and for preliminary design and related costs in design-build strategies. It is also analogous with a project phase that includes preliminary and final design and baseline development.

89. Project Execution Plan. DOE's core document for management of a project. It establishes the policies and procedures to be followed in order to manage and control project planning, initiation, definition, execution, and transition/closeout, and uses the outcomes and outputs from all project planning processes, integrating them into a formally approved document. A PEP includes an accurate reflection of how the project is to be accomplished, resource requirements, technical considerations, risk management, configuration management, and roles and responsibilities.

90. Project Management. Those services provided to DOE on a specific project, beginning at the start of design and continuing through the completion of construction, for planning, organizing, directing, controlling and reporting on the status of the project.

91. Project Management Plan. The contractor-prepared document that sets forth the plans, organization and systems that the contractor will utilize to manage the project. Its content and the extent of detail of the PMP will vary in accordance with the size and type of project and state of project execution.

92. Project Management Support Office. An office established exclusively to oversee and manage the activities associated with projects.

93. Project Peer Reviews. Periodic review of a project performed by peers (with similar experience to project personnel), independent from the project, to evaluate technical, managerial, cost and scope, and other aspects of the project, as appropriate. These reviews are typically led by the PMSO.

94. Quality Assurance. All those actions performed by the DOE prime contractor during the project that provide confidence that quality is achieved. It is executed through a formalized Quality Assurance Program.

95. Quality Control. Those actions related to the physical characteristics of a material, structure, component, or system which provide a means to control the quality of the material, structure, component, or system to predetermined requirements.

96. Readiness Assessment. An assessment to determine a facility's readiness to startup or restart when an ORR is not required or when a contractor's standard procedures for startup are not judged by the contractor or DOE management to provide an adequate verification of readiness.

97. Resource-Loaded Schedule. Schedules with resources of staff, facilities, cost, equipment and materials which are needed to complete the activities required.

98. Risk. Factor, element, constraint or course of action that introduces an uncertainty of outcome, either positively or negatively that could impact project objectives.

99. Risk Assessment. Identification and analysis of project and program risks to ensure an understanding of each risk in terms of probability and consequences.

100. Risk Management. The handling of risks through specific methods and techniques. Effective risk management is an essential element of every project. The DOE risk management concept is based on the principles that risk management must be analytical, forward-looking, structured, informative and continuous. Risk assessments should be performed as early as possible in the project and should identify critical technical, performance, schedule and cost risks. Once risks are identified, sound risk mitigation strategies and actions should be developed and documented.

101. Risk Management Plan. Documents how the risk processes will be carried out during the project.

102. Rough Order of Magnitude Estimate. An estimate based on high-level objectives, provides a high-level view of the project deliverables, and has lots of wiggle room. Most ROM estimates have a range of variance from -25% all the way to +75%.

103. Safeguards and Security. An integrated system of activities, systems, programs, facilities and policies for the protection of classified information and/or classified matter, unclassified control information, nuclear materials, nuclear weapons, nuclear weapon components, and/or the Department's and its contractors' facilities, property and equipment.

104. Sustainability. To create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations.

105. System Engineering Approach. A proven, disciplined approach that supports management in clearly defining the mission or problem; managing system functions and requirements; identifying and managing risk; establishing bases for informed decision-making; and, verifying that products and services meet customer needs. The goal of the system engineering approach is to transform mission operational requirements into system architecture, performance parameters and design details.

106. Tailoring. An element of the acquisition process and must be appropriate considering the risk, complexity, visibility, cost, safety, security, and schedule of the project. Tailoring does not imply the omission of essential elements in the acquisition process or other processes that are appropriate to a specific project's requirements or conditions.

107. Technical Independent Project Review. An independent project review conducted at or near the completion of preliminary design, and is required prior to CD-2 approval, for Hazard Category 1, 2, and 3 nuclear facilities. At a minimum, the focus of this review is to determine that the safety documentation is sufficiently conservative and bounding to be relied upon for the next phase of the project.

108. Technology Maturation Plan. A TMP details the steps necessary for developing technologies that are less mature than desired to the point where they are ready for project insertion.

109. Technology Readiness Assessment. An assessment of how far technology development has proceeded. It provides a snapshot in time of the maturity of technologies and their readiness for insertion into the project design and execution schedule.

110. Technical Readiness Level. A metric used for describing technology maturity. It is a measure used by many U.S. government agencies to assess maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating that technology into a system or subsystem.

111. Total Estimated Cost. All engineering design costs (after conceptual design), facility construction costs and other costs specifically related to those construction efforts. TEC will include, but is not limited to: project, design and construction management; contract modifications (to include equitable adjustments) resulting in changes to these costs; design; construction; contingency; contractor support directly related to design and construction; and equipment rental and refurbishment.

112. Total Project Cost. All costs between CD-0 and CD-4 specific to a project incurred through the startup of a facility, but prior to the operation of the facility. Thus, TPC includes TEC plus OPC.

113. Value Engineering. A structured technique commonly used in project management to optimize the overall value of the project. Often, creative strategies will be employed in an attempt to achieve the lowest life-cycle cost available for the project. The VE effort is a planned, detailed review/evaluation of a project to identify alternative approaches to providing the needed assets.

114. Value Management. An organized effort directed at analyzing the functions of systems, equipment, facilities, services and supplies for achieving the essential functions at the lowest life-cycle cost that is consistent with required performance, quality, reliability and safety. VM encompasses VE.

115. Value Study. An intensive review of requirements and the development of alternatives by the use of appropriate value techniques utilizing aspects of engineering, requirements analysis, the behavioral sciences, creativity, economic analysis and the scientific method.

116. Variance. A measurable change from a known standard or baseline. It is the difference between what is expected and what is actually accomplished. A variance is a deviation or departure from the approved scope, cost or schedule performance. Variances must be tracked and reported. They should not be eliminated, but mitigated through corrective actions. Baseline changes, if needed, are submitted for changes in technical scope, funding or directed changes.

117. Work Breakdown Structure. Used by the project management team to organize and define a project into manageable objectives and create a blueprint by which the steps leading to the completion of a project are obtained. It is an outline of the project that becomes more detailed under the subheadings or work packages.

ACRONYMS

ANSI	American National Standards Institute
AoA	Analysis of Alternatives
AP	Acquisition Plan
AS	Acquisition Strategy
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
BCP	Baseline Change Proposal
BOD	Beneficial Occupancy Date
CCB	Change Control Board
CD	Critical Decision
CDNS	Chief of Defense Nuclear Safety
CDR	Conceptual Design Report
CE	Chief Executive for Project Management
CFO	Office of the Chief Financial Officer
CFR	Code of Federal Regulations
CNS	Chief of Nuclear Safety
CO	Contracting Officer
CPARS	Contractor Performance Assessment Reporting System
CPP	Contractor Project Performance
CRD	Contractor Requirements Document
CSDR	Conceptual Safety Design Report
CTA	Central Technical Authority
DEAR	Department of Energy Acquisition Regulation
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DID	Data Item Description
EAC	Estimate at Completion
EIA	Electronic Institute of America
EIR	External Independent Review
EM	Environmental Management

EO	Executive Order
ESAAB	Energy Systems Acquisition Advisory Board
EVM	Earned Value Management
EVMS	Earned Value Management System
FAR	Federal Acquisition Regulation
FDO	Fee Determining Official
FPD	Federal Project Director
FIMS	Facility Information Management System
FR	Federal Register
FY	Fiscal Year
G	Guide
GAO	U.S. Government Accountability Office
GPP	General Plant Project
HPC	High Performance Computing
ICE	Independent Cost Estimate
ICR	Independent Cost Review
IMP	Integrated Master Plan
IMS	Integrated Master Schedule
IPA	Intergovernmental Personnel Act
IPMR	Integrated Program Management Report
IPR	Independent Project Review
IPT	Integrated Project Team
ISM	Integrated Safety Management
ISMS	Integrated Safety Management System
KPP	Key Performance Parameter
LEED	Leadership in Energy and Environmental Design
LOE	Level of Effort
M	Manual
MIE	Major Items of Equipment
MNS	Mission Need Statement
M&O	Management and Operating
NDIA	National Defense Industrial Association

NEPA	National Environmental Policy Act
NNSA	National Nuclear Security Administration
NRC	U.S. Nuclear Regulatory Commission
NQA	Nuclear Quality Assurance
O	Order
OBS	Organizational Breakdown Structure
OE	Operating Expense
OMB	Office of Management and Budget
OPC	Other Project Costs
ORR	Operational Readiness Review
OTB	Over-Target Baseline
OTS	Over-Target Schedule
P	Policy
PARS	Project Assessment and Reporting System
PASEG	Planning and Scheduling Excellence Guide
PB	Performance Baseline
PDRI	Project Definition Rating Index
PDS	Project Data Sheet
PDSA	Preliminary Documented Safety Analysis
PED	Project Engineering and Design
PEP	Project Execution Plan
PHAR	Preliminary Hazard Analysis Report
PL	Public Law
PM	Office of Project Management Oversight and Assessments
PMB	Performance Measurement Baseline
PMCDP	Project Management Career Development Program
PME	Project Management Executive
PMRC	Project Management Risk Committee
PMSO	Project Management Support Office
PRD	Program Requirements Document
PSO	Program Secretarial Officer
PMP	Project Management Plan

QA	Quality Assurance
QAP	Quality Assurance Program
QPR	Quarterly Project Review
RA	Readiness Assessment
RMP	Risk Management Plan
ROM	Rough Order of Magnitude
SBAA	Safety Basis Approval Authority
SDS	Safety Design Strategy
SER	Safety Evaluation Report
SPE	Senior Procurement Executive
STD	Standard
TEC	Total Estimated Cost
TIPR	Technical Independent Project Review
TPC	Total Project Cost
TMP	Technology Maturation Plan
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
UFGS	Unified Facilities Guide Specification
USC	United States Code
VE	Value Engineering
VM	Value Management
WBS	Work Breakdown Structure

REFERENCES

1. 10 CFR Part 830, *Nuclear Safety Management*.

2. 10 CFR Part 830, Subpart A, *Quality Assurance Requirements*.

3. 10 CFR Part 830, Subpart B, *Safety Basis Requirements*.

4. 10 CFR 830.206, *Preliminary Documented Safety Analysis*.

5. 10 CFR 830.207, *DOE Approval of Safety Basis*.

6. 10 CFR Part 851, *Worker Safety and Health Program*, Appendix A, Section 1(d).

7. 10 CFR Part 1021, *National Environmental Policy Act Implementing Procedures*.

8. 2 CFR Part 910, *Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards*.

9. 29 CFR 1910.119, *Process Safety Management of Highly Hazardous Chemicals*.

10. 29 CFR 1910.120, *Hazardous Waste Operations and Emergency Response*.

11. 40 CFR Part 68, *Chemical Accident Prevention Provisions*.

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DOCUMENT 2

NOT
MEASUREMENT
SENSITIVE

DOE G 413.3-4A
9-15-2011

Technology Readiness Assessment Guide

[*This Guide describes suggested non-mandatory approaches for meeting requirements. Guides* *<u>are not</u>* *requirements documents and* *<u>are not</u>* *to be construed as requirements in any audit or appraisal for compliance with the parent Policy, Order, Notice, or Manual.*]

U.S. Department of Energy
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FOREWORD

This Department of Energy (DOE) Guide is for use by all DOE elements. This Guide assists individuals and teams involved in conducting Technology Readiness Assessments (TRAs) and developing Technology Maturation Plans (TMPs) for the DOE capital asset projects subject to DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, dated 11-29-10. This Guide presents a tailored version of a National Aeronautics and Space Administration (NASA) and Department of Defense (DoD) technology readiness assessment model to assist in identifying those elements and processes of technology development required to ensure that a project satisfies its intended purpose in a safe and cost-effective manner that will reduce life cycle costs and produce results that are defensible to expert reviewers. DOE Guides are part of the DOE Directives Program and are issued to provide supplemental information and additional guidance regarding the Department's expectations of its requirements as contained in rules, Orders, Notices, and regulatory standards. Guides may also provide acceptable methods for implementing these requirements but are not prescriptive by nature. Guides are not substitutes for requirements, nor do they replace technical standards that are used to describe established practices and procedures for implementing requirements.

TABLE OF CONTENTS

1.0 Introduction

1.1 Purpose

Technology development is the process of developing and demonstrating new or unproven technology, the application of existing technology to new or different uses, or the combination of existing and proven technology to achieve a specific goal. Technology development associated with a specific acquisition project must be identified early in the project life cycle and its maturity level should have evolved to a confidence level that allows the project to establish a credible technical scope, schedule and cost baseline.[1] Projects that perform concurrent technology development and design implementation run the risk of proceeding with an ill-defined project baseline. The purpose of this document is to present a tailored version of a proven NASA and DoD technology assessment model that will assist DOE Program Offices in identifying those elements and processes of technology development required to reach proven maturity levels to ensure project success. A successful project is a project that satisfies its intended purpose in a safe, timely, and cost-effective manner that would reduce life-cycle costs and produce results that are defensible to expert reviewers (Reference: *DoD Technology Readiness Assessment Deskbook*, July 2009).

This document was developed to assist individuals and teams that will be involved in conducting Technology Readiness Assessments (TRAs) and developing Technology Maturation Plans (TMPs) for the Department of Energy (DOE) capital acquisition assets subject to DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets.* TRAs and TMPs activities are a tool to assist in identifying technology risks and enable the correct quantification of scope, cost and schedule impacts in the project. This document is intended to be a “living document” and will be modified periodically as the understanding of TRA processes evolves within the DOE programs. **DOE programs could use this Guide (the TRA process model) to assist in the development of their own TRA Process Guides/Manuals tailored to their own particular technologies and processes.** A program TRA Guide/Manual should take precedence over the DOE G 413.3-4A when conducting a TRA for projects under that specific program, as applicable to their technologies and/or processes.

DOE G 413.3-4A should not be applicable or appropriate to a project if: (1) the technology was adequately demonstrated previously for identical situations in one or more separate projects (see Appendix H, section 2.0, Technology Heritage); or (2) the technology readiness level does not apply if the objective of the project is to research scientific principles.

1.2 Background

To meet the requirements of DOE O 413.3B, Independent Project Reviews (IPRs) are one of the measures that can be implemented to ensure the timely resolution of engineering, system integration, technology readiness assessments, design, quality assurance, operations,

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[1] DOE O 413.3B, Table 2.1, requirement for hazard Category 1, 2 and 3 nuclear facilities to conduct an Integrated Project Review (IPR) to ensure early integration of safety in the design of a facility. For example, if a safety system requires technology development, then it must be identified early in the project life cycle. (Refer to DOE G 413.3-9 and DOE-STD-1189-2008)

maintenance of nuclear safety issues (Reference: DOE G 413.3-9, *U.S. Department of Energy Project Review Guide for Capital Asset Projects*). The purpose of an IPR is to acknowledge, identify, and reduce technical risk and uncertainty. The IPR also increases visibility of the risks and identifies any follow on activities that need to take place to mitigate the risks. Technical risk reduction increases the probability of successful achievement of technical scope. IPRs can include TRAs, as applicable and appropriate, to provide an assessment of the maturity level of a new proposed technology prior to insertion into the project design and execution phases to reduce technical risk and uncertainty. A TRA provides a snapshot in time of the maturity of technologies and their readiness for insertion into the project design and execution schedule. A TMP is a planning document that details the steps necessary for developing technologies that are less mature than desired to the point where they are ready for project insertion. TRAs and TMPs are effective management tools for reducing technical risk and minimizing potential for technology driven cost increases and schedule delays.

A TRA evaluates technology maturity using the Technology Readiness Level (TRL) scale that was pioneered by the NASA in the 1980s. The TRL scale ranges from 1 (basic principles observed) through 9 (total system used successfully in project operations). See section 2.0 for an explanation of the adaptation of the TRLs model in the context of DOE projects.

In 1999, the General Accounting Office (GAO) (GAO/NSIAD-99-162) recommended that the DoD adopt NASA's TRLs as a means of assessing technology maturity prior to transition. In 2001, the Deputy Undersecretary of Defense for Science and Technology issued a memorandum that endorsed the use of TRLs in new major programs. Subsequently, the DoD developed detailed guidance for performing TRAs using TRLs in the 2003 *DoD Technology Readiness Assessment Deskbook* [updated in July 2009]. Recent legislation (2006) has specified that the DoD must certify to Congress that the technology has been demonstrated in a relevant environment (TRL 6) prior to transition of weapons system technologies to design or justify any waivers. TRL 6 is also used as the level required for technology insertion into design by NASA; it is normally the last stage where technology has been demonstrated in the engineering/pilot scale in the relevant environment.

In March of 2007, the GAO issued a report on the results of a review of DOE projects performance which concluded, among other findings, that DOE's premature application of technologies was a reason for cost growth and schedule extension. GAO recommended that DOE adopt the NASA/DoD methodology for evaluating new technology maturity in their major construction projects (Reference: *GAO-07-336*). Subsequently, the DOE Office of Environmental Management (EM) conducted several pilot TRAs in their projects using an adaptation of the NASA/DoD TRA model for evaluating technology maturity and reported that the benefits of using the TRAs process include providing a structured, criteria-based, and clearly documented assessment. The process also identifies specific actions to reduce risk, assists in comparing candidate technologies, promotes decision-making discipline, and improves technical communication.

In an April 2008 report on the root cause analysis of contract and project management deficiencies within DOE, it was concluded that DOE has not always ensured that critical new technologies in final project designs have been demonstrated to work as intended. This has led to scope, cost and schedule increases from the originally approved project baselines (Reference:

DOE Root Cause Analysis, Contract and Project Management, April 2008). A Corrective Action Plan to this report was approved in July 2008 which addressed this shortcoming by planning the development of a DOE-wide technology readiness level model to assist DOE programs in the performance of TRAs for new technologies in their major construction and cleanup projects. The Corrective Action Plan includes a metric that requires, by the end of FY 2011, all projects greater than $750M (i.e., Major System Projects) applying new technology to implement technology readiness assessment methodologies no later than Critical Decision-2 (CD-2), as applicable and appropriate. [Reference: Root Cause Analysis, Contract and Project Management, Corrective Action Plan, July 2008]. Section 1.3 in this Guide provides further guidance with a strong message that TRA assessments by the programs for critical new technologies should begin early in the critical decision process. Technology development and associated risks are a key component of the project alternatives down select process and a key item in baseline cost and schedule development which begins at CD-1.

1.3 Technology Development Process Model

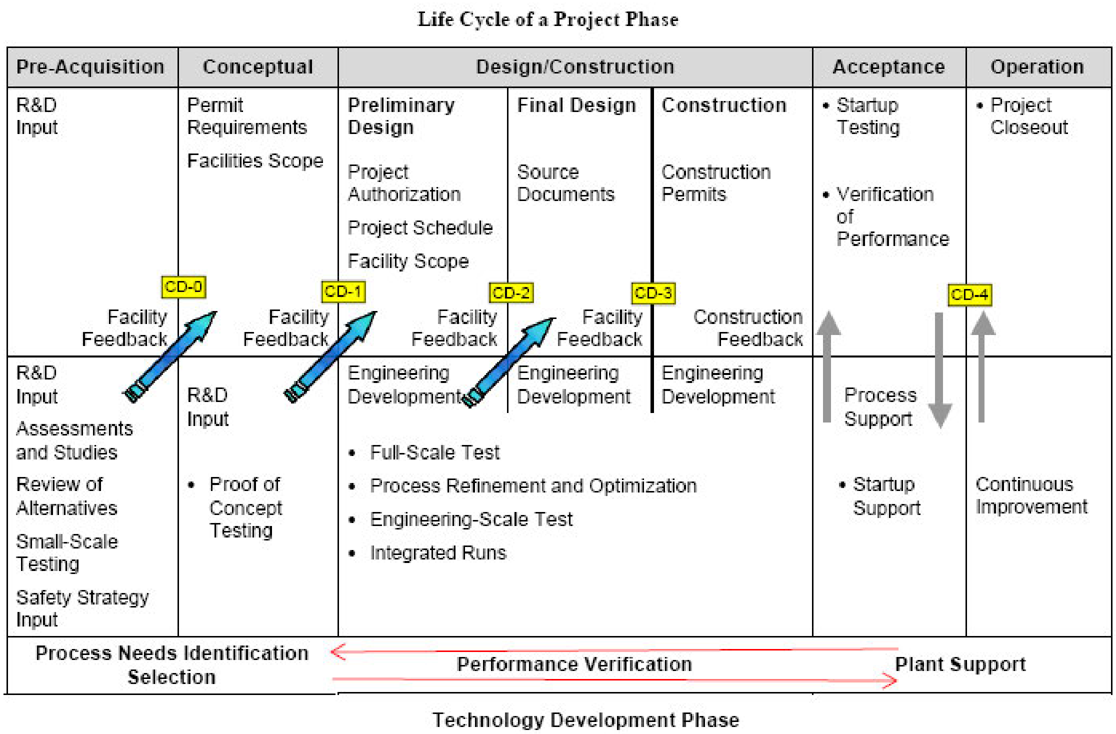
Various technical baseline deliverables, including associated technology development, are produced as a project evolves from pre-acquisition design to operation. The technology development process is not limited to the pre-acquisition and conceptual development stages, but instead, transitions throughout the life of the project. In addition, a safety strategy input is required early in the project life cycle as part of the technology development process.[2] The process recognizes the evolution of the project and the iteration necessary to continue support of the design. This integrated technology development approach also addresses emerging issues related to the technology that are driven by the design process, to include the corresponding safety function.

Figure 1 identifies the integration of the technology development phases with the project stages. In practice, technology development precedes design, which is followed by design implementation (construction). This is depicted with bold blue arrows signifying completion of technology development activities supporting the follow-in process in the project development. Also the red arrows at the bottom part of the figure reflect the early continuous interaction of the plant support group (operations) with the technology development and design group for setting process and performance requirements to support plant startup, commissioning and operations.

The following sub-sections provide suggested guidance to line management within projects or programs to ensure that technology development activities are brought to an appropriate level of maturity and transitioned for each project stage with a continued effort to reduce technological risk, as applicable and appropriate to the specific project and DOE program.

[2] DOE O 413.3B, Table 2.1, a safety design strategy is required for Hazard Category 1, 2 and 3 nuclear facilities for projects subject to DOE-STD-1189-2008.

Figure 1. Technology Development Integration with Project Management.



1.3.1 Technology Development Program Plans

Technology development plans are prepared when new technology development activities are identified during project planning. They provide a comprehensive planning document describing technology development activities required for the successful execution of the project, and the development relationship to the overall project scope and schedule relative to project phases. Areas addressed by the plan should include process needs identification, selection, system engineering, evaluation, performance verification, and demonstrations.

In support of technology development, it usually follows that a roadmap is developed to provide the technology development path forward for successful deployment of the selected technology. A work scope matrix is then developed that expands on the roadmap. The matrix provides the high-level details of each segment of research and development, assigning responsibility for the execution of each segment and documenting the path through each segment in the form of logic diagrams that are linked to the roadmap.

1.3.1.1 Process Needs Identification, Selection, and Evaluation

Process needs identification, selection, and evaluations occur during the pre-acquisition and conceptual design stages. Within these stages, as applicable and appropriate, the technology development program identifies the needs and requirements of a system or component and associated risks. This may include laboratory or pilot work to better understand system or process performance. The product of these activities provides input to performance requirement documents and criteria. Involving the plant support group early at this stage will help to ensure the manufacturability of designs, plants can presents lessons learned from previous designs, and suggest design improvements, as well as help identify the critical new technologies.

The next step in this effort involves selecting equipment that meets or most closely meets the performance requirements or criteria. In the selection process, existing equipment or processes are utilized to the maximum extent possible. However, in many cases, particularly those processes performed in hazardous or remote environments, the equipment may not be commercially available. In these situations, efforts are made to adapt commercial technologies to the specific environment and requirements. During this activity, the available equipment is compared and those identified as most closely meeting the defined requirements are selected for further evaluation.

Equipment and or process evaluation involves experimental or pilot facility testing of the process or equipment identified in the selection process. Although selection identified those processes and equipment that most closely meet design requirements, it is not uncommon for evaluation of those selected processes and equipment to identify areas where the process or equipment fails to meet requirements. In those cases, it may be necessary to return to the selection of alternatives to modify or select another preferred option. The following subsections describe various activities used to support the identification, selection, and evaluation of the selected technology.

Assessments and Studies

Inherent with technology development is the risk associated with first-of-kind applications. A technical risk assessment should be performed to identify risks that may affect the achievement of technical objectives that ultimately affect cost, schedule and performance. Results of technical risk assessments and risk-handling strategies are factored into technical assessments/reviews and studies [References: DOE G 413.3-7A; DOE G 413.3-9; and DOE O 413.3B].

Technical assessments and studies are conducted during the pre-acquisition project stage to evaluate and select the design approach that best meets the customer's goals, objectives, and preliminary technical and functional requirements. Topics addressed during this activity should include, as applicable, supporting program risks, technology maturation risks, process technology, facility concepts, major system concepts, component technology, safety, and risk-handling strategies identified through completion of technical risk assessments.

Review of Alternatives

Results of technology development assessments and studies are documented and reviewed to determine the validity of the approach that best meets project goals, objectives, and the physical, functional, performance, and operational requirements of the project at the best value; to include testing and validation of all required functions, including any safety functions.

A team consisting of members from the customer, engineering, operations, maintenance organizations, technology development program management, and selected subject matter experts reviews the documented assessments and study results. The team review focuses on the results of the assessments and studies relative to the alternatives considered, evaluation of systems used to select the recommended design approach, and the potential life-cycle cost savings. The objective of the review is to review the documented assessment and study evidence to identify the basis for endorsing the selected design approach, including development and testing of the technology to ensure its maturation in subsequent project phases.

Small-Scale and Proof-of-Concept Testing

Small-scale and proof-of-concept testing is performed at the conceptual project stage to verify initial assumptions relative to system and process performance. Test results are compared with the initial input parameters. Based on the reviews of test results, refinements in the technology (i.e., its design) are applied when necessary to ensure that the technology concept meets project requirements prior to the start of project design activities. As necessary, the technology development program plans are modified consistent with these test results.

1.3.2 Performance Verification

Performance verification occurs during the design and construction project stages. Once a process or equipment has been selected and proven to perform in an acceptable manner, verification against the design requirements is performed to ensure that the process or equipment will perform properly in the operating environment. Verification addresses performance of the selected process or equipment on both the component level and from an integrated system perspective. Verification attributes may include checking that the operating parameters are within the operating envelope of supporting systems (e.g., power, feed rate, etc.) as well as meeting the physical expectations of the equipment or examining properties of material produced against the stated requirements.

Following verification activities, full-scale testing to assess the durability and reliability of the process and/or equipment is conducted. Integrated runs involving combining components, systems, or processes are performed to provide a demonstration of process conditions over extended periods of time and provide opportunities of process optimization. This testing stage is intended to prove that the long-term operating goals, especially where remote operations are required, can be reliably achieved while producing the end product at acceptable quality standards in a safe and controlled manner.

1.3.3 Plant Support

Following construction completion, support for the new technology is provided through start up and turnover to operations. This continued integration of technology development provides an opportunity for the operations technical staff to attain a better understanding of the technology application. However, it is recommended that the plant support group involvement should start early in the pre-acquisition and conceptual phases to ensure the manufacturability of designs, to incorporate lessons learned from previous designs and operational experiences, and to help in the identification of what the new critical technologies are in the project (see Figure 1).

1.3.4 Technology Readiness Assessment (TRA) Reviews

IPR teams may be established to conduct TRA reviews and provide recommendations to the program/project sponsor and the Acquisition Executive in terms of the project technology readiness and maturity. These review teams serve in an advisory capacity at key project design points such as CD-0, CD-1, CD-2, and CD-3. (see section 2.0). At a minimum, team membership may consist of senior-level technical personnel and subject matter experts on the project. The team should also be able to leverage outside experts as appropriate to contribute to the review process. The team should perform its review relying on documented reports and other formal evidence, and minimize reliance on verbal assurances from project personnel. A technology review report is issued after each review, presenting the results of the review and specific recommendations for maturing technologies relative to the design process, as needed.

When this IPR review activity includes a sub-team of experts that are selected from personnel who are independent of the project, the sub-team reviews can be considered to satisfy the expectation to conduct a TRA, as discussed in the sections of this Guide that follow.

Ad hoc teams of subject matter experts may also perform additional technology development reviews at any point in the development process. These reviews target specific areas of development. The results from these reviews and recommendations are formally communicated to the project team and user.

1.3.4.1 Records

Records retention is usually dictated by customer/program requirements and the requirements from DOE O 413.3B in support of the project reviews process, and to support the formulation of lessons learned reports. Because of the significant documentation generated by technology development activities, judgment should be exercised prior to discarding any documented plans, reports, or studies utilized to validate technology development selection and test results.

2.0 Technology Readiness Assessment Process Model

"A TRA is a systematic, metric-based process and accompanying report that assesses the maturity of certain technologies [called Critical Technology Elements (CTEs)] used in systems." [2003 *DoD Technology Readiness Assessment Deskbook* (updated July 2009)].

The TRA is an assessment of how far technology development has proceeded based upon documented evidence. It is not a pass/fail exercise and is not intended to provide a value judgment of the technology developers or the technology development program. It is a review process to ensure that critical technologies reflected in a project design have been demonstrated to work as intended (technology readiness) before committing to construction expenses. TRAs should be conducted by technically qualified personnel who are independent of the project. A TRA can:

- Identify the gaps in testing, demonstration and knowledge of a technology's current readiness level and the information and steps needed to reach the readiness level required for successful inclusion in the project;

- Identify at-risk technologies that need increased management attention or additional resources for technology development; and

- Increase the transparency of management decisions by identifying key technologies that have been demonstrated to work or by highlighting immature or unproven technologies that might result in increased project risk.

The TRA process model consists of three sequential steps:

(1) **Identifying the Critical Technology Elements (CTEs)**. CTEs are the at-risk technologies that are essential to the successful operation of the facility, and are new or are being applied in new or novel ways or environment (see section 3.0 for more details of CTEs).

(2) **Assessing the Technology Readiness Level (TRL)**. The TRL scale used by the DoD and NASA, and adopted by EM in their pilot demonstration program is used for conducting Technology Readiness Assessments. Other DOE programs, in developing their own program guides/manuals, should consider lessons learned from EM, DoD and NASA, and their own domain or experience in measuring technology readiness, as applicable and appropriate to their specific projects and programs. TRL indicates the maturity level of a given technology, as defined in Table 1 primarily for hardware items. Figure 2 provides a schematic of the meaning of the TRL's in the context of DOE/EM waste processing projects. The TRL scale ranges from 1 (basic principle observed) through 9 (total system used successfully in project operations). TRL is not an indication of the quality of technology implementation in the design. Testing should be done in the proper environment and the technology tested should be of an appropriate scale and fidelity. A DOE/ EM example of the TRL requirements and definitions regarding testing "scale," "system fidelity," and "environment" are provided in Tables 2 and 3. (See section 4.0 for more details on TRLs)

(3) **Developing a Technology Maturation Plan (TMP).** If the TRL level for a CTE does not meet the expectation level at each Critical Decision level (especially for CD-2 and later), then a maturity level gap exists that requires further evaluation testing or engineering work in order to bring the immature technology to the appropriate maturity level. The development or revision of a Technology Maturation Plan (TMP) identifies the activities required to bring immature CTEs up to the desired TRL (see section 5.0 for more details on the TMP).

Table 1. Technology Readiness Levels

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected mission conditions.	The technology is in its final form and operated under the full range of operating mission conditions. Examples include using the actual system with the full range of wastes in hot operations.
System Commissioning	**TRL 8**	Actual system completed and qualified through test and demonstration.	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with actual waste in hot commissioning. Supporting information includes operational procedures that are virtually complete. An Operational Readiness Review (ORR) has been successfully completed prior to the start of hot testing.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in relevant environment	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing full-scale prototype in the field with a range of simulants in cold commissioning[1]. Supporting information includes results from the full-scale testing and analysis of the differences between the test environment, and analysis of what the experimental results mean for the eventual operating system/environment. Final design is virtually complete.
Technology Demonstration	**TRL 6**	Engineering/pilot-scale, similar (prototypical) system validation in relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include testing an engineering scale prototypical system with a range of simulants.[1] Supporting information includes results from the engineering scale testing and analysis of the differences between the engineering scale, prototypical system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. TRL 6 begins true engineering development of the technology as an operational system. The major difference between TRL 5 and 6 is the step up from laboratory scale to engineering scale and the determination of scaling factors that will enable design of the operating system. The prototype should be capable of performing all the functions that will be required of the operational system. The operating environment for the testing should closely represent the actual operating environment.
Technology Development	**TRL 5**	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity, laboratory scale system in a simulated environment with a range of simulants[1] and actual waste[2]. Supporting information includes results from the laboratory scale testing, analysis of the differences between the laboratory and eventual operating system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. The major difference between TRL 4 and 5 is the increase in the fidelity of the system and environment to the actual application. The system tested is almost prototypical.

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	The basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of ad hoc hardware in a laboratory and testing with a range of simulants and small scale tests on actual waste[2]. Supporting information includes the results of the integrated experiments and estimates of how the experimental components and experimental test results differ from the expected system performance goals. TRL 4-6 represent the bridge from scientific research to engineering. TRL 4 is the first step in determining whether the individual components will work together as a system. The laboratory system will probably be a mix of on hand equipment and a few special purpose components that may require special handling, calibration, or alignment to get them to function.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative tested with simulants.[1] Supporting information includes results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. At TRL 3 the work has moved beyond the paper phase to experimental work that verifies that the concept works as expected on simulants. Components of the technology are validated, but there is no attempt to integrate the components into a complete system. Modeling and simulation may be used to complement physical experiments.
Basic Technology Research	**TRL 2**	Technology concept and/or application formulated	Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies. Supporting information includes publications or other references that outline the application being considered and that provide analysis to support the concept. The step up from TRL 1 to TRL 2 moves the ideas from pure to applied research. Most of the work is analytical or paper studies with the emphasis on understanding the science better. Experimental work is designed to corroborate the basic scientific observations made during TRL 1 work.
	TRL 1	Basic principles observed and reported	This is the lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples might include paper studies of a technology's basic properties or experimental work that consists mainly of observations of the physical world. Supporting Information includes published research or other references that identify the principles that underlie the technology.

[1] Simulants should match relevant chemical and physical properties.

[2] Testing with as wide a range of actual waste as practicable and consistent with waste availability, safety, ALARA, cost and project risk is highly desirable.

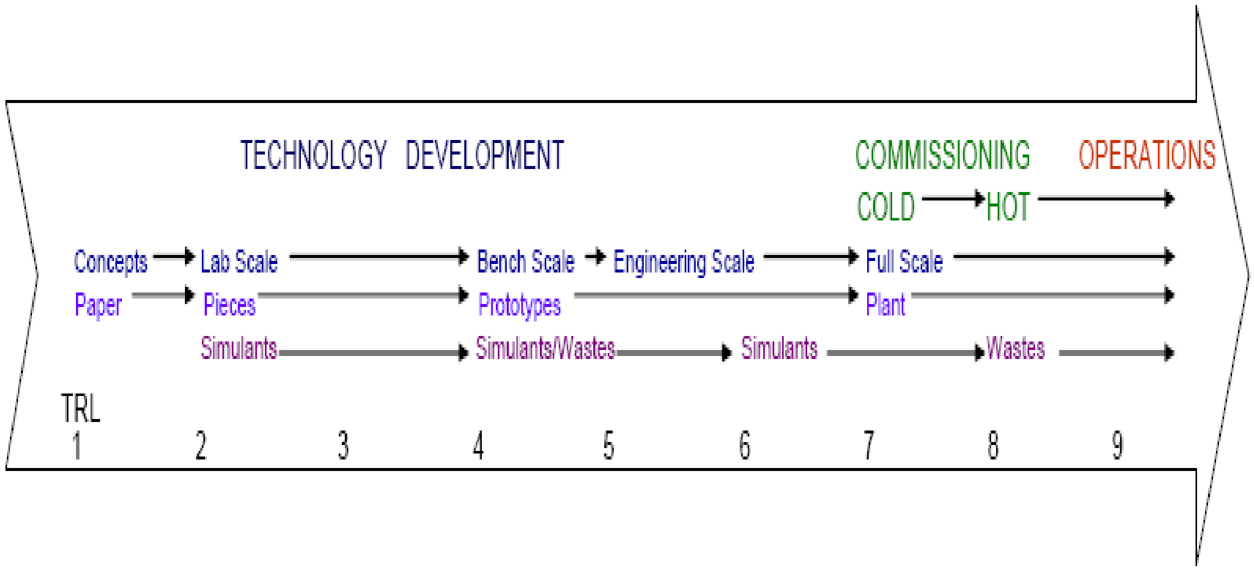


Figure 2. Schematic of DOE/EM Technology Readiness Levels

Table 2. DOE/EM TRL Scale, fidelity and Environment Definitions

Scale	
Full Plant Scale	Matches final application
Engineering Scale[1]	Typical (1/10 < system < Full Scale)
Laboratory/Bench[1]	< 1/10 Full Scale

[1] The Engineering Scale and Laboratory/Bench scale may vary based on engineering judgment.

System Fidelity	
Identical System Configuration	-matches final application in all respects
Similar Systems Configuration	-matches final application in almost all respects
Pieces	-system matches a piece or pieces of the final application
Paper	-system exists on paper (i.e., no hardware system)

Environment (Waste)	
Operational (Full Range)	Full range of actual waste
Operational (Limited Range)	Limited range of actual waste
Relevant	Simulants plus a limited range of actual wastes
Simulated	Range of simulants

Table 3. DOE/EM TRL Testing Requirements

TRL Level	Scale of Testing	Fidelity	Environment[1,2]
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot Scale	Similar	Relevant
5	Lab/Bench	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	

[1] Simulants should match relevant physical and chemical properties
[2] Testing with as wide a range of actual waste as practicable; and consistent with waste availability, safety , ALARA, cost, and project risk is highly desirable

*** Note: See Tables 5 & 6 for definitions of the TRL testing descriptive terms used in the table.**

2.1 Relationship of TRAs and TMPs to the DOE Critical Decision Process

Technology development should be the responsibility of the program/project, as it is applicable and appropriate. A TRA provides management an independent assessment of the program/project's progress in its technology development activities in support of a project.

The TRA process can be employed in a variety of situations requiring the determination of the state of technology development. In the realm of project management, TRAs and the resulting TMPs can be used as a project management tool to reduce the technical and cost risks associated with the introduction of new technologies. The TRA process can serve as one of the tools employed in helping to make effective Critical Decisions, as required by DOE O 413.3B. DOE O 413.3B (Appendix C, page C-27) requires for Major System Projects where new critical technologies are being deployed that a TRA shall be conducted and the associated TMP developed prior to CD-2. On those projects where a significant critical technology element modification occurs subsequent to CD-2, another TRA should be conducted prior to CD-3. For other projects the implementation of TRAs may be a discretionary decision of the Acquisition Executive or the DOE Program, but the associated risks may need to be identified and captured per Appendix F of DOE-STD-1189-2008, as applicable and appropriate. See also DOE G 413.3-7A, *Risk Management Guide*, dated January 2011, for additional information on risk management.

The five CDs are major milestones approved by the Secretarial Acquisition Executive or Acquisition Executive that establish the Mission Need, the recommended alternative, the Acquisition Strategy, the Performance Baseline, and other essential elements required to ensure that the project meets applicable mission, design, security, and safety requirements. Each CD marks an increase in commitment of resources by the Department and requires successful completion of the preceding phase or CD. Collectively, the CDs affirm the following:

- There is a need that cannot be met through other than material means [CD-0];
- The selected alternative and approach is the optimum solution [CD-1];
- The proposed scope, schedule and cost baseline is achievable and minimum key performance parameters (KPPs) that must be achieved at CD-4 [CD-2];
- The project is ready for implementation [CD-3]; and
- The project is ready for turnover or transition to operations [CD-4].

The recommended guidance is to conduct TRAs during conceptual design and preliminary design processes; and at least 90 days prior to CD milestones. The assessment process should follow the guidance in this document by applying the system engineering approach to assess proper integration of systems with new technologies into the project (system within systems rather than piecemeal review), to include testing and validation of all the critical technologies, including the safety functions in the relevant operational environment. Deviations from the recommended approach may result in unquantifiable and unknown project risks. Figure 3 shows how TRAs and other key reviews support each of the CDs. (There are numerous additional requirements for each CD. See Tables 2.1-4 of DOE O 413.3B and DOE-STD-1189-2008 for a complete listing.)

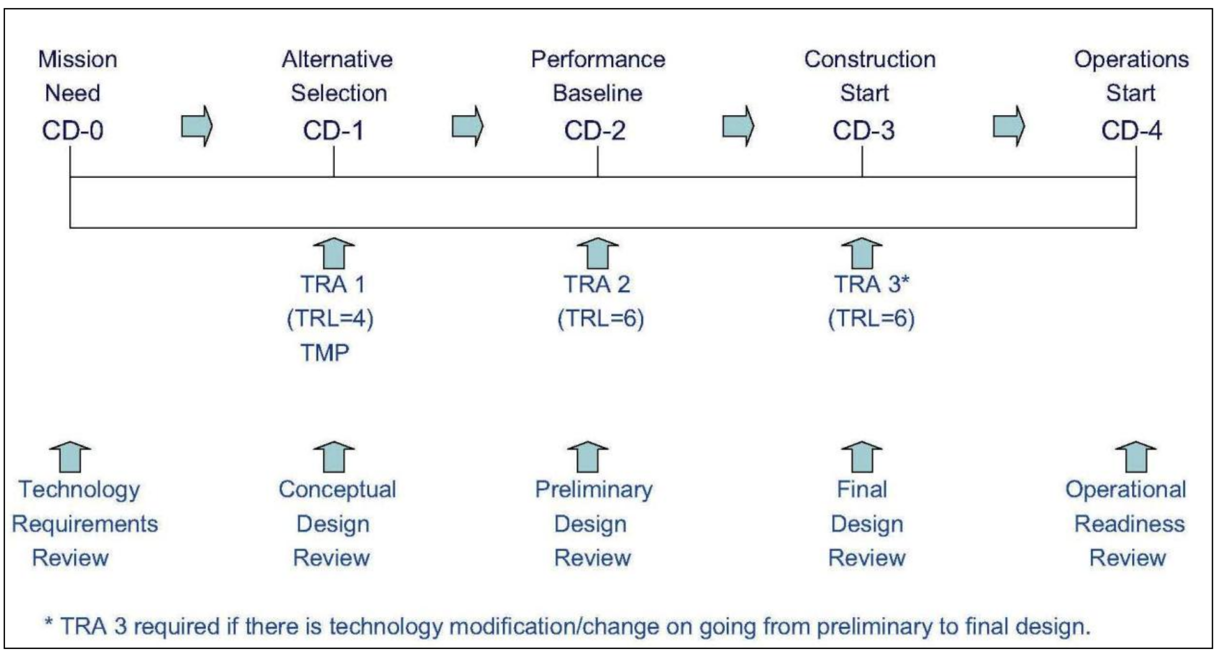


Figure 3. Suggested Technology Assessments and Review Requirements for Critical Decisions

<u>Note</u>: The technology reviews, the design reviews, and the Operational Readiness Reviews (ORR) are conducted in advance of the CD milestone to support the milestone decision. The TRL values above (in parenthesis) at each CD point are recommended minimum values. DOE programs should justify and document through risk management processes deviations from the recommended minimum TRLs at each CD based on their particular technology's complexity and associated risks, as deemed applicable and appropriate.

<u>Graded Approach for TRAs:</u> The recommended approach is that TRAs should be conducted in advance for each CD such that they feed the associated technology and safety risks into the overall project risk assessment for evaluating cost and schedule impacts. The recommended integrating mechanism for such an approach could be through the IPR which evaluates the project overall technical and safety risks, among other things. DOE programs should justify and document through risk management processes deviations from the recommended minimum TRLs at each CD in Figure 3 weighing their particular technology's complexity and associated risks, as deemed applicable and appropriate. Any discrepancy/gaps on the TRL findings from a TRA with the expectations at each CD should trigger a TMP to bring the TRL to par with the expectations for TRL at CD-2 (establishing project baseline) and CD-3 (start of construction). If not so, the Acquisition Executive should be made aware of the resulting risks in a quantifiable form, to include safety implications. Deviating from the recommended approach could result in project risks that are not identified and captured per Appendix F of DOE-STD-1189-2008.

<u>CD-0, Approve Mission Need</u>: Identification of a mission-related need and translation of this gap into functional requirements for filling the need. *The mission need is independent of a particular solution and should not be defined by equipment, facility, technological solution, or physical end item*. The focus for technology development assessments, at this stage, should be on a clear statement of the requirements of the input and the desired output of the process, to include the safety strategy input, as applicable and appropriate. A Technology Requirements Review would assess the adequacy of requirements definition and characterization information and determine any additional work necessary, to include an assessment of technology unknowns that need to be further evaluated. If additional work is necessary to adequately define technical scope of the project, a plan should be developed detailing its scope and schedule.

<u>CD-1, Alternative Selection and Cost Range</u>: Identification of the preferred technological alternative, preparation of a conceptual design, and development of initial cost estimates. A TRA should be performed during conceptual design, to support the CD-1 approval process and a TMP prepared, as applicable and appropriate. Any TMPs should be linked to the project risk assessment process as a whole. Prior to CD-1 approval, it is recommended that all Critical Technology Elements (CTEs) of the design should have reached at least TRL 4 and a TMP should have been prepared, or revised, for all CTEs that are not assessed to have reached the appropriate recommended level for CD-2, as applicable and appropriate.

Prior to CD-1 approval, the Program Secretarial Officer must conduct an IPR as required in DOE O 413.3B: "For Hazard Category 1, 2, and 3 nuclear facilities, conduct an IPR to ensure early integration of safety into the design process." The review must ensure safety documentation is complete, accurate, and reliable for entry in the next phase of the project (Reference: DOE-STD-1189-2008). The IPR should include within its scope a TRA, as applicable and appropriate. If a safety system requires technology development, then it must be identified early or the objective of credible technical scope, schedule, and cost baseline cannot be successfully achieved (note: the activity is not optional, but the means to achieve the activity is optional).

CD-2, Performance Baseline: Completion of preliminary design, and development of a performance baseline that contains a detailed scope, schedule, and cost estimate, and KPPs that must be achieved at CD-4. The process of technology development, in accordance with the program/project's technology development plans and any TMPs issued as a result of a prior TRA, should ensure that all CTEs have reached at least TRL 6, which indicates that the technology is ready for insertion into detailed design, as applicable and appropriate. A TRA should be performed at least 90 days prior to reaching CD-2 to independently assure that the CTEs have in fact reached TRL 6 or the supportable recommended program/project's target level for CD-2, as applicable and appropriate. Projects are encouraged to achieve TRL 7 prior to CD-3 as a recognized best practice, but in no instance it is recommended that CD-2 be approved with a TRL less than 6. In either case, the residual risks should be accounted in the Risk Management Plan, recorded in the risk register and assigned the proper contingency in the project baseline (see DOE G 413.3-7A).

Prior to CD-2 approval (refer to DOE O 413.3B), the PSO must conduct a TRA and develop a TMP for major system projects where new critical technologies are being developed, as appropriate.

CD-3, Start of Construction: Completion of essentially all design and engineering and beginning of construction, implementation, procurement, or fabrication. A TRA is recommended if there is a significant CTE modification subsequent to CD-2 as detailed design work progressed. If substantial modification to a CTE occurs, the recommended TRA should be performed and a TMP should be prepared or updated to ensure that the modified CTE will attain TRL 6, prior to its insertion into the detailed design and baseline, as applicable and appropriate. Prior to the start of operations, start-up testing and operational readiness reviews should ensure that the CTEs have advanced to the target maturity level at CD-4 (TRL 6 toward TRL 9), as applicable and appropriate.

Prior to CD-3 approval (refer to DOE O 413.3B), the PSO must conduct a TRA for major system projects where a significant critical technology element modification occurs subsequent to CD-2.

CD-4, Start of Operations or Project Completion: Readiness to operate and/or maintain the system, facility, or capability. Successful completion of all facility testing and entry into operations corresponds to attainment of TRL 9. Nuclear and other hazardous operations may have additional post CD-4 start-up requirements and qualifications that must be completed before full operations begin under mission conditions.

2.2 Relationship of TRAs to Independent Project Reviews

IPRs are one of the measures that can be taken to ensure the timely resolution of engineering, system integration, technology readiness assessments, design, quality assurance, operations, and maintenance and nuclear/non-nuclear safety issues. It should also be emphasized that supporting program issues and their resolution should also be reviewed under the IPR since they could overshadow the technology development or other elements of the project, and as such, present an element of uncertainty to the project. The purpose of an IPR is to assist reducing technical risk and uncertainty which increases the probability of successful implementation of technical scope including new technologies.

IPRs can include TRAs to provide an assessment of the maturity level of a new proposed technology prior to insertion into the project design and execution phases to reduce technical risk and uncertainty.

The TRA should not be considered a *risk* assessment, but it should be viewed as a tool for assessing program risk and the adequacy of technology maturation planning by the program/project. The TRA scores the current readiness level of selected system elements (i.e., CTEs), using defined TRLs (see section 4.0). The TRA highlights critical technologies and other potential technology risk areas that may need the program manager/Federal Project Director attention. If the system does not meet pre-defined TRL scores, then a CTE TMP should be required. As discussed in section 5.0, this TMP explains in detail how the target TRL (the CTEs maturity) will be advanced prior to the next milestone Critical Decision and it allows the program/project to properly reflect the CTEs risk within the project's baseline.

3.0 Model for Identifying Critical Technology Elements (CTEs)

The following definition of a CTE was adopted from the 2003 DoD, Technology Readiness Assessment Deskbook, updated July 2009:

A technology element is "critical" if the system being acquired depends on this technology element to meet operational requirements (with acceptable development cost and schedule and with acceptable production and operation costs) and if the technology element or its application is either new or novel, or in an area that poses major technological risk during design or demonstration. Said another way, an element that is new or novel or being used in a new or novel way is critical if it is necessary to achieve the successful development of a system, its acquisition, or its operational utility.

Disciplined identification of CTEs is important to a program. The management process/procedure for CTE identification is as important as the technical task because it adds to the credibility of the resulting CTE list. If a CTE is overlooked and not brought by the program/project to the requisite maturity level for later project insertion at the start of System Design and Development, the system performance, program schedule, and cost could be jeopardized. On the other hand, if an overly conservative approach is taken and a plethora of technologies are categorized as critical, energy and resources are likely to be diverted from the few technologies that deserve an intense maturation effort.

The *Defense Acquisition Guidebook*, updated July 2011, specifically recommends the use of the Work Breakdown Structure (WBS) for a project to initially assist in identifying the CTEs (see Figure 4 for a sample DOE project WBS). The WBS has several beneficial attributes for this purpose:

- It is readily available when system engineering practices are used.

- It evolves with the system concept and design.
- It is composed of all products that constitute a system and, thus, is an apt means to identify all the technologies used by the system.
- It relates to the functional architecture and, therefore, to the environment in which the system is intended to be employed.
- It reflects the system design/architecture and the environment and performance envelope for each product in the system.

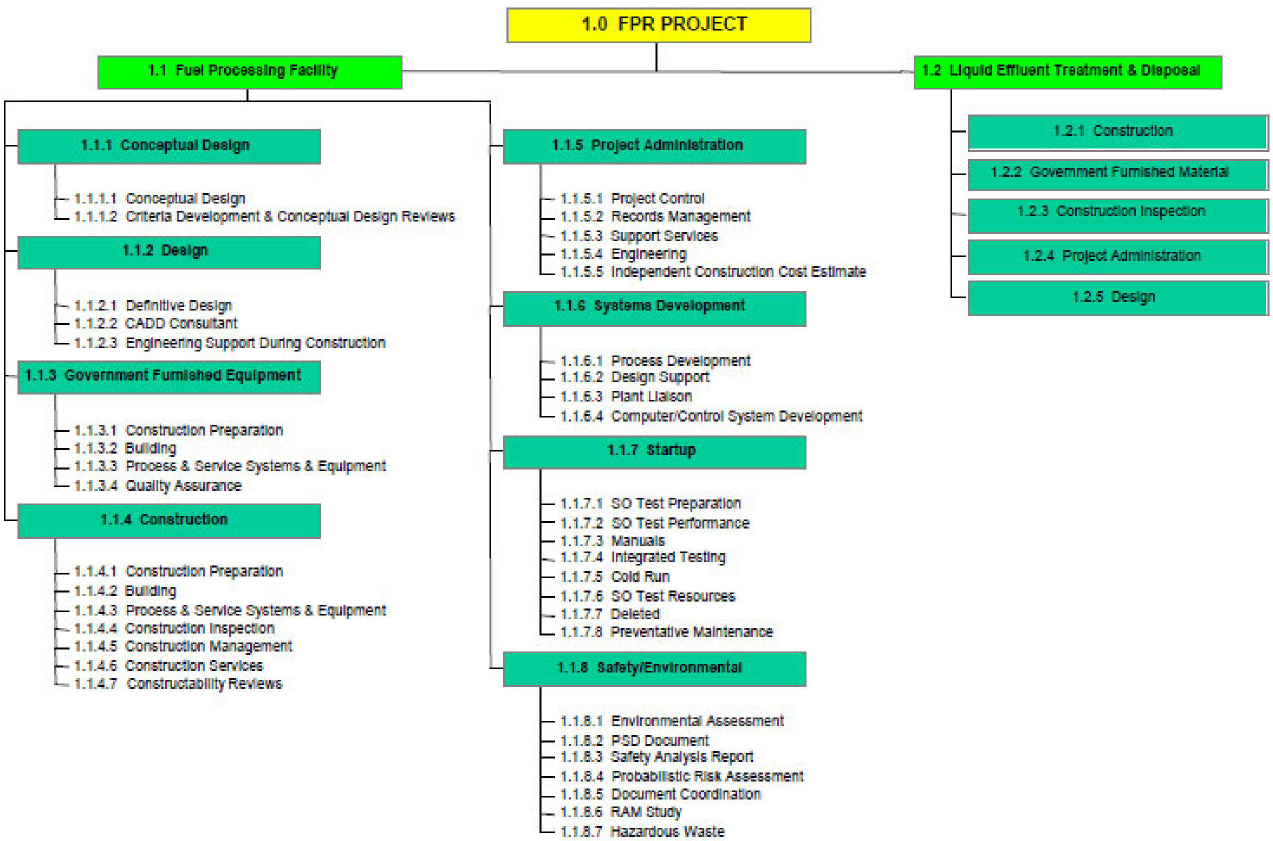


Figure 4. Sample DOE Project Work Breakdown Structure

Some programs within DOE (such as EM) have found that a WBS is not readily usable for CTE identification, and system flow diagrams (for example in waste processing technologies) were a more helpful tool for identifying CTEs (see Figure 4a). DOE programs elements should develop their own guidance on how to best approach the identification of CTEs for their technologies.

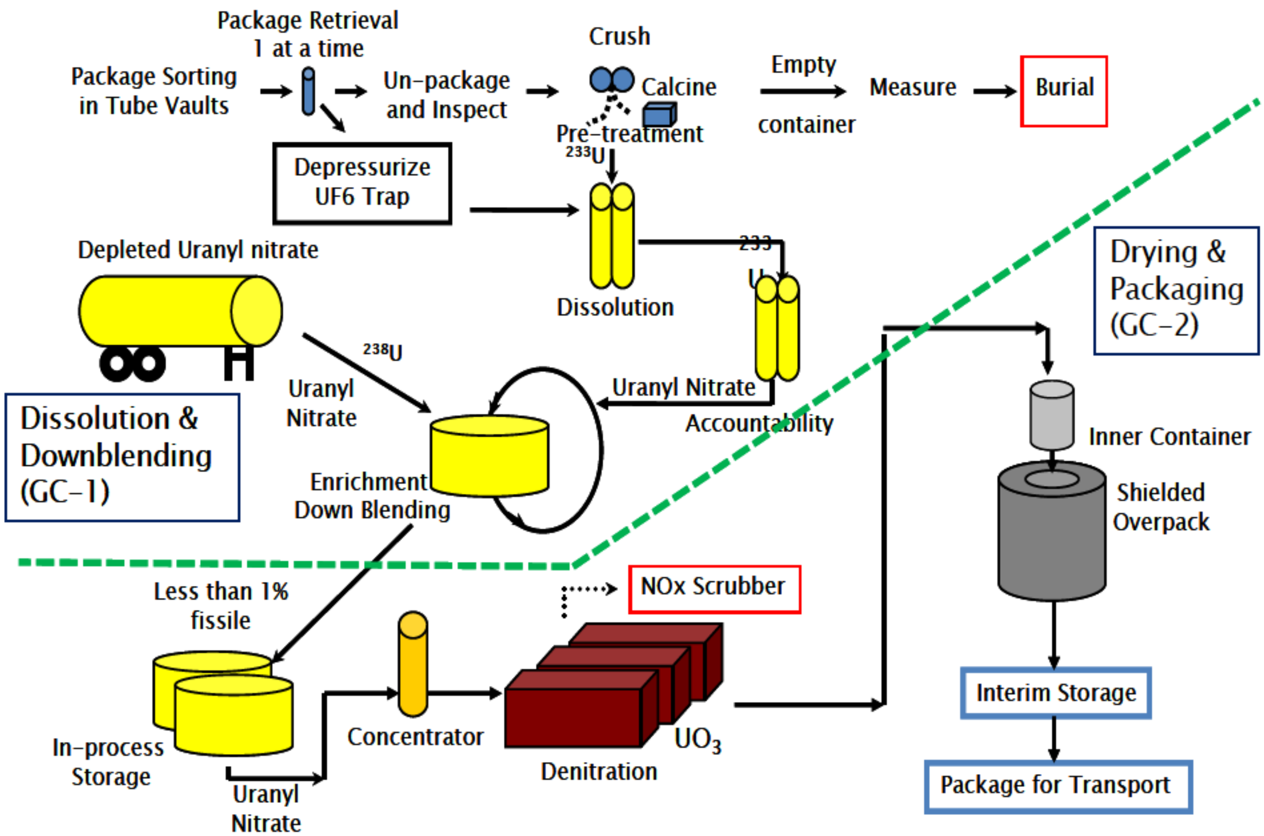


Figure 4a. DOE/EM Example of a Flow Diagram to Assist in Identifying CTEs

From a management process/procedure perspective, CTE identification should be a two-step process. In the first step, the CTE definition is applied across the system's WBS or flow diagram to identify critical technology candidates. This process should be thorough, disciplined, and conservative. Any questionable technology should be identified as a candidate CTE. For these questionable technologies, the information required to resolve their status should be documented.

The program manager, the program office technical staff and the system contractors – the people best informed about the system – should lead the first step. In any case, they should be able to defend the logic of the method/process used for identifying the CTEs.

The second step consists of resolving, where possible, the status of technologies in question by filling the information gaps noted in the first step. An independent panel of technical experts convened by the sponsoring program office should conduct the second step.

All individuals involved in these steps should be familiar with:

- CTE identification in the context of a TRA and its importance to the technical and programmatic success of the program.
- The concept of the WBS (or systems architecture) or flow diagram as a complete description of the products/things that comprise a system.

- The distinction between hardware, software, and manufacturing technologies and the metrics that evaluate their maturity (as described in Table 1 and section 4.0).
- The affordability and production criteria for CTEs.
- The role that "environment" has in identifying CTEs.

CTE Determination Criteria

The technical task in the second step involves the use of a series of questions to test whether the CTE definition applies. The series of questions are divided in two sets of criteria:

(1) Criticality to program criteria, and

(2) New or novel criteria.

Appendix E presents a sample template for the series of questions suggested for determining whether a technology element is a CTE. It is advisable that this template be completed for each candidate CTE so that a formal record of the CTE determination can be maintained by the project.

For a technology to be critical, the answer to one of the following questions should be "yes":

Criticality to Program Criteria

- Does the technology directly impact a functional requirement of the process or facility?
- Do the limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required?
- Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?
- Do limitations in the understanding of the technology impact the safety of the design?
- Are there uncertainties in the definition of the end state requirements for this technology?

In addition, the answer to one of the following questions should also be "yes":

New or Novel Criteria

- Is the technology new or novel?
- Is the technology modified?
- Have the potential hazards of the technology been assessed?
- Has the technology been repackaged so that a new relevant environment is realized?

- Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

The environment in which the system will operate plays a significant role in answering these last four questions. Generally, the requirement statement for the system will provide some description of the environment in which the system is expected/required to operate. This can be called the *external* or i*mposed environment.* It may be natural or man-made, friendly or hostile (e.g., weather, terrain and hostile jamming, terrorism, and so forth). Another environment – the one generally more important for identifying and evaluating CTEs – can be called *internal* or *realized environment.* It is derived from the performance required of each design item (product, subsystem, component, WBS element). The design analysis should include the required or expected performance envelope and conditions for each WBS or flow diagram technology element.

A complete definition of the operational environment for the system and its components is necessary to determine that the planned environment is identical to prior applications where this technology has been successfully used. Deviations between the planned environment and the environment of prior applications results in the need to qualify (mature) the planned use of the technology by the program/project.

People with the requisite technical knowledge and the independence needed to make a good judgment should guide the actual set of questions asked for each CTE candidate. The program manager and the suppliers should present clear, convincing, and succinctly summarized data that show what is known/not known about the environment and should explain the similarities and dissimilarities between the expected/demonstrated environments.

4.0 Model for Technology Readiness Level Assessments

Determination of a TRL should be conducted by the program/project as part of normal project planning and development early in the project, and assessed by a TRA team of independent project experts prior to key critical decisions. Both the project and the TRA team can use the following process:

TRL is a measure used by some United States government agencies (sometimes as a direct result of Congressional direction) and many of world's major companies (and agencies) to assess the maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating that technology into a system or subsystem. Generally speaking, when a new technology is first invented or conceptualized, it is not suitable for immediate application. Instead, new technologies are usually subjected to experimentation, refinement, and increasingly realistic testing. Once the technology is sufficiently proven or matured, it can be incorporated into a system/subsystem. TRL at its most basic definition describes the maturity of a given technology relative to its development cycle.

Technology maturity is a measure of the degree to which proposed CTEs meet program objectives and can be related to program risk. A TRA examines program concepts, technology requirements, and demonstrated technology capabilities including the safety function, in order to determine technological maturity. Table 4 provides a summary view of the technology maturation process model adopted from NASA and DoD, and somewhat modified by DOE-EM, which could be tailored for use by other DOE programs. This DOE-wide model has the following attributes: it includes (a) “basic” research in new technologies and concepts (targeting identified goals, but not necessarily specific systems), (b) focused technology development addressing specific technologies for one or more potential identified applications, (c) technology development and demonstration for each specific application before the beginning of full system development of that application, (d) early identification of all potential hazards from the technology and the testing of the safety functions in the relevant environment, (e) system development (through first unit fabrication), and (f) system “launch” and operations.

Hazard Analysis/Safety: Design and performance requirements for CTEs should address hazards early to ensure safety is “designed in” early instead of “added on” later with increased cost and decreased effectiveness. Analysis of hazards results in the identification of potential accident scenarios and the determination of how to prevent or mitigate accidents. Safety Structures, Systems and Components (SSCs) are identified and incorporated into the design to prevent or mitigate the consequences of hazards to the facility worker, the collocated worker and the public. These SSCs are classified as safety class, safety significant or defense in depth as required by their safety function. Testing and validation of safety functions in the relevant environment for the CTEs is part of the TRA, as applicable and appropriate. (Reference: DOE O 420.1B and DOE O 413.3B]

Table 4. DOE Technology Readiness Level Scale

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	TRL 9	Actual system operated over the full range of expected conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	TRL8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in a relevant environment.	Prototype full scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	TRL 6	Engineering/pilot-scale, similar (prototypical) system validation in a relevant environment.	Representative engineering scale model or prototype system, which is well beyond the lab scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
Technology Development	TRL 5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
	TRL 4	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	TRL 3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	TRL 1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.

The TRL scale used in Table 4 requires that testing of a prototypical design in a relevant environment be completed prior to incorporation of the technology into the final design of the facility. All technology readiness levels should include compliance with DOE-STD-1189-2008 and DOE O 413.3B to include worker and public safety considerations early in the design process.

The testing performed on the CTEs to demonstrate its operational capability and performance is compared to the TRLs in Table 5 (DOE/EM application). The TRL definitions provide a convenient means to understand further the relationship between the scale of testing, fidelity of testing system, and testing environment and the TRL. This scale requires that for a TRL 6 testing should be completed at an engineering or pilot scale, with a testing system fidelity that is similar to the actual application. Table 6 provides additional definitions of the TRL descriptive terms often used by DoD in the testing recommendations for TRLs for some of their technologies.

Table 5. DOE/EM Relationship of Testing Recommendations to the TRL

TRL	Scale of Testing[1]	Fidelity[2]	Environment[3]
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot	Similar	Relevant
5	Lab	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	

1. Full Scale = Full plant scale that matches final application
   1/10 Full Scale < Engineering/Pilot Scale < Full Scale (Typical)
   Lab Scale < 1/10 Full Scale (Typical)
2. Identical System – configuration matches the final application in all respects
   Similar System – configuration matches the final application in almost all respects
   Pieces System – matches a piece or pieces of the final application
   Paper System – exists on paper (no hardware)
3. Operational (Full Range) – full range of actual waste
   Operational (Limited Range) – limited range of actual waste
   Relevant – range of simulants + limited range of actual waste
   Simulated – range of simulants

Table 6. Additional Definitions of TRL Descriptive Terms
(Source: *Defense Acquisition Guidebook*)

Term	Definition
Breadboard	Integrated components that provide a representation of a system/ subsystem and that can be used to determine concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble final system/subsystem in function only.
High Fidelity	Addresses form, fit, and function. A high-fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting.
Low Fidelity	A representative of the component or system that has limited ability to provide anything but first-order information about the end product. Low-fidelity assessments are used to provide trend analysis.
Model	A functional form of a system, generally reduced in scale, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.
Operational Environment	Environment that addresses all the operational requirements and specifications required of the final system to include platform/ packaging.
Prototype	A physical or virtual model used to evaluate the technical or manufacturing feasibility or military utility of a particular technology or process, concept, end item, or system.
Relevant Environment	Testing environment that simulates the key aspects of the operational environment.
Simulated Operational Environment	Either (1) a real environment that can simulate all the operational requirements and specifications required of the final system or (2) a simulated environment that allows for testing of a virtual prototype. Used in either case to determine whether a developmental system meets the operational requirements and specifications of the final system.

The primary purpose of using the above Technology Readiness Level definitions (Levels 1 through 9) is to help management in making decisions concerning the development and maturation of technology to ensure it can perform its intended mission. Advantages include:

- Provides a common standard for systematically measuring and communicating the readiness of new technologies or new applications of existing technologies at a given point in time in the project life cycle.

- Provides a measure of risk as a management tool. The gap between the maturity of the technology and the project requirements represents the risks or unknowns about the technology.

- Assist in making decisions concerning technology funding.

- Assist in making decisions concerning transition of technology.

- Assist in selecting the best technology alternative.

4.1 Supporting Documentation for the Technology Readiness Levels Assessments

Table 7 lists typical generic documentation (not all inclusive and varies by technology application and program) that should be extracted or referenced to support a TRL assignment.

Table 7. Hardware TRL Definitions, Descriptions and Supporting Information
(Source: *Defense Acquisition Guidebook*)

TRL	Definition	Description	Supporting Information
1	Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.	Published research that identifies the principles that underlie this technology. References to who, where, when.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.	Publications or other references that outline the application being considered and that provide analysis to support the concept.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active R&D is initiated. This includes analytical studies and laboratory studies to validate physically the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.
4	Component and/or breadboard validation in a laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.	System concepts that have been considered and results from testing laboratory-scale breadboard(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.
5	Component and/or breadboard validation in a relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.	Results from testing a laboratory breadboard system are integrated with other supporting elements in a simulated operational environment. How does the "relevant environment" differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?

Table 7. Hardware TRL Definitions, Descriptions and Supporting Information (continued)

TRL	Definition	Description	Supporting Information
6	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
7	System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space). Examples include testing the prototype in a test bed aircraft.	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before finalizing the design?
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.	OT&E reports.

4.2 CTEs Assessments for Maturity (Technology Readiness Level)

The evaluation process should include the following steps for all CTEs (Reference: DoD Technology Readiness Assessment Deskbook, July 2009):

- Describe the technology (subsystem, component, or technology). Describe the function it performs and, if needed, how it relates to other parts of the system. Provide a synopsis of development history and status. This can include facts about related uses of the same or similar technology, numbers or hours of testing of breadboards, numbers of prototypes built and tested, relevance of the test conditions, and results achieved.

- Describe the environment in which the technology has been demonstrated. Provide a brief analysis of the similarities between the demonstrated environment and the intended operational environment.

- Apply the criteria for TRLs and assign a readiness level to the technology. State the readiness level (e.g., TRL 5) and the rationale for choosing this readiness level.

- Provide references to papers, presentations, data, and facts that support the assessment. Includes data tables and graphs that illustrate that a key fact is appropriate.

- If the CTEs are presented in categories (e.g., super-conducting magnets, detectors or sensors), the information specified in the previous bullets (e.g., describing the technology, describing the function it performs, and so forth) should be provided for each CTE within a category.

- State the review team's position concerning the maturity (technology readiness level) of the CTEs and whether this maturity is adequate for the system to enter the next stage of development. If the position supports entering the next stage even though some CTEs are less mature than would ordinarily be expected, explain what circumstances or planned work justifies this position. Include references to a separately submitted Technology Maturation Plan (see section 5.0) for each immature CTE.

4.3 Technology Readiness Level Calculator

The TRL Calculator is a tool developed by the US Air Force Research Laboratory for applying TRLs for technology development programs (Reference: Nolte, William L., et al., "*Technology Readiness Level Calculator,"* October 20, 2003, Air Force Research Laboratory (AFRL), presented at the NDIA System Engineering Conference). In its present form, the calculator is a Microsoft Excel spreadsheet application that allows the user to answer a series of questions about a technology project. Once the questions have been answered, the calculator displays the TRL achieved. Because the same set of questions is answered each time the calculator is used, the calculator provides a standardized, repeatable process for evaluating the maturity of any hardware or software technology under development. In this way, the TRL Calculator is one tool that can serve to answer the question of how one can measure TRLs for CTEs using a standardized method.

The present version of the calculator is limited to values of TRLs corresponding to TRL 6 or lower. This is because, in the Air Force Research Laboratory, the stated objective of a technology development program is to mature the technology to TRL 6. While it is certainly possible to mature a given technology beyond that level, there are no purely programmatic activities that take place within the laboratory beyond TRL 6. Because the calculator was initially created for use in the laboratory, a TRL 6 was deemed sufficient. Extending the TRL concept to a level corresponding to TRL 9 is the subject of future work by the original developers of the tool. (A copy of the latest version of the US Air Force's TRL Calculator can be obtained directly for William Nolte at the AFRL.)

A modified version of the DoD TRL Calculator has been used extensively during the conduct of DOE-EM TRAs and is included in Appendix F as an example of a tailored version. DOE programs should adapt/modify the suggested calculator to their particular technologies and processes. The TRL Calculator herein is used in a two step process. First, a set of top-level questions (Table F1 of Appendix F) is used to determine the anticipated TRL. The anticipated TRL is determined from the question with the first "yes" answer. Second, evaluation of the detailed questions (Tables F2 through F7 of Appendix F) is started one level below the anticipated TRL. To attain a specific TRL, the CTE should receive a "yes" response to all questions at the TRL level from which the questions are found. If it is determined from the detailed questions that the technology has not attained the maturity of the starting level, then the next levels down are evaluated in turn until all of the questions for a specific TRL are answered "yes". The TRL is defined by the level from which all questions are answered affirmatively. However, it is recognized that a negative response to one single question for the TRL under evaluation might not be indicative of the relative importance of the particular item to the success of the technology. In this instance a graded approach could be appropriate during the evaluation and justified when assigning the highest TRL number achieved for the technology. TRL calculators are expected to evolve over time based upon lessons learned from previous versions of calculators used by the programs.

TRLs are documented within the TRA Report. As a minimum, the TRL should be expressed numerically and described in text. Additionally, the basis for the TRL determination should be clearly and concisely documented. DOE/EM has found that completing the forms found in Appendix F for all CTEs serves to document the basis for the TRL decision.

4.4 TRA Report

The purpose of the TRA Report is to document the description of the process used to conduct the TRA and provide a comprehensive explanation of the assessed TRL for each CTE. While the Appendix F forms document the answers to the questions, the basis for these answers is what the report should focus on. The report should provide citation to and summary descriptions of the salient aspects of the reference documents which serve the basis for the answers documented in the forms.

The TRA review team leader is responsible for coordinating the report preparation with detailed input from the review team members (see DOE G 413.3-9 for the protocol to conduct project reviews of which TRA reviews is one under the category of Technical IPRs; Appendix D is the suggested template for a TRA Review Plan). See Appendix G for the suggested format of the report. As a minimum, completion of the TRA should provide:

- A comprehensive review, using an established program/project Work Breakdown Structure or flow diagram as an outline, of the entire platform or system. This review, using a conceptual or established baseline design configuration, identifies CTEs.
- An objective scoring of the level of technology maturity for each CTE by subject matter experts.
- Results should assist the Integrated Project Team in preparing maturation plans for achieving an acceptable maturity roadmap for CTEs prior to critical milestones decision dates.
- A final report documenting the findings of the assessment review team.
- Continuous improvement is an important part of an evolving TRA process and as such lessons learned that benefit future TRAs and/or technology development projects should be identified during the conduct of the TRA. These lessons learned should be documented within the TRA Report or they may be documented in a separate document. In the case of a separate lessons learned document, the TRA report should be referenced within the document and the document should be filed with the TRA Report.

A TRA team should plan to reference relevant portions of the project's report in developing its own report.

5.0 Technology Maturation Plan

5.1 Process Overview

The purpose of the TMP is to describe planned technology development and engineering activities to mature CTEs that did not receive at least TRL 6 or higher. This threshold should be a DOE Program level option tailored to their specific technologies, as required and appropriate. TRL 6 is the recommended standard for advancing from the conceptual design phase to the design finalization phase due to the vast amount of industry, DoD and NASA experience that shows that unless a technology has been advanced to this level of maturity at the time of CD- 2 (project baseline) approval, the potential for baseline performance deviations is so great and the later corrective actions so disruptive and costly to the project that proper project management control cannot be expected to be successful at bringing the project to completion within the originally approved technical, cost and schedule baselines. DOE-EM has adopted a level 6 during their most recent TRAs in their effort to reduce the probability of cost and schedule overruns due to immature CTEs.

The program/project should be beginning the development of its TMP subsequent to the approval of the project's mission need at CD-0. As a result of conducting a TRA, the project may be required to revise its TMP in order to address and remedy TRL deficiencies noted in a TRA report. TRA induced changes to TMPs can be likened to a corrective action plan in that the changes to the TMP are prepared by the project and describes the additional or corrective actions for those CTEs that did not mature as the project had intended [because they did not received the desired TRL by the time the associated critical decision was reached (i.e., for example CD-1, TRL=4; CD-2, TRL=6)].

5.2 TMP Preparation

The suggested major steps in preparing a TMP are summarized below (each DOE Program Office should develop its own protocol for concurrences and approvals of this documentation):

- The Project Manager/Contractor prepares the draft TMP. The suggested format and contents of the document are provided below and in Appendix H.
- At CD-0 and thereafter as appropriate, the Project Manager for the project provides the draft report to the Federal Project Director and the DOE Program Office for review and approval. To expedite the schedule, these reviews are often accomplished in parallel.
- If the project is modifying a TMP in response to a TRA, after approval by the program/project, the TMP is provided to the TRA review team for review. The review verifies (1) responsiveness to gaps identified in the draft TRA, (2) reasonableness of the proposed approach, and (3) reasonableness of the proposed schedule and costs associated with technology maturation requirements.

Note: The Project Manager should have updated a TMP prior to the TRA review team visit, anticipating the necessary changes based on the project's own internal program reviews of its technology maturation status.

- As applicable, the Project Manager resolves the review comments, revises the TMP, and forwards the revised TMP to the Federal Project Director.
- The Federal Project Director approves the final TMP.
- The Federal Project Director incorporates the impact of changes in the project's TMP into the project risk management plan.

As described in Appendix H, the TMP revision should summarize any previous TIPRs, other technical assessments, and any previous TRAs that may have contributed to the need for the revision of the document. This summary should include the TRLs for each CTE as documented in the latest TRA. Previous technology development activities that brought the technology to its current state of readiness should be described. Also, ongoing technology development should be included because progress and completion of this ongoing work will influence the interfaces and schedule for the TMP. The TMP should describe the approach used in defining the additional required technology development activities that will be conducted. Approaches may include evaluating incomplete criteria in the TRL calculator, risk assessments, and value engineering.

In preparing the TMP for relatively mature technologies, TRA results should be evaluated using a risk evaluation and value engineering approach. Figure 5 provides a diagram of the technology maturation planning process. An identified technology readiness issue (or technology need) is evaluated using the system engineering functions and requirement analysis. Then, a first order of risk evaluation is conducted to determine whether the current path can be followed with negligible risk or if alternatives (current path with modifications or a new system) should be pursued. A more detailed, second order risk evaluation is conducted to determine if the modifications or new system alternatives have sufficient payoff to be incorporated into the TMP.

In describing the required technology development activities, specific maturation plans should be prepared for each CTE assessed at less than TRL 6 (threshold option for the DOE Program Office to decide). The plan for each CTE should include:

- Key Technology Addressed
- Objective
- Current State of the Art
- Technology Development Approach
- Scope
- Schedule
- Budget

The high-level schedule and budget (including the total maturation costs) that incorporate the major technology development activities for each CTE should be provided. Any major decision points such as proceeding with versus abandoning the current technology or selection of a backup technology should be included in the schedule. More detailed schedules will be prepared for executing and managing the work.

5.3 TMP Execution

After the TMP is approved, the Contractor will prepare or modify detailed test plans to conduct the technology development activities described in the TMP. These test plans will define the test objectives, relevant environment, the scale of the planned tests, and performance targets (or success criteria) for the tests. Then, more detailed cost and schedule estimates will be prepared by the Contractor to support preparation of a Baseline Change Proposal (BCP), if required. The BCPs will be approved in accordance with the approved Project Execution Plan or as directed by the DOE Program Office when outside the project scope.

The Contractor may conduct the technology development in house or work with DOE to select a technology developer by open procurements to industry, identification of national laboratories with appropriate expertise, etc. Schedule status will be maintained by the contractor based on periodic updates from the technology development performer. Any significant changes in scope and schedule will require formal change control by the contractor and the DOE organization providing the funding through the assigned DOE Contracting Officer.

Technical reports will be written as major technology development tasks are completed. A Final Technical Report will be prepared when all of the technology development tasks in the TMP have been completed as required by the TRL 6 criteria, or higher, as it may apply.

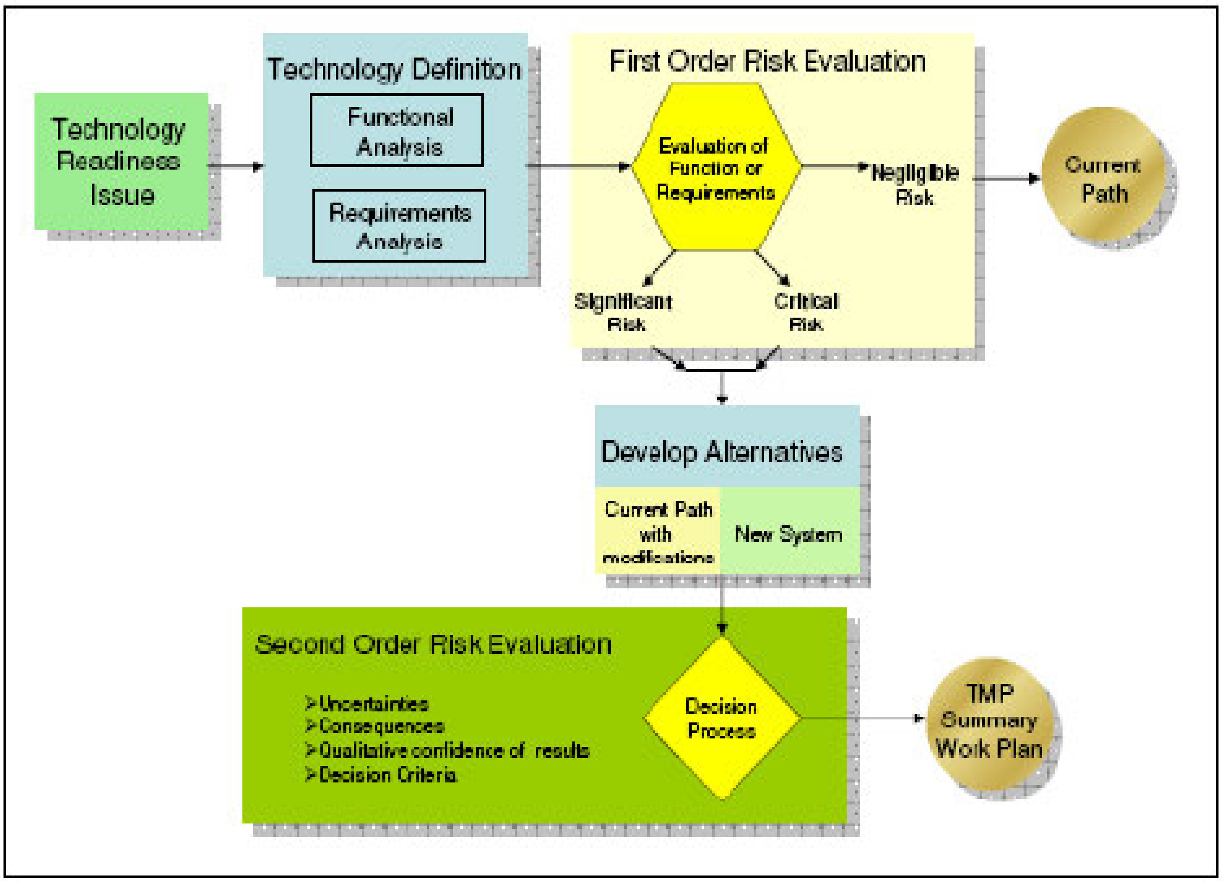


Figure 5. Technology Maturation Planning Process

APPENDIX A: GLOSSARY

1. Acquisition Executive. The individual designated by the Secretary of Energy to integrate and unify the management system for a program portfolio of projects and implement prescribed policies and practices.

2. Breadboard. Integrated components that provide a representation of a system/subsystem and that can be used to determine concept feasibility and to develop technical data. Typically it is configured for laboratory use to demonstrate the technical principles of immediate interest. It may resemble the final system/subsystem in function only.

3. Critical Technology Element (CTE). A technology element is "critical" if the system being acquired depends on the technology element to meet operational requirements (with acceptable development, cost and schedule; and with acceptable production and operations costs) and if the technology element or its application is either new or novel.

4. External Independent Review. A project review performed by personnel from OECM and augmented by individuals outside DOE, primarily to support validation of either the Performance Baseline (CD-2) or Construction/Execution Readiness (CD-3). OECM selects an appropriate group of subject matter experts in a contracted capacity to assist with these reviews.

5. High Fidelity. A representative of the component or system that addresses form, fit and function. A high-fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specification within a laboratory setting.

6. Independent Cost Estimate. A cost estimate, prepared by an organization independent of the project sponsor, using the same detailed technical and procurement information to make the project estimate. It is used to validate the project estimate to determine whether it is accurate and reasonable.

7. Independent Cost Review. An independent evaluation of a project's cost estimate that examines its quality and accuracy, with emphasis on specific cost and technical risks. It involves the analysis of the existing estimate's approach and assumptions.

8. Independent Project Review. A project management tool that serves to verify the project's mission, organization, development, processes, technical requirements, baselines, progress and/or readiness to proceed to the next successive phase in DOE's Acquisition Management System.

9. Key Performance Parameter (KPP). A vital characteristic, function, requirement or design basis, that if changed, would have a major impact on the facility or system performance, scope, schedule, cost and/or risk, or the ability of an interfacing project to meet its mission requirements. A parameter may be a performance, design, or interface requirement. Appropriate parameters are those that express performance in terms of

accuracy, capacity, throughput, quantity, processing rate, purity, reliability, sustainability, or others that define how well a system, facility or other project will perform. In aggregate, KPPs comprise the scope of the project.

10. Low Fidelity. A representative of the component or system that has limited ability to provide anything but first-order information about the end product. Low fidelity assessments are used to provide trend analysis.

11. Operational Environment. Environment that addresses all the operational requirements and specifications required of the final system to include platform/packaging.

12. Project Definition Rating Index. This is a project management tool which is used for assessing how well the project scope is defined. The tool uses a numeric assessment which rates a wide range of project elements to determine how well the project is defined.

13. Relevant Environment. Testing environment that simulates the key aspects of the operational environment; such as physical and chemical properties.

14. Simulated Operational Environment. Either (1) a real environment that can simulate all the operational requirements and specifications required of the final system or (2) a simulated environment that allows for testing of a virtual prototype. Used in either case to determine whether a developmental system meets the operational requirements and specifications of the final system.

15. Technical Independent Project Review. An independent project review conducted prior to obtaining CD-2 for Hazard Category 1, 2, and 3 nuclear facilities. At a minimum, the focus of this review is to determine that the safety documentation is sufficiently conservative and bounding to be relied upon for the next phase of the project.

16. Technology Maturation Plan. A TMP details the steps necessary for developing technologies that are less mature than desired to the point where they are ready for project insertion.

17. Technology Readiness Assessment. An assessment of how far technology development has proceeded. It provides a snapshot in time of the maturity of technologies and their readiness for insertion into the project design and execution schedule.

18. Technology Readiness Level. A metric used for describing technology maturity. It is a measure used by many U.S. government agencies to assess maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating that technology into a system or subsystem.

19. Technology Readiness Level Calculator. A tool developed by the U.S. Air Force Research Laboratory for applying TRLs to technology development programs. In its present stage of development, the calculator is a Microsoft Excel spreadsheet application that allows the user to answer a series of questions about a technology project. Once the questions have been answered, the calculator displays the TRL achieved.

APPENDIX B: ACRONYMS

AE	Acquisition Executive
CD	Critical Decision
CDR	Conceptual Design Report
CFR	Code of Federal Regulations
CO	Contracting Officer
CY	Calendar Year
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
CTE	Critical Technology Element
EIR	External Independent Review
EIS	Environmental Impact Statement
EM	Environmental Management
EPA	U.S. Environmental Protection Agency
ESAAB	Energy Systems Acquisition Advisory Board
EVMS	Earned Value Management System
FAR	Federal Acquisition Regulations
FONSI	Finding of No Significant Impact
FPD	Federal Project Director
FY	Fiscal Year
GAO	Government Accountability Office
GPRA	Government Performance and Results Act
HA	Hazard Assessment
ICE	Independent Cost Estimate
ICR	Independent Cost Review
IMS	Integrated Master Schedule
IOC	Initial Operating Capability
IPR	Independent Project Review
IPS	Integrated Project Schedule
IPT	Integrated Project Team
ICE	Independent Cost Estimate
IPR	Independent Project Review
ISM	Integration Safety Management
ISMS	Integrated Safety Management System

ISO	International Standards Organization
IT	Information Technology
KPP	Key Performance Parameter
MNS	Mission Need Statement
MS	Major System Project
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NNSA	National Nuclear Security Administration
NQA-1	Nuclear Quality Assurance Standard – 1 (ANSI/ASME standard)
NRC	National Research Council
OBS	Organizational Breakdown Structure
OECM	Office of Engineering and Construction Management
OMB	Office of Management and Budget
OPC	Other Project Costs
ORR	Operational Readiness Review
OSHA	Occupational Safety and Health Administration
PARS	Project Assessment and Reporting System
PB	Performance Baseline
PBC	Performance-Based Contract
PBS	Performance Baseline Summary
PDS	Project Data Sheet
PED	Project Engineering and Design
PEP	Project Execution Plan
PM	Program Manager
PMB	Performance Measurement Baseline
PPBES	Planning, Programming, Budgeting and Execution System
PSO	Program Secretarial Office
PMSO	Project Management Support Office
QA	Quality Assurance
QAP	Quality Assurance Plan
QAPP	Quality Assurance Program Plan
QC	Quality Control
RAMI	Reliability, Accessibility, Maintainability, Inspectability
RCRA	Resource Conservation and Recovery Act

RD	Requirements Document
RFP	Request for Proposal
RLS	Resource Loaded Schedule
SAE	Secretarial Acquisition Executive
TEC	Total Estimated Cost (Capital)
TIPR	Technical Independent Project Review
TPC	Total Project Cost
TRA	Technology Readiness Assessment
TMP	Technology Maturation Plan
TRL	Technology Readiness Level
VM	Value Management
WBS	Work Breakdown Structure
WA	Work Authorization

APPENDIX C: REFERENCES

10 CFR 830, Subpart A, Quality Assurance Requirements.

10 CFR 830, Subpart B, Safety Basis Requirements.

10 CFR 830.206, Preliminary Documented Safety Analysis.

29 CFR 1910.119, Process Safety Management of Highly Hazardous Chemicals.

48 CFR 970.5223-1, Integration of Environment. Safety, and Health into Work Planning and Execution.

DOE O 205.1B, *Department of Energy Cyber Security Program*, dated 5-16-11.

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DOE O 414.1D, *Quality Assurance*, dated 4-25-11.

DOE O 420.1B, *Facility Safety*, dated 12-22-05.

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DOE O 451.1B Chg 2, *National Environmental Policy Act Compliance Program*, dated 6-25-10.

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DOE, Office of Environmental Management, *Project Definition Rating Index (EM-PDRI) Manual*, Revision 1, dated February 2001.

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DOE, Office of River Protection, Richland, Washington, Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Analytical Laboratory, Balance of Facilities and LAW Waste Vitrification Facilities, dated March 2007.

DOE, Office of Science, *Independent Review Handbook*, dated May 2007.

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NNSA, Office of Project Management and System Support, *Project Definition Rating Index (PDRI) Manual*, Revision 0, dated June 2008.

Nolte, William L., et al., *Technology Readiness Level Calculator, Air Force Research Laboratory, presented at the National Defense Industrial Association Systems Engineering Conference*, October 20, 2003

APPENDIX D: TEMPLATE FOR A TECHNOLOGY READINESS ASSESSMENT (TRA) REVIEW PLAN

1.0 INTRODUCTION

Briefly state who requested the TRA, what organization is responsible for conducting the TRA, and what technology is to be assessed. State where the technology is being developed (i.e., facility, site).

2.0 PURPOSE

Briefly state the objective of the TRA. Specifically, state how the customer will use the results from the TRA. Additionally, state any other drivers for conduct of the TRA (e.g., Critical Decision milestone support, technology downselect support).

3.0 TECHNOLOGY BACKGROUND

Provide a general description of the technology and the project supported by the technology. The description should include details regarding the function that the technology accomplishes for the project and a brief summary of status of the technology development. Additionally, summarize the results of any previous TRAs conducted on the technology.

4.0 TRA TEAM

Include a table that lists the position, title, name and area of expertise of each TRA Team Member

Position	*Title*	*Company*	*Name*	*Area of Expertise*
Team Leader	*Person 1 Title*	*Person 1 company*	*Person 1 name*	*Person 1 expertise*
Team Member	*Person 2 Title*	*Person 2 company*	*Person 2 name*	*Person 2 expertise*
Team Member	*Person 3 Title*	*Person 3 company*	*Person 3 name*	*Person 3 expertise*
Team Member	*Person 4 Title*	*Person 4 company*	*Person 4 name*	*Person 4 expertise*

5.0 TRA ESTIMATED SCHEDULE *(conservative Projected Durations which may vary by project complexity)*

Task Number	Projected Duration	Task Description
1	6 weeks	Establish TRA Team
2	4 weeks	Distribute critical documents to Team
3	4 weeks	Conduct onsite assessment activities
4	4 weeks	Draft TRA Report
5	4 weeks	Issue Final Report

6.0 TRA ESTIMATED COST

Provide an estimate of the total man-hours and associated cost for conduct of the TRA. Additionally, state the organization responsible for funding the TRA.

7.0 DEFINITIONS

8.0 REFERENCES

Appendices

APPENDIX E: TEMPLATE FOR THE IDENTIFICATION OF CRITICAL TECHNOLOGY ELEMENTS (CTEs)

A CTE is identified if there is at least one positive response for each set of criteria

Set 1 - Criteria	Yes	No
1. Does the technology directly impact a functional requirement of the process or facility?		
2. Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?		
3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?		
4. Do limitations in the understanding of the technology impact the safety of the design?		
5. Are there uncertainties in the definition of the end state requirements for this technology?		

Set 2 - Criteria	Yes	No
1. Is the technology new or novel?		
2. Is the technology modified?		
3. Have the potential hazards of the technology been assessed?		
4. Has the technology been repackaged so a new relevant environment is realized?		
5. Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?		

Appendix F: Template Examples for the TRL Assessment Calculator as Modified for DOE-EM

Note: The process/mechanics to follow with the use of the calculator are found in the reference: Nolte, William L., et al., "Technology Readiness Level Calculator," October 20, 2003, Air Force Research Laboratory (AFRL), presented at the NDIA System Engineering Conference. Tables F-2 – F-7 were primarily based on an EM waste processing facility. DOE programs should modify the tables to fit program needs and/or updated.

Table F-1. Top Level Questions for Determining Anticipated TRL

Top-Level Question		Yes/No	If Yes, Then Basis and Supporting Documentation
TRL 9	Has the actual equipment/process successfully operated in the full operational environment (hot operations)?		
TRL 8	Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?		
TRL 7	Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?		
TRL 6	Has prototypical engineering scale equipment/process testing been demonstrated in a relevant environment; to include testing of the safety function?		
TRL 5	Has bench-scale equipment/process testing been demonstrated in a relevant environment?		
TRL 4	Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?		
TRL 3	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?		
TRL 2	Has an equipment and process concept been formulated?		
TRL 1	Have the basic process technology process principles been observed and reported?		

Note: All TRLs should include compliance with DOE-STD-1189-2008. Testing and validation of safety functions in the relevant environment for the critical technology element is part of the TRA to include worker and public safety considerations.

Table F-2. TRL 1 Questions for Critical Technical Element

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. "Back of envelope" environment.	
T		2. Physical laws and assumptions used in new technologies defined.	
T		3. Paper studies confirm basic principles.	
P		4. Initial scientific observations reported in journals/conference proceedings/technical reports.	
T		5. Basic scientific principles observed and understood.	
P		6. Know who cares about the technology, e.g., sponsor, funding source, safety and hazardous materials handling (DOE-STD-1189-2008 compliance), etc.	
T		7. Research hypothesis formulated.	
T		8. Basic characterization data exists.	
P		9. Know who would perform research and where it would be done.	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table F-3. TRL 2 Questions for Critical Technical Elements

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
P		1. Customer identified.	
T		2. Potential system or components have been identified.	
T		3. Paper studies show that application is feasible; to include compliance with DOE-STD-1189-2008.	
P		4. Know what program the technology would support.	
T		5. An apparent theoretical or empirical design solution identified.	
T		6. Basic elements of technology have been identified.	
T		7. Desktop environment (paper studies).	
T		8. Components of technology have been partially characterized.	
T		9. Performance predictions made for each element.	
P		10. Customer expresses interest in the application.	
T		11. Initial analysis shows what major functions need to be done.	
T		12. Modeling & Simulation only used to verify physical principles.	
P		13. System architecture defined in terms of major functions to be performed.	
T		14. Rigorous analytical studies confirm basic principles.	
P		15. Analytical studies reported in scientific journals/conference proceedings/technical reports.	
T		16. Individual parts of the technology work (No real attempt at integration).	
T		17. Know what output devices are available.	
P		18. Preliminary strategy to obtain TRL Level 6 developed (e.g., scope, schedule, cost); to include compliance with DOE-STD-1189-2008.	
P		19. Know capabilities and limitations of researchers and research facilities.	
T		20. The scope and scale of the waste problem has been determined.	
T		21. Know what experiments are required (research approach).	
P		22. Qualitative idea of risk areas (cost, schedule, performance).	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table F-4. TRL 3 Questions for Critical Technical Elements

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. Academic (basic science) environment.	
P		2. Some key process and safety requirements are identified; to include compliance with DOE-STD-1189-2008.	
T		3. Predictions of elements of technology capability validated by analytical studies.	
P		4. The basic science has been validated at the laboratory scale.	
T		5. Science known to extent that mathematical and/or computer models and simulations are possible.	
P		6. Preliminary system performance characteristics and measures have been identified and estimated.	
T		7. Predictions of elements of technology capability validated by Modeling and Simulation (M&S).	
M		8. No system components, just basic laboratory research equipment to verify physical principles.	
T		9. Laboratory experiments verify feasibility of application.	
T		10. Predictions of elements of technology capability validated by laboratory experiments.	
P		11. Customer representative identified to work with development team.	
P		12. Customer participates in requirements generation.	
P		13. Requirements tracking system defined to manage requirements creep.	
T		14. Key process parameters/variables and associated hazards have begun to be identified; to include compliance with DOE-STD-1189-2008.	
M		15. Design techniques have been identified/developed.	
T		16. Paper studies indicate that system components ought to work together.	
P		17. Customer identifies technology need date.	
T		18. Performance metrics for the system are established (What must it do).	
P		19. Scaling studies have been started.	
M		20. Current manufacturability concepts assessed.	

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
M		21. Sources of key components for laboratory testing identified.	
T		22. Scientific feasibility fully demonstrated.	
T		23. Analysis of present state of the art shows that technology fills a need.	
P		24. Risk areas identified in general terms.	
P		25. Risk mitigation strategies identified.	
P		26. Rudimentary best value analysis performed for operations.	
T		27. Key physical and chemical properties have been characterized for a number of waste samples.	
T		28. A simulant has been developed that approximates key waste properties.	
T		29. Laboratory scale tests on a simulant have been completed.	
T		30. Specific waste(s) and waste site(s) has (have) been defined.	
T		31. The individual system components have been tested at the laboratory scale.	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table F-5. TRL 4 Questions for Critical Technical Elements

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. Key process variables/parameters been fully identified and preliminary hazard evaluations have been completed and documented to include compliance with DOE-STD-1189-2008.	
M		2. Laboratory components tested are surrogates for system components.	
T		3. Individual components tested in laboratory~~/~~ or by supplier.	
T		4. Subsystems composed of multiple components tested at lab scale using simulants.	
T		5. Modeling & Simulation used to simulate some components and interfaces between components.	
P		6. Overall system requirements for end user's application are known.	
T		7. Overall system requirements for end user's application are documented.	
P		8. System performance metrics measuring requirements have been established.	
P		9. Laboratory testing requirements derived from system requirements are established.	
M		10. Available components assembled into laboratory scale system.	
T		11. Laboratory experiments with available components show that they work together.	
T		12. Analysis completed to establish component compatibility (Do components work together).	
P		13. Science and Technology Demonstration exit criteria established (S&T targets understood, documented, and agreed to by sponsor).	
T		14. Technology demonstrates basic functionality in simulated environment; to include test and validation of safety functions.	
M		15. Scalable technology prototypes have been produced (Can components be made bigger than lab scale).	
P		16. The conceptual design has been documented (system description, process flow diagrams, general	

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
		arrangement drawings, and material balance).	
M		17. Equipment scale-up relationships are understood/accounted for in technology development program.	
T		18. Controlled laboratory environment used in testing.	
P		19. Initial cost drivers identified.	
M		20. Integration studies have been started.	
P		21. Formal risk management program initiated.	
M		22. Key manufacturing processes for equipment systems identified.	
P		23. Scaling documents and designs of technology have been completed.	
M		24. Key manufacturing processes assessed in laboratory.	
P/T		25. Functional process description developed. (Systems/subsystems identified).	
T		26. Low fidelity technology "system" integration and engineering completed in a lab environment.	
M		27. Mitigation strategies identified to address manufacturability/ producibility shortfalls.	
T		28. Key physical and chemical properties have been characterized for a range of wastes.	
T		29. A limited number of simulants have been developed that approximate the range of waste properties.	
T		30. Laboratory-scale tests on a limited range of simulants and real waste have been completed.	
T		31. Process/parameter limits and safety control strategies are being explored.	
T		32. Test plan documents for prototypical lab- scale tests completed.	
P		33. Technology availability dates established.	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table F-6. TRL 5 Questions for Critical Technical Elements

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. The relationships between major system and sub-system parameters are understood on a laboratory scale.	
T		2. Plant size components available for testing.	
T		3. System interface requirements known (How would system be integrated into the plant?).	
P		4. Preliminary design engineering begins.	
T		5. Requirements for technology verification established; to include testing and validation of safety functions.	
T		6. Interfaces between components/ subsystems in testing are realistic (bench top with realistic interfaces).	
M		7. Prototypes of equipment system components have been created (know how to make equipment).	
M		8. Tooling and machines demonstrated in lab for new manufacturing processes to make component.	
T		9. High fidelity lab integration of system completed, ready for test in relevant environments; to include testing and validation of safety functions.	
M		10. Manufacturing techniques have been defined to the point where largest problems defined.	
T		11. Lab-scale, similar system tested with range of simulants.	
T		12. Fidelity of system mock-up improves from laboratory to bench-scale testing.	
M		13. Availability and reliability (RAMI) target levels identified.	
M		14. Some special purpose components combined with available laboratory components for testing.	
P		15. Three dimensional drawings and P&IDs for the prototypical engineering-scale test facility have been prepared.	
T		16. Laboratory environment for testing modified to approximate operational environment; to include testing and	

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
		validation of safety functions.	
T		17. Component integration issues and requirements identified.	
P		18. Detailed design drawings have been completed to support specification of engineering-scale testing system.	
T		19. Requirements definition with performance thresholds and objectives established for final plant design.	
P		20. Preliminary technology feasibility engineering report completed; to include compliance with DOE-STD-1189-2008.	
T		21. Integration of modules/functions demonstrated in a laboratory/bench-scale environment.	
T		22. Formal control of all components to be used in final prototypical test system.	
P		23. Configuration management plan in place.	
T		24. The range of all relevant physical and chemical properties has been determined (to the extent possible).	
T		25. Simulants have been developed that cover the full range of waste properties.	
T		26. Testing has verified that the properties/performance of the simulants match the properties/performance of the actual wastes.	
T		27. Laboratory-scale tests on the full range of simulants using a prototypical system have been completed.	
T		28. Laboratory-scale tests on a limited range of real wastes using a prototypical system have been completed.	
T		29. Test results for simulants and real waste are consistent.	
T		30. Laboratory to engineering scale scale-up issues are understood and resolved; to include testing and validation of safety functions.	

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		31. Limits for all process variables/parameters and safety controls are being refined.	
P		32. Test plan for prototypical lab-scale tests executed – results validate design; to include testing and validation of safety functions.	
P		33. Test plan documents for prototypical engineering-scale tests completed.	
P		34. Finalization of hazardous material forms and inventories, completion of process hazard analysis, and identification of system/components level safety controls at the appropriate preliminary design phase.	
P		35. Risk management plan documented; to include compliance with DOE-STD-1189-2008.	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

Table F-7. TRL 6 Questions for Critical Technical Elements

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
T		1. The relationships between system and sub-system parameters are understood at engineering scale allowing process/design variations and tradeoffs to be evaluated.	
M		2. Availability and reliability (RAMI) levels established.	
P		3. Preliminary design drawings for final plant system are complete; to include compliance with DOE-STD-1189-2008.	
T		4. Operating environment for final system known.	
P		5. Collection of actual maintainability, reliability, and supportability data has been started.	
P		6. Performance Baseline (including total project cost, schedule, and scope) has been completed.	
T		7. Operating limits for components determined (from design, safety and environmental compliance).	
P		8. Operational requirements document available; to include compliance with DOE-STD-1189-2008.	
P		9. Off-normal operating responses determined for engineering scale system.	
T		10. System technical interfaces defined.	
T		11. Component integration demonstrated at an engineering scale.	
P		12. Scaling issues that remain are identified and understood. Supporting analysis is complete.	
P		13. Analysis of project timing ensures technology will be available when required.	
P		14. Have established an interface control process.	
P		15. Acquisition program milestones established for start of final design (CD-2).	
M		16. Critical manufacturing processes prototyped.	
M		17. Most pre-production hardware is available to support fabrication of the system.	
T		18. Engineering feasibility fully demonstrated (e.g., would it work).	
M		19. Materials, process, design, and integration methods have been employed (e.g., can design be produced?).	

T/P/M	Y/N	Criteria	Basis and Supporting Documentation
P		20. Technology "system" design specification complete and ready for detailed design.	
M		21. Components are functionally compatible with operational system.	
T		22. Engineering-scale system is high-fidelity functional prototype of operational system.	
P		23. Formal configuration management program defined to control change process.	
M		24. Integration demonstrations have been completed (e.g. construction of testing system); to include testing and validation of safety functions.	
P		25. Final Technical Report on Technology completed; to include compliance with DOE-STD-1189-2008.	
P		26. Finalization of hazardous material forms and inventories; completion of process hazard analysis, identification of system/components level safety controls at the appropriate preliminary/final design phase.	
M		27. Process and tooling are mature to support fabrication of components/system	
T		28. Engineering-scale tests on the full range of simulants using a prototypical system have been completed.	
T		29. Engineering to full-scale scale-up issues are understood and resolved.	
T		30. Laboratory and engineering-scale experiments are consistent.	
T		31. Limits for all process variables/parameters and safety controls are defined.	
T		32. Plan for engineering-scale testing executed - results validate design.	
M		33. Production demonstrations are complete (at least one time).	

T-Technology, technical aspects; M-Manufacturing and quality; P-Programmatic, customer focus, documentation

APPENDIX G: TEMPLATE FOR A TRA REPORT

REPORT CONTENT:

EXECUTIVE SUMMARY

Briefly state who requested the TRA, what organization was responsible for conducting the TRA, what technology was assessed? Provide a summary table of the CTEs and corresponding TRLs determined during the review.

INTRODUCTION

Technology Reviewed

Provide a detailed description of the technology that was assessed.

TRA Process

Provide an overview of the approach used to conduct the TRA. Reference applicable planning documents.

RESULTS

Provide the following for each CTE assessed:

- ***Function***
  Describe the CTE and its function.
- ***Relationship to Other Systems***
  Describe how the CTE interfaces with other systems.
- ***Development History and Status***
  Summarize pertinent development activities that have occurred to date on the CTE.
- ***Relevant Environment***
  Describe relevant parameters inherent to the CTE or the function it performs.
- ***Comparison of the Relevant Environment and the Demonstrated Environment***
  Describe differences and similarities between the environment in which the CTE has been tested and the intended environment when fully operational.
- ***Technology Readiness Level Determination***
  State the TRL determined for the CTE and provide the basis justification for the TRL.
- ***Estimated Cost/Schedule***
  State the estimated cost and time requirements, with associate uncertainties, and programmatic risks associated with maturing each technology to the required readiness level.

ATTACHMENTS

Include the following planning documents:

- *TRA Plan*
- *Supporting documentation for identification of CTEs*
- *Completed tables:*

- *Top Level Questions for Determining Anticipated TRL (Appendix F, Table F-1)*
- *TRL Questions for CTE (Appendix F, Tables F-2 through F-7)*

- *List of support documentation for TRL determination*
- *TRL Summary table*
- *Lessons Learned*
- *Team biographies*

Appendix H: Template Guide for a Technology Maturation Plan

(Note: The TMP is a high level summary document. It is not a collection of detailed test plans.)

TABLE OF CONTENTS
LIST OF TABLES
LIST OF FIGURES
ABBREVIATIONS AND ACRONYMS

1.0 INTRODUCTION

- Purpose of the Project

  Provide a brief summary of the project's mission, status, technology(s) being deployed, etc.

- Purpose of the TMP

  Describe the objectives and content of this TMP and relate it to the status of the project and any upcoming CDs.

2.0 TECHNOLOGY ASSESSMENTS OF THE PROJECT

- Summary of Previous TIPRs

  Summarize any previous TIPRs or other technical assessments that may have contributed to the need for a TRA and this TMP.

- Summary of Previous TRA(s)

  Describe the results of previous TRAs with particular emphasis on the latest TRA that is driving this TMP. Include the definition of TRLs as used in the TRA. Discuss the CTEs that were determined for the project.

- Technology Heritage

  Summarize the previous technology development activities that brought the technology to its current state of readiness. Include discussions of any full-scale plant deployments of the technology in similar applications.

- Current Project Activities and Technology Maturation

  Describe ongoing technology development activities (if any) that were initiated prior to this TMP. Completion of these activities should define the starting point for this TMP.

- Management of Technology Maturity

  Indicate the DOE and contractor organizations that will be responsible for managing the activities described in this TMP. Include a brief discussion of key roles and responsibilities.

3.0 TECHNOLOGY MATURATION PLAN

- Development of Technology Maturation Requirements

  Describe the approach used in defining the required technology development activities that will be conducted as described in this TMP. These could include *evaluating incomplete criteria in the TRL Calculator, risk assessments, and value engineering.*

- Life-Cycle Benefit

  Briefly discuss life-cycle benefits to the project that will result from successful completion of the TMP technology development activities.

- Specific TMPs for each CTE will be described following the format below for each CTE that was defined in the latest TRA.

  - CTE A

    - Key Technology Addressed (Describe the function that the CTE carries out in the project.)
    - Objective (Succinctly state the objective of the CTE)
    - Current State of Art (Describe in one paragraph the current status of the CTE including the specific TRL assigned in the latest TRA.)
    - Technology Development Approach (In paragraph form, describe how the needed technology development work to reach TRL 6 will be performed. This could include the performing organization, location, simulant versus actual waste, etc.)
    - Scope (Provide a list of the key steps to be taken in performing the work. Include a table that gives milestones, performance targets, TRL achieved at milestones, and a rough order of magnitude cost of development.)

  - CTE B

    - Key Technology Addressed
    - Objective
    - Current State of Art
    - Technology Development Approach
    - Scope

  - CTE C (etc., as needed)

4.0 TECHNOLOGY MATURITY SCHEDULE

Provide and briefly discuss a high-level schedule of the major technology development activities for each CTE. Any major decision points such as proceeding with versus abandoning the current technology, selection of a back-up technology, etc. should be included. Detailed schedules should be given in test plans or used for status meetings during implementation.

5.0 SUMMARY TECHNOLOGY MATURITY BUDGET

Present the rough order of magnitude costs to reach TRL 6 for each major technology development activity for all CTEs in the project. Include the total technology maturation costs.

6.0 REFERENCES

Appendix A.	Crosswalk of CTEs identified in previous independent reviews and assessments (if applicable)
Appendix B.	TRL Calculator as Modified by the DOE Program Office (if applicable)
Table 1.	TRLs Used in this Assessment (taken from DoD)
Table 2, etc.	Table(s) for each CTE, listing of test activities, planned completion date, performance targets, resulting TRL level as each increment of testing is completed, and rough order of magnitude costs.
Table X.	Technology Maturity Budget for Project
Figure 1.	Process Flow Diagram (for technology being assessed)
Figure 2.	Technology Maturity Schedule
Figure 3.	Project Execution Strategy Diagram

The Deputy Secretary of Energy
Washington, DC 20585

May 24, 2019

MEMORANDUM FOR MARK R. ARENAZ
IDAHO OPERATIONS OFFICE

FROM: DAN BROUILLETTE

SUBJECT: Appointment of the Federal Project Director for the Versatile Reactor Project at the Idaho National Laboratory and Idaho Operations Office

As required by Department of Energy (DOE) Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, I hereby approve your appointment as the Federal Project Director for the Office of Nuclear Energy capital asset project: Versatile Test Reactor (VTR) Project.

The preliminary cost range of the VTR Project is $3-6 billion with an expected Critical Decision (CD)-4 date in the Fiscal Year 2025 to 2030. I have found that you have demonstrated the requisite competencies, communication, and leadership skills throughout your DOE career necessary to successfully fulfill this position. It is my expectation that you will vigorously apply your knowledge and many years of experience to make this project a success for the Department and the nation.

If you have any questions, please contact John Herczeg, Deputy Assistant Secretary for Nuclear Fuel Cycle and Supply Chain, at (301) 903-1175.

cc: E. McGinnis, NE-2
D. Miotla, NE-20
J. Herczeg, NE-4
R. Boston, NE-ID
M. Peek, PM-1

DOCUMENT 4

VTR VERSATILE TEST REACTOR

Intra-Program Memo
Versatile Test Reactor Program

Date: July 22, 2019

To: John D. Bumgardner, VTR Project Manager

From: Jason P. Andrus, VTR Safety Basis and PRA Manager

Subject: VTR Preliminary Hazards Analysis Reports requirements for CD-1 from DOE O 413.3B

This memo documents the VTR approach to meeting the requirements from DOE O 413.3B, "Program and Project Management for the Acquisition of Capital Assets," associated with the development of Preliminary Hazards Analysis Reports (PHARs) for facilities categorized as Less than Hazard Category 3 (LTHC-3) facilities prior to Critical Decision (CD)-1 (item 30 in CD deliverables tracking spreadsheet). For CD-1 under the VTR, no specific PHARs will be developed as all radioactive material operations will be considered as part of the VTR Conceptual Safety Design Report.

As a result of the mission need and the supporting VTR design, the VTR reactor facility is a Hazard Category 1 facility and will require a Safety Design Strategy and Conceptual Safety Design Report to support CD-1. The VTR reactor will be supported by facility support infrastructure which may contain quantities of radioactive material of sufficiently low quantities that they could potentially be categorized as LTHC-3. Given the interconnected nature of these systems it is proposed for all design activities leading upto CD-1 that the potential hazards and design considerations of the associated required controls for the entire plant will be captured in the VTR SDS and CSDR. Subsequently, after CD-1 during the preliminary design phase we will evaluate if there is potential for and any benefit to treating individual portions in separate safety basis documents.

JPA:MGY

cc: Minerva Yu (SharePoint Upload)
Jordi-Roglans Ribas

NOTE: The Versatile Test Reactor Intra-program Memorandums are intended to communicate and document information such as background, status, and decisions relating to program activities. Memorandums do not replace or modify formal documentation processes.

INL Equity

INL Equity

for hearing may be made through the Commission's web-based comment system, a link to which is provided at *www.drbc.gov.* Use of the web-based system ensures that all submissions are captured in a single location and their receipt is acknowledged. Exceptions to the use of this system are available based on need, by writing to the attention of the Commission Secretary, DRBC, P.O. Box 7360, 25 Cosey Road, West Trenton, NJ 08628–0360. For assistance, please contact Paula Schmitt at *paula.schmitt@drbc.gov.*

Accommodations for Special Needs. Individuals in need of an accommodation as provided for in the Americans with Disabilities Act who wish to attend the meeting or hearing should contact the Commission Secretary directly at 609–883–9500 ext. 203 or through the Telecommunications Relay Services (TRS) at 711, to discuss how we can accommodate your needs.

Additional Information, Contacts. Additional public records relating to hearing items may be examined at the Commission's offices by appointment by contacting Denise McHugh, 609–883–9500, ext. 240. For other questions concerning hearing items, please contact David Kovach, Project Review Section Manager at 609–883–9500, ext. 264.

Dated: July 29, 2019.

Pamela M. Bush,

Commission Secretary and Assistant General Counsel.

[FR Doc. 2019–16610 Filed 8–2–19; 8:45 am]

BILLING CODE 6360–01–P

DEPARTMENT OF EDUCATION

[Docket No.: ED–2019–ICCD–0094]

Agency Information Collection Activities; Comment Request; HEAL Program: Physician's Certification of Borrower's Total and Permanent Disability

AGENCY: Federal Student Aid (FSA), Department of Education (ED).

ACTION: Notice.

SUMMARY: In accordance with the Paperwork Reduction Act of 1995, ED is proposing an extension of an existing information collection.

DATES: Interested persons are invited to submit comments on or before October 4, 2019.

ADDRESSES: To access and review all the documents related to the information collection listed in this notice, please use *http://www.regulations.gov* by searching the Docket ID number ED–2019–ICCD–0094. Comments submitted in response to this notice should be submitted electronically through the Federal eRulemaking Portal at *http://www.regulations.gov* by selecting the Docket ID number or via postal mail, commercial delivery, or hand delivery. If the *regulations.gov* site is not available to the public for any reason, ED will temporarily accept comments at *ICDocketMgr@ed.gov.* Please include the docket ID number and the title of the information collection request when requesting documents or submitting comments. *Please note that comments submitted by fax or email and those submitted after the comment period will not be accepted.* Written requests for information or comments submitted by postal mail or delivery should be addressed to the Director of the Information Collection Clearance Division, U.S. Department of Education, 550 12th Street SW, PCP, Room 9086, Washington, DC 20202–0023.

FOR FURTHER INFORMATION CONTACT: For specific questions related to collection activities, please contact Beth Grebeldinger, 202–377–4018.

SUPPLEMENTARY INFORMATION: The Department of Education (ED), in accordance with the Paperwork Reduction Act of 1995 (PRA) (44 U.S.C. 3506(c)(2)(A)), provides the general public and Federal agencies with an opportunity to comment on proposed, revised, and continuing collections of information. This helps the Department assess the impact of its information collection requirements and minimize the public's reporting burden. It also helps the public understand the Department's information collection requirements and provide the requested data in the desired format. ED is soliciting comments on the proposed information collection request (ICR) that is described below. The Department of Education is especially interested in public comment addressing the following issues: (1) Is this collection necessary to the proper functions of the Department; (2) will this information be processed and used in a timely manner; (3) is the estimate of burden accurate; (4) how might the Department enhance the quality, utility, and clarity of the information to be collected; and (5) how might the Department minimize the burden of this collection on the respondents, including through the use of information technology. Please note that written comments received in response to this notice will be considered public records.

Title of Collection: HEAL Program: Physician's Certification of Borrower's Total and Permanent Disability.

OMB Control Number: 1845–0124.

Type of Review: An extension of an existing information collection.

Respondents/Affected Public: Individuals or Households; State, Local, and Tribal Governments.

Total Estimated Number of Annual Responses: 78.

Total Estimated Number of Annual Burden Hours: 20.

Abstract: This is a request for an extension of OMB approval of information collection requirements associated with the form for the Health Education Assistance Loan (HEAL) Program, Physician's Certification of Borrower's Total and Permanent Disability currently approved under OMB No. 1845–0124. The form is HEAL Form 539. A borrower and the borrower's physician must complete this form. The borrower then submits the form and additional information to the lending institution (or current holder of the loan) who in turn forwards the form and additional information to the Secretary for consideration of discharge of the borrower's HEAL loans. The form provides a uniform format for borrowers and lenders to use when submitting a disability claim.

Dated: July 31, 2019.

Kate Mullan,

PRA Coordinator, Information Collection Clearance Program, Information Management Branch, Office of the Chief Information Officer.

[FR Doc. 2019–16620 Filed 8–2–19; 8:45 am]

BILLING CODE 4000–01–P

DEPARTMENT OF ENERGY

Notice of Intent To Prepare an Environmental Impact Statement for a Versatile Test Reactor

AGENCY: Office of Nuclear Energy, Department of Energy.

ACTION: Notice of intent.

SUMMARY: As required by the ''Nuclear Energy Innovation Capabilities Act of 2017'' the Department of Energy (DOE) assessed the mission need for a versatile reactor-based fast-neutron source. Having identified the need for such a fast-neutron source, the Act directs DOE to complete construction and approve the start of facility operations, to the maximum extent practicable, by December 31, 2025. To this end, the Department intends to prepare an environmental impact statement (EIS) in accordance with the National Environmental Policy Act (NEPA) and its implementing regulations. This EIS will evaluate alternatives for a versatile reactor-based fast-neutron source facility and associated facilities for the

preparation, irradiation and post-irradiation examination of test/experimental fuels and materials.

DATES: DOE invites public comment on the scope of this EIS during a 30-day public scoping period commencing August 5, 2019, and ending on September 4, 2019. DOE will hold webcast scoping meetings on August 27, 2019 at 6:00 p.m. ET/4:00 p.m. MT and on August 28, 2019 at 8:00 p.m. ET/6:00 p.m. MT.

In defining the scope of the EIS, DOE will consider all comments received or postmarked by the end of the scoping period. Comments received or postmarked after the scoping period end date will be considered to the extent practicable.

ADDRESSES: Written comments regarding the scope of this EIS should be sent to Mr. Gordon McClellan, Document Manager, by mail at: U.S. Department of Energy, Idaho Operations Office, 1955 Fremont Avenue, MS 1235, Idaho Falls, Idaho 83415; or by email to *VTR EIS@nuclear.energy.gov.* To request further information about the EIS or to be placed on the EIS distribution list, you may use any of the methods listed in this section. In requesting to be added to the distribution list, please specify whether you would like to receive a copy of the Summary and Draft EIS on a compact disk (CD); a printed copy of the Summary and a CD with the Draft EIS; a full printed copy of the Summary and Draft EIS; or if you prefer to access the document via the internet. The Draft EIS and Summary will be available at: *https://www.energy.gov/nepa.*

FOR FURTHER INFORMATION CONTACT: For information regarding the Versatile Test Reactor (VTR) Project or the EIS, contact Mr. Gordon McClellan at the address given above; or email *VTR EIS@nuclear.energy.gov*; or call (208) 526–6805. For general information on DOE's NEPA process, contact Mr. Jason Sturm at the address given above; or email *VTR EIS@nuclear.energy.gov*; or call (208) 526–6805.

SUPPLEMENTARY INFORMATION:

Background

Part of the mission of DOE is to advance the energy, environmental, and nuclear security of the United States and promote scientific and technological innovation in support of that mission. DOE's 2014–2018 Strategic Plan states that DOE will ''support a more economically competitive, environmentally responsible, secure and resilient U.S. energy infrastructure.'' Specifically, ''DOE will continue to explore advanced concepts in nuclear energy that may lead to new types of reactors with further safety improvements and reduced environmental and nonproliferation concerns.''

Many commercial organizations and universities are pursuing advanced nuclear energy fuels, materials, and reactor designs that complement the efforts of DOE and its laboratories in achieving DOE's goal of advancing nuclear energy. These designs include thermal and fast-spectrum [1] reactors targeting improved fuel resource utilization and waste management and utilizing materials other than water for cooling. Their development requires an adequate infrastructure for experimentation, testing, design evolution, and component qualification. Existing irradiation test capabilities are aging, and some are over 50 years old. The existing capabilities are focused on testing of materials, fuels, and components in the thermal neutron spectrum and do not have the ability to support the needs for fast reactors. Only limited fast-neutron-spectrum-testing capabilities, with restricted availability, exist outside the United States.

Recognizing that the United States does not have a dedicated fast-neutron-spectrum testing capability, DOE performed a mission needs assessment to assess current testing capabilities (domestic and foreign) against the required testing capabilities to support the development of advanced nuclear technologies. This needs assessment was consistent with the Nuclear Energy Innovation Capabilities Act of 2017, or NEICA, (Pub. L. 115–248) to assess the mission need for, and cost of, a versatile reactor-based fast-neutron source with a high neutron flux, irradiation flexibility, multiple experimental environment (*e.g.,* coolant) capabilities, and volume for many concurrent users. This assessment identified a gap between required testing needs and existing capabilities. That is, there currently is an inability to effectively test advanced nuclear fuels and materials in a fast-neutron spectrum irradiation environment at high neutron fluxes. Specifically, the DOE Office of Nuclear Energy (NE), Nuclear Energy Advisory Committee (NEAC) report, *Assessment of Missions and Requirements for a New U.S. Test Reactor,* confirmed that there was a need in the U.S. for fast-neutron testing capabilities, but that there is no facility that is readily available domestically or internationally. The NEAC study confirmed the conclusions of an earlier study, *Advanced Demonstration and Test Reactor Options Study.* That study established the strategic objective that DOE ''provide an irradiation test reactor to support development and qualification of fuels, materials, and other important components/items (*e.g.,* control rods, instrumentation) of both thermal and fast neutron-based advanced reactor systems.'' To meet its obligation to support advanced reactor technology development, DOE needs to develop the capability for large-scale testing, accelerated testing, and qualification of advanced nuclear fuels, materials, instrumentation, and sensors. This testing capability is essential for the United States to modernize its nuclear energy infrastructure and for developing transformational nuclear energy technologies that re-establish the U.S. as a world leader in nuclear technology commercialization.

The key recommendation of the NEAC report was that ''DOE–NE proceed immediately with pre-conceptual design planning activities to support a new test reactor'' to fill the domestic need for a fast-neutron test capability. The considerations for such a capability include:

- An intense, neutron-irradiation environment with prototypic spectrum to determine irradiation tolerance and chemical compatibility with other reactor materials, particularly the coolant.
- Testing that provides a fundamental understanding of materials performance, validation of models for more rapid future development, and engineering-scale validation of materials performance in support of licensing efforts.
- A versatile testing capability to address diverse technology options and, sustained and adaptable testing environments.
- Focused irradiations, either long- or short-term, with heavily instrumented experimental devices, and the possibility to do in-situ measurements and quick extraction of samples.
- An accelerated schedule to regain and sustain U.S. technology leadership and to enable the competiveness of U.S-based industry entities in the advanced reactor markets. This can be achieved through use of mature technologies for the reactor design (*e.g.,* sodium coolant

[1] Fast neutrons are highly energetic neutrons (ranging from 0.1 to 5 million electron volts [MeV] and travelling at speeds of thousands to tens of thousands kilometers per second) emitted during fission. The fast-neutron spectrum refers to the range of energies associated with fast neutrons. Thermal neutrons are neutrons that are less energetic than fast neutrons (more than a million times less energetic [about 0.025eV] and travelling at speeds of less than 5 kilometers per second), having been slowed by collisions with other materials such as water. The thermal neutron spectrum refers to the range of energies associated with thermal neutrons.

in a pool-type, metallic-alloy-fueled fast reactor) while enabling innovative experimentation.

A summary of preliminary requirements that meet these considerations include:

• Provide a high peak neutron flux (neutron energy greater than 0.1 MeV) with a prototypic fast-reactor-neutron-energy spectrum; the target flux is 4×10^{15} neutrons per square centimeter per second (neutrons/cm^2-sec) or greater.

• Provide high neutron dose rate for materials testing [quantified as displacements per atom]; the target is 30 displacements per atom per year or greater.

• Provide an irradiation length that is appropriate for fast reactor fuel testing; the target is 0.6 to 1 meter.

• Provide a large irradiation volume within the core region; the target is 7 liters.

• Provide innovative testing capabilities through flexibility in testing configuration and testing environment (coolants) in closed loops.

• Provide the ability to test advanced sensors and instrumentation for the core and test positions.

• Expedite experiment life cycle by enabling easy access to support facilities for experiments fabrication and post-irradiation examination.

• Provide life-cycle management (spent nuclear fuel storage pending ultimate disposal) for the reactor driver fuel (fuel needed to run the reactor) while minimizing cost and schedule impacts.

• Make the facility available for testing as soon as possible by using proven technologies with a high technology readiness level.

Having identified the need for the VTR, NEICA directs DOE ''to the maximum extent practicable, complete construction of, and approve the start of operations for, the user facility by not later than December 31, 2025.''

Secretary of Energy Rick Perry announced the launch of the Versatile Test Reactor Project on February 28, 2019 as a part of modernizing the nuclear research and development (R&D) user facility infrastructure in the United States.

An initial evaluation of alternatives during the pre-conceptual design planning activity recommends the development of a well-instrumented sodium-cooled, fast-neutron-spectrum test reactor in the 300 megawatt-thermal power level range. This design would provide a flexible, reconfigurable testing environment for known and anticipated testing. It is the most practical and cost-effective strategy to meet the mission need and address constraints and considerations identified above. The evaluation of alternatives is consistent with the conclusions of the test reactor options study and the NEAC recommendation.

DOE expects that the VTR, coupled with the existing supporting R&D infrastructure, would provide the basic and applied physics, materials science, nuclear fuels, and advanced sensor communities with a unique research capability. This capability would enable a comprehensive understanding of the multi-scale and multi-physics performance of nuclear fuels and structural materials to support the development and deployment of advanced nuclear energy systems. To this end, DOE is collaborating with universities, commercial industry, and national laboratories to identify needed experimental capabilities.

Purpose and Need for Agency Action

The purpose of this DOE action is to provide a domestic versatile reactor-based fast-neutron source and associated facilities that meet identified user needs (*e.g.,* providing a high neutron flux of at least 4×10^{15} neutrons/cm^2-sec and related testing capabilities). Associated facilities include those for the preparation of driver fuel and test/experimental fuels and materials and those for the ensuing examination of the test/experimental fuels and materials; existing facilities would be used to the extent possible. The United States has not had a viable domestic fast-neutron-spectrum testing capability for over two decades. DOE needs to develop this capability to establish the United States' testing capability for next-generation nuclear reactors—many of which require a fast-neutron spectrum for operation—thus enabling the United States to regain technology leadership for the next generation nuclear fuels, material, and reactors. The lack of a versatile fast-neutron-spectrum testing capability is a significant national strategic risk affecting the ability of DOE to fulfill its mission to advance the energy, environmental, and nuclear security of the United States and promote scientific and technological innovation. This testing capability is essential for the United States to modernize its nuclear energy industry. Further, DOE needs to develop this capability on an accelerated schedule to avoid further delay in the United States' ability to develop and deploy advanced nuclear energy technologies. If this capability is not available to U.S. innovators as soon as possible, the ongoing shift of nuclear technology dominance to other international states (*e.g.,* China, the Russian Federation) will accelerate, to the detriment of the U.S. nuclear industrial sector.

Proposed Action

The Proposed Action is for DOE to construct and operate the VTR at a suitable DOE site. DOE would utilize existing or expanded, collocated, post-irradiation examination capabilities as necessary to accomplish the mission. DOE would use or expand existing facility capabilities to fabricate VTR driver fuel and test items and to manage radioactive wastes and spent nuclear fuel.

Versatile Test Reactor

The Nuclear Energy Innovation Capabilities Act of 2017 (Pub. L. 115–248) directed DOE, to the maximum extent practicable, to approve the start of operations for the user facility by not later than December 31, 2025. DOE recognized that a near-term deadline would require the technology selected for the user facility to be a mature technology, one not requiring significant testing or experimental efforts to qualify the technology needed to provide the capability.

The generation of a high flux of high-energy or fast neutrons requires a departure from the light-water-moderated technology of current U.S. power reactors and use of other reactor moderating and cooling technologies. The most mature technology that could provide the high-energy neutron flux is a sodium-cooled reactor, for which experience with a pool-type configuration and qualification of metallic alloy fuels affords the desired level of technology maturity and safety approach. Sodium-cooled reactor technology has been successfully used in Idaho at the Experimental Breeder Reactor (EBR)-II, in Washington at the Fast Flux Test Facility, and in Michigan at the Fermi 1 Nuclear Generating Station.

The current VTR concept would make use of the proven, existing technologies incorporated in the small, modular GE Hitachi Power Reactor Innovative Small Module (PRISM) design. The PRISM design [2] meets the need to use a sodium-cooled, pool-type reactor of proven (mature) technology. The VTR would be a smaller (approximately 300 megawatt thermal) version of the GE Hitachi

[2] The PRISM design is based on the EBR–II reactor, which operated for over 30 years. PRISM received a review by the Nuclear Regulatory Commission as contained in NUREG–1368, *Preapplication Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid-Metal Reactor,* which concluded that ''no obvious impediments to licensing the PRISM design had been identified.''

PRISM power reactor. The reactor, primary heat removal system, and safety systems would be similar to those of the PRISM design. VTR, like PRISM, would use metallic alloy fuels. The conceptual design for the first fuel core of the VTR proposes to utilize a uranium-plutonium-zirconium alloy fuel. Such an alloy fuel was tested previously in the EBR–II reactor. Later reactor fuel could consist of other mixtures and varying enrichments of uranium and plutonium and could use other alloying metals in place of zirconium.

The VTR core design, however, would differ from the PRISM core in order to accommodate several positions for test and experimental assemblies. Additional experiments could be placed in locations normally occupied by driver fuel in the PRISM reactor. The VTR is not a power reactor; there would be no PRISM power block for the generation of electricity. Heat generated by the VTR would be dissipated through air-cooled heat exchangers; no water would be used in reactor cooling systems.

The VTR would provide the capability to test fuels, materials, instrumentation, and sensors for a variety of existing and advanced reactor designs, including sodium-cooled reactors, lead/lead-bismuth eutectic-cooled reactors, gas-cooled reactors, and molten salt reactors. Test vehicles for coolants other than sodium would consist of closed loops containing the test material enclosed in cartridges that isolate the experiments from the primary coolant, allowing performance of tests on different coolant types. Due to the high flux possible in the VTR, accelerated testing for reactor materials would be possible. These experiments would extend the state-of-the art knowledge of reactor technology. Tests and experiments could also be developed that would improve safeguards technologies. In addition to fast reactor test and experimentation, the VTR could be used for research on long-term fuel cycles, fusion reactor materials, and neutrino science/detector development.

The VTR would not be used as a breeder reactor. All of the driver fuel removed from the reactor core would be stored to allow radioactive decay to reduce dose rates, and then conditioned for disposal; no nuclear materials would be removed from the fuel for the purpose of reuse.

Post-Irradiation Examination Facilities

Concurrent with the irradiation capabilities provided by the VTR, the mission need requires the capabilities to examine the test samples irradiated in the reactor to determine the effects of a high flux of high-energy or fast neutrons. Typically, the test samples would be encapsulated in cartridges such that the material being tested is fully contained. The highly radioactive test sample capsule would be removed from the reactor after a period of irradiation, ranging from days to years, depending on the nature of the test requirements, and transferred to a fully shielded facility where the test item could be analyzed and evaluated remotely. The examination facilities are ''hot-cell'' facilities, which include concrete walls several feet thick, multi-layered, leaded-glass windows several feet thick, and remote manipulators that allow operators to perform a range of tasks remotely without incurring substantial radiation dose from the test samples within the hot cell; in some cases, an inert atmosphere is required to prevent test sample degradation. DOE intends that the hot-cell facilities where the test items are examined and analyzed after removal from the reactor would be in close proximity to the VTR to minimize on- or offsite transportation of the highly radioactive samples.

Other Support Facilities

Key nuclear infrastructure components required to support the VTR and post-irradiation examination include:

- Facilities for VTR driver fuel and test item fabrication
- Facilities for managing radioactive wastes
- Facilities for management of irradiated VTR driver fuel

Nuclear materials for the VTR driver fuel could come from several locations including from within the DOE complex, commercial facilities, or possibly foreign sources. The nuclear materials and zirconium would be alloyed and formed into ingots from which the fuel would be fabricated. The alloy ingots could be produced at one of the locations providing the nuclear materials or the materials could be shipped to a location within the DOE complex for creating the alloy. DOE anticipates fabricating driver fuel from the ingots at the Savanah River site or the Idaho National Laboratory.

DOE would collaborate with a range of university, commercial industry, and national laboratory partners for experiment development. Fabrication of the test and experimental modules could occur at DOE facilities or at the university or commercial industry partners' facilities.

Preliminary Description of Alternatives

As required by the Council on Environmental Quality and DOE NEPA implementing regulations at 40 CFR parts 1500–1508 and 10 CFR part 1021, respectively, DOE will evaluate a range of reasonable alternatives for the construction and operation of a VTR and its associated facilities. As required by NEPA, the alternatives will include a No Action Alternative to serve as a basis for comparison with the action alternatives.

Specific action alternatives proposed for analysis in the EIS include alternative DOE national laboratory sites for the construction and operation of the VTR and the provision of post-irradiation examination. Under all action alternatives and as described previously, the VTR would be a small (approximately 300 megawatt thermal), sodium-cooled, pool-type, metal-fueled reactor based on the GE Hitachi PRISM power reactor. DOE projects approval for the start of operations to occur as early as the end of 2026.

There are ancillary activities necessary to support any of the action alternatives. These include the fabrication of driver fuel, the assembly of test/experimental modules at existing, modified or newly constructed test/experiment assembly facilities, and the management of waste and spent nuclear fuel. After irradiation in the VTR, test/experimental cartridges would be transferred to post irradiation examination facilities. DOE would make use of existing facilities to the extent possible, but these post-irradiation examination facilities may require modification or expansion. These activities would be part of each action alternative.

1. Idaho National Laboratory (INL) VTR Alternative

Under the INL VTR Alternative, DOE would site the VTR at the Materials and Fuels Complex (MFC) at INL and use existing hot-cell and other facilities at the MFC for post-irradiation examination. This area of INL is the location of the Hot Fuel Examination Facility (HFEF), the Irradiated Materials Characterization Laboratory (IMCL), the Experimental Fuels Facility (EFF), the Fuel Conditioning Facility (FCF), and the decommissioned Zero Power Physics Reactor (ZPPR). The existing security fence would be expanded to include VTR.

The existing facilities within the MFC would be modified as necessary to support fabrication of VTR driver fuel or test items and to support post-irradiation examination of irradiated targets withdrawn from the VTR. These types of activities are ongoing within the MFC. Under the conceptual design, the existing infrastructure including utilities and waste management facilities would be utilized to support construction and operation of the VTR. While some modifications and upgrades to the infrastructure might be necessary, the current infrastructure should be largely adequate to support the VTR.

The post-irradiation examination capabilities at MFC, including existing facilities, equipment, technical, engineering and support staff, would be capable of supporting the anticipated post-irradiation examination activities that the VTR would create. The potential increase in workload among the MFC facilities in the post-startup timeframe might require increased technical and operating staff.

Driver fuel for the VTR would likely be manufactured at the MFC or the Savanah River site, depending on multiple factors including the source of the nuclear material and the availability and capabilities of DOE, commercial, or foreign suppliers.

2. Oak Ridge National Laboratory (ORNL) VTR Alternative

Under the ORNL VTR Alternative, the VTR would be sited at ORNL at a location to be identified.

Several existing facilities would be used and/or modified to provide operational support and needed post irradiation examination capabilities. The existing Irradiated Fuels Examination Laboratory (IFEL) Building 3525 and the Irradiated Materials Examination and Testing (IMET) Building 3025E hot cell facility would be used to support post irradiation examination and material testing. The IFEL is a Category 2 nuclear facility and contains hot cells that are currently used for examination of a wide variety of fuels. The IMET is a Category 3 nuclear facility and contains hot cells that are used for mechanical testing and examination of highly irradiated structural alloys and ceramics. Both facilities would need modifications to accommodate VTR work activities.

The existing Radiochemical Engineering Development Center (REDC) also would be used to support VTR operations. REDC consists of two hot-cell facilities, both constructed during the mid-1960s. REDC operates in conjunction with ORNL's High Flux Isotope Reactor (HFIR) in remote and hands-on fabrication of targets for irradiation and subsequent processing and recovery of valuable radioisotopes. The existing capabilities of the REDC may not be adequate to support the anticipated workload from the VTR and would need to be modified or expanded. Existing glovebox laboratories in Building 7920, currently used for chemical extraction and processing, could be used for fuel and/or test item fabrication. Building 7930 houses heavily shielded hot cells and analytical laboratories that could be used for remote examination of irradiated fuels and test items.

Driver fuel for the VTR would likely be manufactured elsewhere, depending on a number of factors including the source of the nuclear material and the availability and capabilities of DOE, commercial, or foreign suppliers.

3. No Action Alternative—Do Not Construct a VTR

As required by NEPA, DOE will include a No Action Alternative to serve as a basis for comparison with the action alternatives. Under the No Action alternative, DOE would not pursue the construction and operation of a VTR and would make use of the limited capabilities of existing facilities to the extent they are capable and available for testing in the fast-neutron-flux spectrum.

Potential Environmental Issues for Analysis

DOE proposes to address the issues listed in this section when considering the potential impacts of the construction and operations of the proposed facilities (the VTR and associated pre- and post-irradiation facilities) and the transportation of materials (non-irradiated fuel, irradiated [spent] fuel and test materials, and waste):

- Potential effects on public health from exposure to radionuclides under routine and credible accident scenarios including natural disasters: Floods, hurricanes, tornadoes, and seismic events.
- Potential impacts on surface and groundwater, floodplains and wetlands, and on water use and quality.
- Potential impacts on air quality (including global climate change) and noise.
- Potential impacts on plants, animals, and their habitats, including species that are Federal- or state-listed as threatened or endangered, or of special concern.
- Potential impacts on geology and soils.
- Potential impacts on cultural resources such as historic, archeologic, and Native American culturally important sites.
- Socioeconomic impacts on potentially affected communities.
- Potential disproportionately high and adverse effects on minority and low-income populations.
- Potential impacts on land-use plans, policies and controls, and visual resources.
- Potential impacts on waste management practices and activities.
- Potential impacts of intentional destructive acts, including sabotage and terrorism.
- Unavoidable adverse impacts and irreversible and irretrievable commitments of resources.
- Potential cumulative environmental effects of past, present, and reasonably foreseeable future actions.
- Compliance with all applicable Federal, state, and local statutes and regulations, and with international agreements, and required Federal and state environmental permits, consultations and notifications.

Public Scoping Process

NEPA implementing regulations require an early and open process for determining the scope of an EIS and for identifying the significant issues related to the proposed action. To ensure that a full range of issues related to the proposed action are addressed, DOE invites Federal agencies, state, local, and tribal governments, the general public and the international community to comment on the scope of the EIS. Specifically, DOE invites comment on the identification of reasonable alternatives and specific environmental issues to be addressed. Analysis of written and oral public comments provided during the scoping period will help DOE further identify concerns and potential issues to be considered in the Draft EIS.

Webcast Scoping Meeting Information

DOE will host two interactive webcasts during the scoping period as listed under **DATES**. The purpose of the webcasts is two-fold—the first is to provide the public with information about the NEPA process and the VTR Project. The second purpose is to invite public comments on the scope of the EIS.

The webcasts will begin with presentations on the NEPA process and the VTR Project. Following the presentations, there will be a moderated session during which members of the public can provide oral comments on the scope of the EIS analysis. Commenters will be allowed 3 minutes to provide comments. Comments will be recorded. Note that providing oral comments will require joining the meeting by phone.

Members of the public who would like to provide oral comments can pre-register by sending an email to *VTR EIS@nuclear.energy.gov.* Alternatively, participants will be able to request to speak during the webcast. Those who pre-register should indicate at which session they want to speak and their name.

If you are joining the webcast scoping meeting via internet, copy and paste the link below to login to the meeting site, then follow the prompts. If you are joining the webcast meeting via phone, dial the U.S. toll-free number below and follow the prompts. Comments will be accepted during the webcast meeting, by mail, and by email.

• Join webcast scoping meeting via the internet:

August 27: *https://78449.themediaframe.com/dataconf/productusers/ldos/mediaframe/31759/indexl.html.*

August 28: *https://78449.themediaframe.com/dataconf/productusers/ldos/mediaframe/31762/indexl.html.*

(Copy and Paste into web browser).

• Join webcast public meeting by phone: U.S. toll-free: 877–869–3847.

Signed in Washington, DC on July 29, 2019.

Dennis Miotla,

Chief Operating Officer for Nuclear Energy.

[FR Doc. 2019–16578 Filed 8–2–19; 8:45 am]

BILLING CODE 6450–01–P

DEPARTMENT OF ENERGY

Federal Energy Regulatory Commission

Combined Notice of Filings #1

Take notice that the Commission received the following electric rate filings:

Docket Numbers: ER19–2134–000.
Applicants: Wheelabrator Shasta Energy Company Inc.
Description: Supplemental to June 14, 2019 Wheelabrator Shasta Energy Company Inc. tariff filing.
Filed Date: 7/24/19.
Accession Number: 20190724–5142.
Comments Due: 5 p.m. ET 8/14/19.

Docket Numbers: ER19–2329–001.
Applicants: Midcontinent Independent System Operator, Inc., Ameren Illinois Company.
Description: Tariff Amendment: 2019–07–29_SA 2880 Att A-Proj Spec No. 4 WVPA-EnerStar-West Union Substitute to be effective 6/3/2019.
Filed Date: 7/29/19.
Accession Number: 20190729–5090.
Comments Due: 5 p.m. ET 8/19/19.

Docket Numbers: ER19–2486–000.
Applicants: Imperial Valley Solar 2, LLC.
Description: § 205(d) Rate Filing: COC LGIA CTA Filing to be effective 7/30/2019.
Filed Date: 7/29/19.
Accession Number: 20190729–5126.
Comments Due: 5 p.m. ET 8/19/19.

Docket Numbers: ER19–2487–000.
Applicants: Imperial Valley Solar 2, LLC.
Description: § 205(d) Rate Filing: COC New Substation Filing to be effective 7/30/2019.
Filed Date: 7/29/19.
Accession Number: 20190729–5127.
Comments Due: 5 p.m. ET 8/19/19.

Docket Numbers: ER19–2489–000.
Applicants: GridLiance High Plains LLC.
Description: Compliance filing: GHP eTariff Order No. 842 Revisions to be effective 5/15/2018.
Filed Date: 7/30/19.
Accession Number: 20190730–5000.
Comments Due: 5 p.m. ET 8/20/19.

Docket Numbers: ER19–2490–000.
Applicants: Midcontinent Independent System Operator, Inc.
Description: § 205(d) Rate Filing: 2019–07–30_SA 3336 ATC-Waterloo Utilities D–TIA to be effective 9/29/2019.
Filed Date: 7/30/19.
Accession Number: 20190730–5029.
Comments Due: 5 p.m. ET 8/20/19.

Docket Numbers: ER19–2491–000.
Applicants: Interstate Power and Light Company.
Description: § 205(d) Rate Filing: Concurrence to Wholesale Distribution Service Agreement (George) to be effective 9/1/2019.
Filed Date: 7/30/19.
Accession Number: 20190730–5058.
Comments Due: 5 p.m. ET 8/20/19.

Docket Numbers: ER19–2492–000.
Applicants: PacifiCorp.
Description: § 205(d) Rate Filing: BPA Construction Agmt—Conversion Ross-Lex-Swift Rev 2 to be effective 9/29/2019.
Filed Date: 7/30/19.
Accession Number: 20190730–5060.
Comments Due: 5 p.m. ET 8/20/19.

Docket Numbers: ER19–2493–000.
Applicants: Arizona Public Service Company.
Description: § 205(d) Rate Filing: Rate Schedule No. 217 to be effective 10/1/2019.
Filed Date: 7/30/19.
Accession Number: 20190730–5063.
Comments Due: 5 p.m. ET 8/20/19.

Docket Numbers: ER19–2494–000.
Applicants: Arizona Public Service Company.
Description: § 205(d) Rate Filing: Revisions to Service Agreement Nos. 218 and 335 to be effective 7/1/2019.
Filed Date: 7/30/19.
Accession Number: 20190730–5079.
Comments Due: 5 p.m. ET 8/20/19.

Docket Numbers: ER19–2495–000.
Applicants: Wessington Springs Wind, LLC.
Description: Baseline eTariff Filing: Wessington Springs Wind, LLC Application for MBR Authority to be effective 9/29/2019.
Filed Date: 7/30/19.
Accession Number: 20190730–5090.
Comments Due: 5 p.m. ET 8/20/19.

The filings are accessible in the Commission's eLibrary system by clicking on the links or querying the docket number.

Any person desiring to intervene or protest in any of the above proceedings must file in accordance with Rules 211 and 214 of the Commission's Regulations (18 CFR 385.211 and 385.214) on or before 5:00 p.m. Eastern time on the specified comment date. Protests may be considered, but intervention is necessary to become a party to the proceeding.

eFiling is encouraged. More detailed information relating to filing requirements, interventions, protests, service, and qualifying facilities filings can be found at: *http://www.ferc.gov/docs-filing/efiling/filing-req.pdf.* For other information, call (866) 208–3676 (toll free). For TTY, call (202) 502–8659.

Dated: July 30, 2019.

Nathaniel J. Davis, Sr.,

Deputy Secretary.

[FR Doc. 2019–16621 Filed 8–2–19; 8:45 am]

BILLING CODE 6717–01–P

DEPARTMENT OF ENERGY

Federal Energy Regulatory Commission

[Docket No. CP19–193–000]

Columbia Gulf Transmission, L.L.C.; Notice of Schedule for Environmental Review of the Mainline 100 and Mainline 200 Replacement Project

On April 22, 2019, Columbia Gulf Transmission, L.L.C. (Columbia) filed an application in Docket No. CP19–193 requesting a Certificate of Public Convenience and Necessity pursuant to Section 7(c) and 7(b) of the Natural Gas Act to construct, operate, and abandon certain natural gas pipeline facilities. The proposed project is known as the Mainline 100 and Mainline 200 Replacement Project (Project). The Project as proposed would consist of

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DOCUMENT 10

November 15, 2019

U.S. DEPARTMENT OF ENERGY
OFFICE OF NUCLEAR ENERGY

Analysis of Alternatives Versatile Test Reactor Project

TECHSOURCE®

Contract #: GS00F003DA
Order #: 89303018FNE400001

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APPROVALS

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REVISION SUMMARY

Revision No.	Date	Change Description	Pages Affected
0	05/17/19	N/A	N/A
1	07/05/19	Technical Input from VTR Program Staff	All
2	07/15/19	Technical Input from VTR Program Staff	All
3	08/14/19	Technical Input from Factual Accuracy Review	All
4	09/20/19	Technical Input from NE-4	All
5	09/27/19	Technical Input from NE-4	All
6	11/15/19	Technical Input from Independent Review	All

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Table of Contents

List of Figures

List of Tables

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Acronyms

ADTR	Advanced Demonstration and Test Reactor
AFC	Advanced Fuels Campaign
ANS	American National Standard
ANSI	American National Standards Institute
AoA	Analysis of Alternatives
ATR	Advanced Test Reactor
AXEL	Activated Encapsulation Laboratory
BFFL	Boosted Fast Flux Loop
BNL	Brookhaven National Laboratory
CAL	Capsule Assembly Laboratory
CD-0	Critical Decision-0, Approve Mission Need
CD-1	Critical Decision-1, Approve Alternative Selection and Cost Range
CD-2	Critical Decision-2, Approve Performance Baseline
CD-3	Critical Decision-3, Approve Start of Construction/Execution
CD-4	Critical Decision-4, Approve Start of Operations or Project Completion
CEPE	Cost Estimating and Program Evaluation
CPF	coated particle fuel
CVD	chemical vapor deposition
D&D	Deactivation and Decommissioning[1]
DoD	Department of Defense
DOE	Department of Energy
DPR	Division of Policy and Rulemaking
dpa	displacements per atom
EBR-I	Experimental Breeder Reactor No.1
EBR-II	Experimental Breeder Reactor No. 2
EM	Environmental Management
FCF	Fuel Conditioning Facility
FCRD	Fuel Cycle Research and Development
FFTF	Fast Flux Test Facility
FIB	focused ion beam

[1] D&D in its broadest sense, is a truncated abbreviation for five activities generally associated with environmental cleanup of contaminated nuclear facilities: deactivation, decommissioning, de-inventory, decontamination, and demolition (or dismantlement).

FMEF	Fuels and Materials Examination Facility
FMF	Fuel Manufacturing Facility
FMIT	Fusion Materials Irradiation Test
G	Guide
GAO	Government Accountability Office
GFR	Gas-Cooled Fast Reactor
GIF	Gamma Irradiation Facility
GNEP	Global Nuclear Energy Partnership
HAN	Hanford Reservation
HEU	highly enriched uranium
HFEF	Hot Fuels Examination Facility
HFIR	High Flux Isotope Reactor
HLRF	High Level Radiochemistry Facility
HTGR	High Temperature Gas-cooled Reactor
IAEA	International Atomic Energy Agency
ICR	Independent Cost Review
IFEL	Irradiated Fuels Examination Laboratory
IMCL	Irradiated Materials Characterization Laboratory
IMET	Irradiated Material Examination and Test Facility
INL	Idaho National Laboratory
LAMDA	Low Activation Materials Development and Analysis Laboratory
LANL	Los Alamos National Laboratory
LANSCE	Los Alamos Neutron Science Center
LCCE	Life-cycle Cost Estimate
LFTR	Lead/Lead bismuth Fast Test Reactor
LOI	Lines of Inquiry
M&O	Management and Operating
MASF	Maintenance and Storage Facility
MeV	Mega-electron Volt
MFC	Materials and Fuels Complex
MFFF	Mixed Oxide Fuel Fabrication Facility
MNS	Mission Need Statement
MSFTR	Molten Salt Fast Test Reactor

MSR	Molten Salt Reactor
MTS	Materials Test Station
MWth	Megawatt (thermal)
MYRRHA	Multi-purpose Hybrid Research Reactor for High-tech Applications
NBSR	National Bureau of Standards Reactor
NE	Nuclear Energy
NEAC	Nuclear Energy Advisory Committee
NEPA	National Environmental Policy Act
NIST	National Institute of Standards and Technology
NNSA	National Nuclear Security Administration
NPV	Net Present Value
NRC	Nuclear Regulatory Commission
NRR	Nuclear Reactor Regulation
NRW	Normalized Relative Weight
NSUF	National Science User Facility
O	Order
O&M	Operations and Maintenance
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
PIDAS	Perimeter Intrusion Detection Assessment System
PIE	Post Irradiation Examination
PM	Project Management
PME	Project Management Executive
PNNL	Pacific Northwest National Laboratory
PV	Present Value
R&D	Research and Development
REDC	Radiochemical Engineering Development Center
RPL	Radiochemical Processing Laboratory
RSWF	Radioactive Scrap and Waste Facility
RTR	Research and Test Reactors
RTRB	Research and Test Reactors Branches
S.97	Nuclear Energy Innovation Capabilities Act
SAL	Shielded Analytical Laboratory
SC	Office of Science

SCWR	Super-Critical Water-Cooled Reactor
SEM	scanning electron microscopes
SFTR	Sodium-cooled Fast-Spectrum Test Reactor
SME	Subject Matter Expert
SNS	Spallation Neutron Source
SPL	Sample Preparation Laboratory
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
TEM	transmission electron microscope
TPC	total project cost
TREAT	Transient Reactor Test Facility
TRISO	tristructural isotropic
TRL	Technology Readiness Level
TTAF	Test Train Assembly Facility
U.S.	United States
VTR	Versatile Test Reactor
WBS	Work Breakdown Structure
WE-DLFR	Westinghouse – Demonstration Lead Fast Reactor
WIPP	Waste Isolation Pilot Plant
ZPPR	Zero Power Physics Reactor

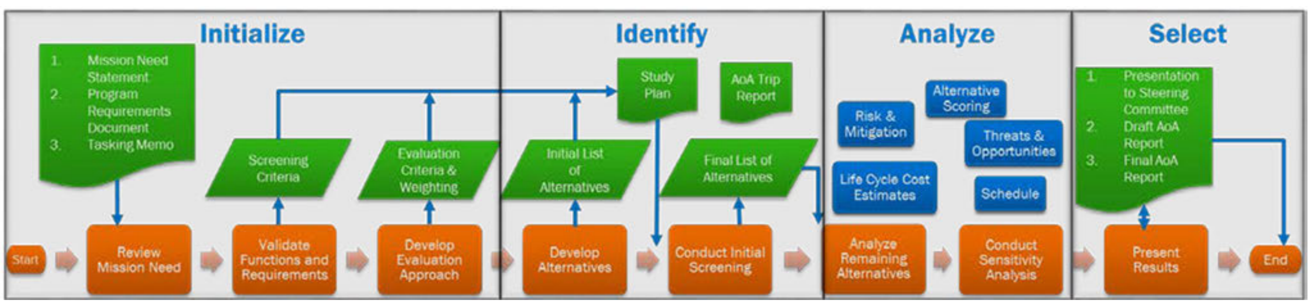
Executive Summary

The U.S. Department of Energy, Office of Nuclear Energy (DOE NE) established the Versatile Test Reactor (VTR) Project in 2017 in response to reports outlining the need for a fast spectrum test reactor, including one issued by the agency's Nuclear Energy Advisory Committee (NEAC) in 2017[1]. In that report, the NEAC recommended that DOE NE proceed immediately with pre-conceptual design planning activities to support a new domestic test reactor (including cost and schedule estimates). Further, the Nuclear Energy Innovation Capabilities Act (S.97) supported this need and authorized DOE to proceed with the relevant activities. The NEAC recommendation, in part, was based on responses from the United States (U.S.) nuclear industry teams developing advanced reactors, many of which require different testing facilities than what is needed for commercial light-water reactor technology in use today. Consequently, DOE NE developed a Mission Need Statement (MNS) for the VTR[2].

DOE NE tasked TechSource with conducting an Analysis of Alternatives (AoA) in accordance with DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, using Government Accountability Office (GAO) "Best Practices for the Analysis of Alternatives"[3]. The objective of this AOA is to provide a detailed analysis and document the basis for NE leadership to recommend a preferred alternative and support a decision by the Project Management Executive (PME).

Figure ES-1 summarizes the overall VTR AoA process. This AoA included site visits to Oak Ridge National Laboratory (ORNL), the Hanford Reservation (HAN), the Idaho National Laboratory (INL), and the Savannah River Site (SRS). This process follows the GAO 22-Step Best Practices referenced in DOE G 413.3-22**,** *Analysis of Alternatives Guide*[3].

Figure ES-1. Overall AoA Process Diagram



DOE NE provided the VTR AoA Team with information to identify and establish project functions, requirements, assumptions and constraints. From the information provided, the VTR AoA Team extracted mission and program requirements from the MNS, the DOE NE task statement, and relevant legislative language to establish the high-level Screening Criteria that must be met to satisfy the mission need. (See Section 3.1 and Appendix C for a Detailed Description). These Screening Criteria were used during the initial screening of all potential alternatives to determine whether an alternative was viable or non-viable. If an alternative was unable to substantially meet one of these criteria, then the alternative was deemed non-viable and not evaluated further.

This VTR AoA report identifies and provides analysis of potential alternatives to provide a fast spectrum neutron testing capability. Further, this report includes the high-level functions/requirements, the alternative descriptions and their associated risks and opportunities, assumptions and constraints, evaluation criteria, life cycle cost estimates (LCCEs), schedule estimates, risk and sensitivity analyses, and the results of the evaluation of alternatives.

The AoA Team reviewed available background documentation including the MNS, DOE NE Task Statement, and Congressional language, to develop a set of higher-level initial Screening Criteria that must be met to satisfy the mission requirements. These Screening Criteria were used to determine those alternatives that are most viable. A more detailed set of Evaluation Criteria were developed for analysis of the ability of the viable alternatives to effectively meet the mission needs. Following the identification of the evaluation criteria, the VTR AoA Team established the scale to weight each attribute to reflect the relative importance to the requirements. To accurately calculate a weighted score for each criterion, the VTR AoA Team normalized the weighting based on the total number of criteria. DOE reviewed and concurred with these Evaluation Criteria and weighting factors. An initial set of eighteen potential alternatives (including reactors and externally driven systems) plus the Status Quo (no action) alternative were identified by the VTR AoA Team for consideration. The screening criteria were applied to the potential alternatives, to assess viability of each alternative. After the initial screening, 6 of the 18 initial alternatives were considered viable and subject to more detailed analysis against the Evaluation Criteria, along with the Status Quo. Table ES-1 provides a list of these alternatives along with their description.

Table ES-1. Viable Alternatives for Evaluation

Alternative	Description
Base Case (Status Quo)	No new facilities, no major modifications to existing facilities. Limited fast flux capability in the U.S. High Flux Isotope Reactor (HFIR) at ORNL currently has highest fast flux. Advanced Test Reactor (ATR) has less. Both test reactors have a large thermal flux component which is not representative of fast reactors, so testing results would be of limited value, although there has been some success in utilizing a thermal neutron absorber on the irradiation vehicle to improve the fast-to-thermal flux ratio. Sufficient damage accumulation in low fast flux environment takes many years (20 to 50). Extremely limited DOE use of foreign fast test reactors due to cost, transportation and political issues. Industry vendors who need fast flux test capability will continue to use DOE user facilities with long wait time for results, propose demonstration plant to be used as a test facility ("license by test protocol"), or try to get into foreign fast test reactors at their own expense.
Modify ATR by addition of BFFL	The ATR is a light-water cooled reactor located at the INL. The reactor's primary "customer" is the U.S. Navy, but over the past several years it has been used by the AFC of the DOE NE FCRD program to irradiate a broad spectrum of fuels and cladding materials of interest, as well as by other NE programs. The reactor is typically operated at a power level in the range of 110 to 120 MWth and has a maximum thermal flux of 1.0E+15 n/cm^2-s, and maximum fast flux of 5.0E+14 n/cm^2-s. ATR has been utilized to support the testing of advanced fuels and materials for improved resource utilization and waste management missions, as well as to support advanced reactor developers. The absence of a domestic facility to provide the prototypic neutron testing environment required to support advanced reactor development and licensing is evident. To respond to this need, which included a fast neutron flux of 2E+15 n/cm^2-s the AFC/ATR developed and implemented an irradiation capsule design with a "thermal flux absorber" (e.g., cadmium) to minimize the thermal component of the flux to approximate a fast spectrum; and proposed (but did not implement) a Boosted Fast Flux Loop (BFFL) to increase the fast flux into the required range. This alternative assumes implementation of the BFFL. There is infrastructure on site to support many/most of the irradiation and PIE requirements of ongoing programs and the VTR mission.

Table ES-1. Viable Alternatives for Evaluation

Alternative	Description
Modify High Flux Isotope Reactor (HFIR) to accommodate 3/7-pin irradiation vehicles	The HFIR is a light-water cooled reactor located at the ORNL. The reactor has a power level of 85 MWth and associated maximum thermal and fast fluxes of 3.0E+15 and 1.0E+15 n/cm^2-s, respectively. The primary application of the HFIR is neutron scattering and isotope production (e.g. medical, Pu238, …). It has been used by the AFC of the DOE NE Fuel Cycle Research and Development (FCRD) program to irradiate fuels and cladding materials of interest, as well as by other NE and non-NE programs. Irradiations designed to approximate a fast spectrum also use a "thermal flux absorber", e.g., Eu2O3, to minimize the thermal component of the flux. Options to boost the flux to the desired target may be feasible, such as incorporating a 3- or 7-pin irradiation vehicle for insertion in the center flux trap have been proposed to boost the fast flux and increase the irradiation volume. There is infrastructure on site to support many/most of the irradiation and PIE requirements of ongoing programs and the VTR mission.
Modify and Restart Fast Flux Test Facility (FFTF)	The FFTF is a deactivated fast test reactor located at the Hanford Reservation in Washington. It is a 400-Megawatt (thermal) (MWth) sodium-cooled fast reactor that used mixed oxide driver fuel and operated from 1982 through 1992. It was used to test fuels (Including metal fuels) and materials for fast reactors and is potentially capable of being reactivated to meet the fast neutron irradiation requirements of the VTR project. The nearby dormant Fuels and Materials Examination Facility (FMEF) could also be activated to provide support for fuel fabrication, although significant modifications would be necessary to manufacture metal fuels. It could also support, pre- and post-irradiation examination of test fuels and materials. There are significant technical and experimental challenges that would have to be addressed if this option were selected as the preferred alternative, including component age-related material degradation, repairs to and recertification of systems modified to support deactivation, upgrades to meet current codes and standards including seismic, and upgrades to meet potential user experimental needs.
Sodium-cooled Fast Spectrum Test Reactor (SFTR)	A new SFTR based on proven technologies built and operated in the past is proposed as a viable alternative for the VTR. The reactor performance requirements can be met, and the experimental user needs can be incorporated into a properly designed SFTR technology-based test reactor, probably in the 250 – 400 MWth range. Liquid sodium has a high thermal conductivity and heat capacity and is compatible with steels and metal alloy fuels. Coolant purification technology and passive safety features have been demonstrated on large scale. The inherent reactivity of sodium requires an inert atmosphere for refueling and maintenance. The experience and lessons learned from the design, construction and operation of several SFTRs, research reactors and commercial reactors around the world can be used to minimize the technical, cost and schedule risks of this technology.

Table ES-1. Viable Alternatives for Evaluation

Alternative	Description
Lead-Cooled Fast Test Reactor (LFTR)	A Pb or Pb-Bi-cooled-fast test reactor would be a new fast spectrum reactor cooled by either lead or lead-bismuth eutectic. The test reactor could be leveraged off any one of several conceptual designs for LFR power reactors, modified to increase flux and to incorporate test irradiation locations in the core to accommodate both static and dynamic experiments. An LFTR could be amenable to a high-power density core and could achieve the desired irradiation conditions with a reactor in the 250-400 MWth range. The preferred fuel for highest flux would probably be U/Pu-nitride. A pool-type design could facilitate experiment access, with in-vessel heat exchangers and above-pool access to experimental channels. Pb coolants have advantages in high thermal capacity, low pressure operation, hard neutron spectrum, high thermal margin to voiding and lack of chemical reactivity. Challenges include new fuel and core materials, and corrosion control. No heavy metal cooled reactors have been built in the U.S., but a number have been tested and fielded abroad, although none were high-flux irradiation test reactors.
Molten Salt-Cooled/Fueled Fast Test Reactor (MSFTR)	A Molten Salt-Cooled-FTR would be a fast spectrum reactor cooled/fueled by molten salt. Options could include both a solid-fuel salt-cooled concept or more likely a molten salt fueled concept (allows greater flexibility in accommodating test articles due to absence of solid fuel assemblies) – to achieve high power density and high flux for irradiation. The reactor could be leveraged off any one of several conceptual designs for MSFTR power reactors, modified to increase flux and to incorporate test irradiation locations in the core to accommodate both static and dynamic experiments. Fast spectrum MSR designs are amenable to high power density cores and could achieve the desired irradiation conditions with a reactor in the 250-400 MWth range. A typical fuel/coolant would be chloride salt loaded with dissolved U/Pu. A pool-type design could facilitate experiment access, with above-pool access to experimental channels. Molten salt fuel has advantages in thermal capacity, low pressure operation, ability to retain actinides and fission products, high thermal margin to voiding, transparency and low chemical reactivity. Challenges include new fuel and core materials, and proliferation/safeguard concerns for liquid fuel designs. Several thermal MSR test reactors have been built and there is both foreign and domestic interest in both thermal and fast MSR concepts.

Following the identification of the viable alternatives, the VTR AoA Team assembled sufficient information for each viable alternative for scoring against the Evaluation Criteria. These scoring results and the weighting factors produced an 'Evaluation Score' for each alternative.

For cost comparison, LCCEs were developed for each of the six VTR Project viable alternatives that passed the initial screening. Additionally, an LCCE was developed for the Status Quo alternative. The life cycle costs include all upfront capital costs, operations, maintenance, periodic major upgrades, and end-of-life deactivation and decommissioning (D&D[2]), including appropriate escalation allowances. The LCCEs are only intended to be used to support the VTR AoA for comparing each alternative's life cycle costs and are not considered budget quality estimates.

[2] D&D in its broadest sense, is a truncated abbreviation for five activities generally associated with environmental cleanup of contaminated nuclear facilities: deactivation, decommissioning, de-inventory, decontamination, and demolition (or dismantlement).

An aggressive and a nominal length schedule estimate were developed for each alternative. This approach provided additional insight when comparing alternatives.

After identifying and describing the scope for the six viable alternatives and the Status Quo or "do nothing" alternative, the VTR AoA Team identified potential risks associated with the overall effort. Each alternative was evaluated in relation to all threats and opportunities. Risks vary among alternatives and can influence the selection of the preferred alternative. Prior to performing the qualitative risk evaluation by alternative, the Team developed a risk matrix to determine the risk level based on probability of occurrence and the consequence level. The VTR AoA Team rated the threats and opportunities and assigned qualitative values in accordance with the process identified in DOE G 413.3-7A, *Risk Management Guide.*

The VTR AoA Team evaluated the alternatives using the weighted scores described in Section 6 and rated how completely each alternative met each evaluation criterion. The criteria scores for each alternative were totaled to create the final Evaluation Score for the alternative.

Table ES-2 presents the final evaluation and risk scores, cost estimates, and schedule range estimates for each of the viable alternatives and the Status Quo alternative.

Table ES-2. VTR Project AoA Results

Alternative	Evaluation Score (Higher Better)	Technology-Related Risk Score* (Lower Better)	Site-Specific Risk Score* (Lower Better)	Life Cycle Costs (LCC) Present Value PV ($B)	Capital Cost (TPC) ($B)	Schedule Range (CD-4)
Alternative 1 Status Quo	43	18	18	$0.7 to $1.6	Not Applicable	Not Applicable
Alternative 2 Modified ATR	48	18	16	$1.7 to $3.9	$0.1 to $0.5	FY25 to FY28
Alternative 3 Modified HFIR	43	18	24	$0.8 to $1.8	$0.04 to $0.2	FY23 to FY24
Alternative 4 FFTF	67	44	14	$4.3 to $11.8	$1.1 to $5.6	FY27 to FY29
Alternative 5 SFTR	84	42	Site TBD	$7.0 to $17.6	$4.6 to $13.2	FY27 to FY29
Alternative 6 LFTR	71	48	Site TBD	$7.9 to $23.0	$7.1 to $24.2	FY31 to FY38
Alternative 7 MSFTR	71	48	Site TBD	$8.2 to $23.9	$7.7 to $25.9	FY31 to FY38

The LCCEs are only intended to be used to support the VTR AoA for comparing each alternative's life cycle costs and are not considered budget quality estimates.

**Risk scores include threats only (no opportunities).*

***The approved cost range from the Approval of CD-0, Approve Mission Need, for the Versatile Test Reactor Project, is $3.0B to $6.0B with a schedule range of 2026 to 2030. This represents the Department of Energy formal position on cost and schedule of the VTR.*

Based on the results of their analysis, the VTR AoA Team concludes:

- The Status Quo alternative does not meet the mission need.
- As shown in Table ES-2, Alternative 5 which requires the construction of a new SFTR scored highest in terms of the identified evaluation criteria. These criteria appropriately weigh performance factors as well as relative cost and schedule for each identified potential alternative. A sensitivity analysis demonstrated that even if the relative weights of the evaluation criteria are modified, the SFTR alternative maintained its top ranking.
- There is a lower risk potential, as well as lower costs and faster implementation schedules, if existing facilities (HFIR and ATR) are used to address the mission need. However, those alternatives do not meet the full suite of performance criteria identified in the MNS.
- There is the potential for upgrading both the ATR and the HFIR facilities to better support the VTR mission (a potential hybrid alternative). The scores, the costs, risks and performance would be additive, and the schedules would be in parallel. The incremental performance of these two thermal spectrum reactors compared to any of the fast spectrum reactors would not result in substantially improved scoring, as the largest performance increase would be in the ATR fast flux booster. Additionally, the combined cost and risk would not result in substantially worsened scoring, as the cost is dominated by the ATR booster and risk is dominated by HFIR mission conflict. Thus, it was determined that the combined upgrades would not result in a significantly improved alternative.
- As expected, the new reactor alternatives have inherently higher initial capital costs and life cycle costs, greater risk levels, as well as potentially longer implementation schedules, than do the alternatives that involve use/modification of existing facilities. However, the higher costs will need to be incurred if the full suite of performance criteria identified in the MNS are to be met.
- The analysis of estimated capital costs and project schedules was based on an assumed availability of annual funding as needed to support an optimum and possible project schedule. This results in very high annual funding levels being necessary over the project schedule for the new reactor alternatives (approaching $1B per year for the new SFTR alternative and even higher for the other reactor technology alternatives) that could be even higher if the high range cost estimates are considered. In the event that actual annual funding levels are limited, a threat considered in the risk analysis, there would be longer project execution schedules and correspondingly higher project costs.

A few observations arise from this study:

- The performance of the existing thermal spectrum test reactors was inadequate for a fast neutron irradiation mission. These reactors have some capability, and that capability can be enhanced. However, these reactors inherently do not have the level of potential for this mission as a fast spectrum reactor.
- Existing facilities have cost and schedule advantages over any new reactor alternative but have more limited performance and the risk of potential mission conflicts.
- FFTF is an intermediate case of an existing but long-shuttered high-performance irradiation test facility that has significant uncertainties regarding technical requirements for restart, stakeholder acceptance and long-term operation that add risk. These significant uncertainties have been evaluated during this AoA; however, the degree of the “unknown unknowns” with respect to risk in meeting the mission need could only be determined by conducting significantly more detailed studies.

- A new test reactor could best meet mission needs with lower risk, but with potentially higher costs and longer schedules.
- Any of the four fast spectrum test reactor alternatives could meet the mission need. The potential restart of FFTF is an issue of age, present condition, and future longevity. The LFTR and MSFTR suffer from significantly lower technical maturity, and the possibility that a technology demonstration facility might be needed prior to construction to mitigate technology risk. Amongst the four fast spectrum reactors, the SFTR was evaluated to be a better alternative.
- The AoA Team visited four DOE sites that could support the VTR mission. Three sites (INL Hanford and ORNL) have existing reactors that are included among the alternatives evaluated. The fourth (SRS) does not have a reactor that could be used for the VTR mission but does have existing facilities that could support a VTR. SRS was included in the site visits to better understand the capabilities and availability of mission support facilities. Actual site selection(s) should also consider the results from a full NEPA evaluation and accompanying siting study. Local stakeholders and state government support (or lack thereof) would also need to be assessed in selecting a potential site or sites.
- While the VTR AoA effort was not a siting study, the VTR AoA Team also briefly explored the relative pros and cons of siting a new test reactor at a DOE site as compared to a non-DOE (not specifically specified) site. The VTR AoA Team believes that it would be preferable to use a DOE site that already includes some of the requisite support facilities needed for the VTR mission and an existing regulatory/security posture to accommodate a new VTR. These observations are further detailed in Appendix I.

The conclusions and observations submitted by the VTR AoA Team are provided as information to aid DOE decision-makers in determining a preferred strategy for addressing the need for a VTR.

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1 SCOPE

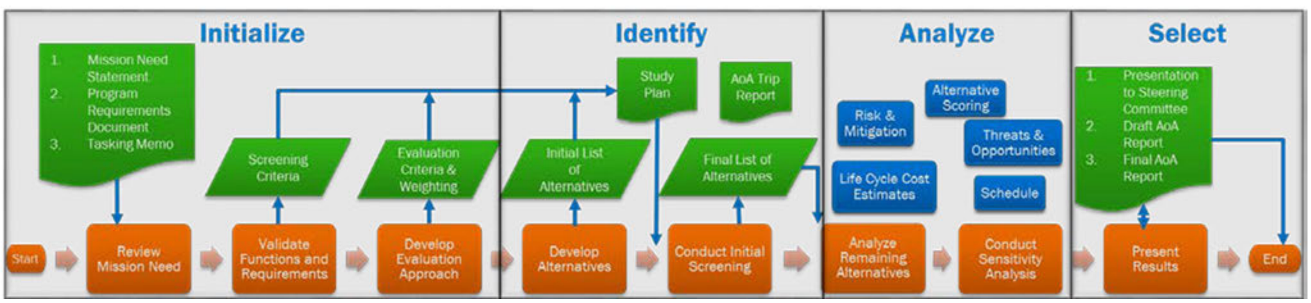
1.1 Overall Process

DOE NE tasked TechSource under contract No. GS00F003DAS to develop an independent AoA for the Versatile Test Reactor (VTR) Project. This task was performed within the framework of DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, and DOE Guide 413.3-22, *Analysis of Alternatives Guide*[3], as adapted from the Government Accountability Office GAO-16-22 Best Practices and the GAO Cost Estimating and Assessment Guide GAO-09-3SP[4]. The purpose of this effort was to provide an assessment of whether the proposed candidate approaches are technically feasible and have the potential to effectively address capability gaps, desired operational attributes, and associated external dependencies.

This AoA was performed by a Team independent of the contractor organization responsible for managing the design and construction or constructing any potential capital asset project. The VTR AoA Team objectively considered all potentially viable alternatives for the project without any predefined preference.

Figure 1-1 summarizes the overall process. The AoA effort included site visits to ORNL, HAN/PNNL, INL, and SRS/SRNL. A kickoff meeting and three multiple-day working sessions were held at the TechSource offices in Germantown, Maryland. The process shown in Table 1-2 follows the GAO 22-Step "Best Practices" referenced in the aforementioned DOE Order and *AoA Guide*.

Figure 1-1. Overall AoA Process Diagram



NE provided the AoA Team with the project requirements contained within the approved MNS, the DOE NE Task Statement, and the applicable Congressional language. These steps (i.e., Steps 1 and 2) are part of Critical Decision 0 (CD-0), Approve Mission Need activities, as specified in DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets.* The VTR AoA Team synthesized these requirements so that they could be used for the initial screening of alternatives. This approach was reviewed and concurred on by the federal government subject matter experts (SMEs) and ensured that the functions and requirements were clearly stated. Screening Criteria were then developed and are listed in Table 5-1 with references to the sources from which they were derived. The VTR AoA Team also developed more detailed Evaluation Criteria that were used to evaluate alternatives that passed initial screening. The criteria are quantitative or qualitative, independent of one another to the extent practical, and traceable to the MNS and other relevant documents. The Team assigned an importance level (highest importance; very important; medium importance; and lowest importance) to each criterion which were approved by DOE NE. Each of the four importance levels has a corresponding weighting factor associated with it, with the highest importance assigned the greatest weighting factor and the lowest importance the least weighting factor.

After establishing the Screening Criteria, the VTR AoA Team developed a broad list of potential alternatives to satisfy the requirements. The next step was to perform an initial screening of the alternatives using the Screening Criteria. Each alternative was evaluated against documented Screening Criteria. If any of the alternatives did not meet the requirements, then either the alternative had to be adjusted (restart Step 4) or the alternative was screened out from further consideration and documented as a non-viable alternative. No further analysis was conducted for alternatives that were screened out. The rationale for the screening decisions is documented in this report. The exception to this process is the Status Quo alternative, which was maintained for comparison purposes only.

After the initial screening of alternatives, the remaining alternatives were further developed with more detailed descriptions and pre-conceptual sketches. Following the detailed descriptions of the alternatives, LCCEs were developed and presented in both as-spent and PV dollars. Project schedule analysis, identification of alternative advantages and disadvantages, and identification and analysis of risks (i.e., threats and opportunities) proceeded in parallel. Using these materials, the alternatives were evaluated against the weighted Evaluation Criteria. The results of the analysis, including the rationale for the scoring, are documented in this report. The Team performed a limited sensitivity analyses on the cost. The Team also performed a sensitivity analysis on the scoring results to substantiate non-bias in the AoA. The results of the AoA process are presented along with the cost range, probable implementation schedule, and relative risk profile for the PME or decision-maker to consider in selecting a preferred alternative.

The TechSource VTR AoA Team aligned its approach with the GAO 22 best practices (see GAO 16-22[3]), which are grouped into six categories as shown in Table 1-1 in accordance with the DOE *AoA Guide.*

Table 1-1. VTR AoA Team Best Practices in Alignment with DOE AoA Guide

- **Phase I. Pre-AoA – CD-0 Mission Need**
  1. Define mission need
  2. Define functional requirements
- **Phase II. Initialize the Formal AoA Process**
  3. Develop AoA timeframe
  4. Establish AoA Team (the AoA Team should be independent of the contractor organization responsible for managing the construction or constructing the capital asset project)
  5. Define selection criteria
  6. Weight selection criteria
  7. Develop AoA process plan
- **Phase III. Identify alternatives**
  8. Develop list of alternatives
  9. Describe alternatives
  10. Include baseline alternative
  11. Assess alternatives' viability (initial screening of alternatives)
- **Phase IV. Analyze alternatives**
  12. Identify significant risks and mitigation strategies
  13. Determine and quantify benefits/effectiveness
  14. Tie/benefits/effectiveness to mission need
  15. Develop life-cycle cost estimates (LCCEs)
  16. Include a confidence interval or range for LCCEs
  17. Perform sensitivity analysis
- **Phase V. Document and review the AoA Process**
  18. Document the AoA process in a manner to best convey the information (e.g., single document or multiple volumes, as appropriate).
  19. Document assumptions and constraints
  20. Ensure AoA process is impartial
  21. Perform independent review
- **Phase VI. Select a preferred alternative**
  22. Compare alternatives

The aforementioned six phases formed the general organization of the AoA study plan and were implemented in a step-wise fashion to perform the AoA.

1.2 GAO Best Practices

This VTR Project AoA report identifies and provides analysis of potential alternatives. Further, this report includes the high-level functions/requirements, the alternative descriptions with their associated risks and opportunities, assumptions and constraints, Evaluation Criteria, LCCEs, and the results of the evaluation of alternatives. The approach used by the VTR AoA Team for conducting the AoA included the following ten primary steps (shown in Table 1-2) condensed from the GAO Best Practices and in accordance with the DOE *AoA Guide*.

Table 1-2. Approach Followed by AoA Team for Conducting the AoA

- **Step 1 –** Identify/Confirm high-level functional requirements to meet the mission need.
- **Step 2 –** Establish the criteria to be used to screen and evaluate the alternatives.
- **Step 3 –** Identify the weighting factors for each evaluation criterion based on their relative importance.
- **Step 4 –** Conduct brainstorming sessions to identify a list of potential alternatives.
- **Step 5 –** Review and screen out alternatives that do not meet the mission and program requirements.
- **Step 6 –** Develop pre-conceptual design alternative descriptions, facility sketches, advantages/disadvantages (pros/cons), and relative risks for each alternative to provide an adequate basis for scoring.
- **Step 7 –** Develop initial project/capital cost estimates and schedules as well as LCCEs for each remaining alternative, including general design and construction, operations and maintenance (O&M), and D&D. Determine PV of the LCCE for each alternative.
- **Step 8 –** Score each alternative according to meeting the Evaluation Criteria using multi-attribute decision analysis or other evaluation techniques that capture technical performance, cost, schedule, and minimize risk (low threat impacts and high potential opportunities).
- **Step 9 –** Document the results.
- **Step 10 –** Present the AoA results to the Project Management Executive (PME) / decision maker.

1.3 AoA TEAM

The VTR AoA Team was comprised of experienced SMEs with diverse backgrounds. The VTR AoA Team members are identified in Table 1-3.

Table 1-3. VTR AoA Team Members and Roles

Name	Organization	Primary Role
Jeff Giangiuli	TechSource	AoA Team Leader
Buzz Savage	TechSource	Management & Technology
Bill Halsey	TechSource	Technology & Siting
Chris Gruber	TechSource	Cost
Dave Berkey	TechSource	Risk
Pam Lawson	TechSource	Document Production & Control
Michael Todosow	BNL	Technology & Siting
Jason Gwaltney	MPR	Schedule

1.4 Federal SME's

The VTR AoA Team was supported by a panel of federal government SMEs that provided technical and policy information and input. The SME support included providing the project requirements on which both the Screening and Evaluation Criteria are based, approving the screening and Evaluation Criteria, providing scoring and risk rating inputs, and governing the process to ensure independence and compliance with all the applicable guides, directives, best practices, and memoranda. The members of the federal government and their role are identified in Table 1-4.

Table 1-4. Federal Government Participants and Roles

Name	Organization	Role
BP Singh/Thomas O'Connor	DOE NE	VTR Project Lead
Janelle Eddins	DOE NE	VTR AoA Monitor
Shawn Campbell	NRC	Technology & AoA QC

2 INTRODUCTION AND MISSION NEED

2.1 Introduction

The U.S. has been an international leader in the development and testing of advanced nuclear reactor technologies since the advent of nuclear power generation. The DOE and its predecessor organizations appropriately provided nuclear fuels and materials development capabilities and large-scale testing facilities in support of all currently deployed nuclear reactor technologies. However, the U.S. has not maintained a domestic fast neutron spectrum testing capability for over two decades. This gap in testing capability is severely crippling the U.S. ability to move forward in the development of next-generation nuclear reactors – many of which require a fast neutron spectrum for operation – and equally impacts the U.S. ability to regain technology leadership in this arena. In the meantime, development of next generation advanced reactors technologies is being actively pursued by DOE national laboratories, universities and industry in competition with similar efforts by international private and/or state supported nuclear technology providers.

Common to advanced nuclear reactor technology development is the urgent need for accelerated testing and qualification of advanced nuclear fuels, materials instrumentation and sensors. The lack of a versatile fast neutron spectrum testing capability is a significant national strategic risk affecting the ability of DOE to fulfill its mission areas. This testing capability is essential for the U.S. to modernize its nuclear energy research and development (R&D) infrastructure for developing transformational nuclear technologies including fission energy, fusion and defense programs. Failure to develop this capability on an accelerated schedule will lead to further degradation of the U.S. ability to develop advanced nuclear energy technologies and the continued improvement of existing technologies. If this capability is not available to U.S. innovators as soon as possible, the ongoing shift of nuclear technology primacy to other international states (e.g., China, the Russian Federation) will accelerate, and the opportunity will be missed to re-energize the U.S. nuclear industrial sector. Furthermore, independent of domestic deployment strategies, relinquishing U.S. leadership in advanced reactor technologies will have national security consequences as U.S. influence in global nuclear safety and security policies and their implementation will be severely diminished [2].

The VTR would be a key facility to revive and expand the nuclear energy sector in the U.S. Specifically, it supports modernization of U.S. infrastructure for early stage R&D to provide the needed test facility to develop transformational nuclear energy technologies. Advancements in nuclear energy, particularly in accelerated testing of advanced materials and fuels in extreme environments, are absolutely necessary for the advanced reactor community in the U.S. to achieve their goals of cost reduction and development of long-life structures, cladding materials and fuels. This facility should be versatile to address diverse technology options and provide sustained, adaptable testing environments. The required functional testing capability for development of advanced nuclear fuels and materials ranges from 20 displacements per atom (dpa) per year to over 500 dpa total accumulated dose. Additionally, to create the prototypic environment needed to qualify advanced nuclear fuels and materials, the irradiation must be performed at elevated temperatures with a fast neutron spectrum (>0.1 million electron volts [MeV]) and with flowing coolants other than water. Current domestic irradiation testing facilities cannot provide a representative, timely irradiation testing environment, and access to very limited international testing facilities is precluded by political, transportation, technical, and cost issues.

Success of the advanced reactor community is key for providing a diverse portfolio of energy supply sources to ensure national security through energy independence and energy dominance. The VTR would allow the U.S. to regain its global technical leadership role in the field of nuclear energy, contribute to the creation of high-paying jobs and economic prosperity, and train the next generation of scientists and engineers needed for the future viability of our nuclear sector [18].

2.2 Mission Need

The NEAC was tasked by Acting Assistant Secretary for Nuclear Energy, John Kotek, in a letter, dated July 29, 2016 to form a team, comprised of members from NEAC subcommittees, "to assess the need and determine the requirements for an irradiation test reactor which would augment existing domestic capabilities to support the development and deployment of advanced non-light water reactors as well as to accommodate the future needs of light water reactor technologies."

The NEAC report included a review of the capabilities of domestic and selected international irradiation testing reactors, and the needs of potential users, e.g., industry. Desirable characteristics identified included neutron flux/fluence, spectrum (the need for both fast and thermal was identified), fuels and materials of interest, test environment (volume, temperature, etc.).

In their final report, the NEAC recommended that DOE NE proceed immediately with pre-conceptual design planning activities to support a new domestic test reactor (including cost and schedule estimates) that will establish a reactor-based fast-spectrum neutron irradiation capability [1].

The Advanced Demonstration and Test Reactor (ADTR) options study reviewed four demonstration and two test reactor “point designs”:

- A modular HTGR [High Temperature Gas-cooled Reactor] (AREVA)
- An SFR [Sodium-cooled Fast Reactor] (General Electric)
- An LFR [Lead/Lead bismuth Fast Reactor] (Westinghouse)
- An FHR (ORNL)
- An SFTR test reactor
- An HTGR test reactor

The study was performed by staff from Argonne National Laboratory (ANL), INL and ORNL with input from nuclear industry participants. The study considered deployment options, cost and schedule, as well as Technology Readiness Levels (TRL) for these options as they related to achieving pre-specified strategic objectives. The main findings of the study [taken from Nuclear Technology, 199, 111-128, August 2017][21] are:

> *(1) for industrial process heat supply, a high temperature gas-cooled reactor is the best choice because of the high outlet temperature of the reactor and its strong passive and inherent safety characteristics; (2) for resource utilization and waste management, a sodium-cooled fast reactor (SFR) is best because of the use of a fast flux to destroy actinides; (3) to realize the advantages of a promising but less-mature technology, a fluoride salt-cooled high-temperature reactor and a lead-cooled fast reactor fare about the same; (4) for fulfilling the needs of a materials test reactor, a SFR is considered best because of its ability to produce high fast flux, incorporate test loops, and provide additional large volumes for testing.*

Supported by the work outlined above, DOE NE established the VTR Project in 2017 in response to reports outlining the need for a fast spectrum test reactor. Recognizing the importance of U.S. leadership in advanced reactor development in terms of economic competitiveness and national security implications, there are a number of nuclear-energy-related authorization bills that are being considered at various levels within the U.S. House and Senate. These bills directly or indirectly affect the VTR program and reflect bi-partisan support for a new test reactor.

On the Senate side, the Nuclear Energy Innovation Capabilities Act of 2017 (NEICA, S.97) enables civilian R&D of advanced nuclear energy technologies by private and public institutions and directs the Secretary of Energy to determine the mission need for a versatile reactor-based fast neutron source, which shall operate as a national user facility. This bill passed the Senate on March 7, 2018 and the House on September 13, 2018 and was signed by the President on September 28, 2018. S.97 establishes the legal basis for planning and design of a reactor-based fast neutron source, sets forth the basic mission requirements and key milestones for establishing the testing capability and directs the Secretary of Energy, to the maximum extent practicable, complete construction of, and approve the start of operations for the facility by no later than December 31, 2025.

The Office of Nuclear Energy approved the VTR MNS on December 10, 2018. The Deputy Secretary approved Critical Decision 0, Approve Mission Need, on February 22, 2019. The approved MNS can be found in Appendix A. The requirements detailed in the MNS formed the basis for the development of the Screening and Evaluation Criteria.

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3 REQUIREMENTS AND ASSUMPTIONS

3.1 Requirements

DOE NE provided the approved MNS to the VTR AoA Team which established the project requirements for the VTR mission. DOE NE also provided the AoA Team with a Task Statement (see Appendix B) for the guidance on the AoA, and the applicable Congressional language (S.97 see Appendix C) to provide additional direction for the AoA. From these three documents, the AoA Team synthesized the requirements, guidance and direction into Screening Criteria and Evaluation Criteria to conduct the AoA. Figure 3-1 outlines the overall approach used to facilitate the analysis.

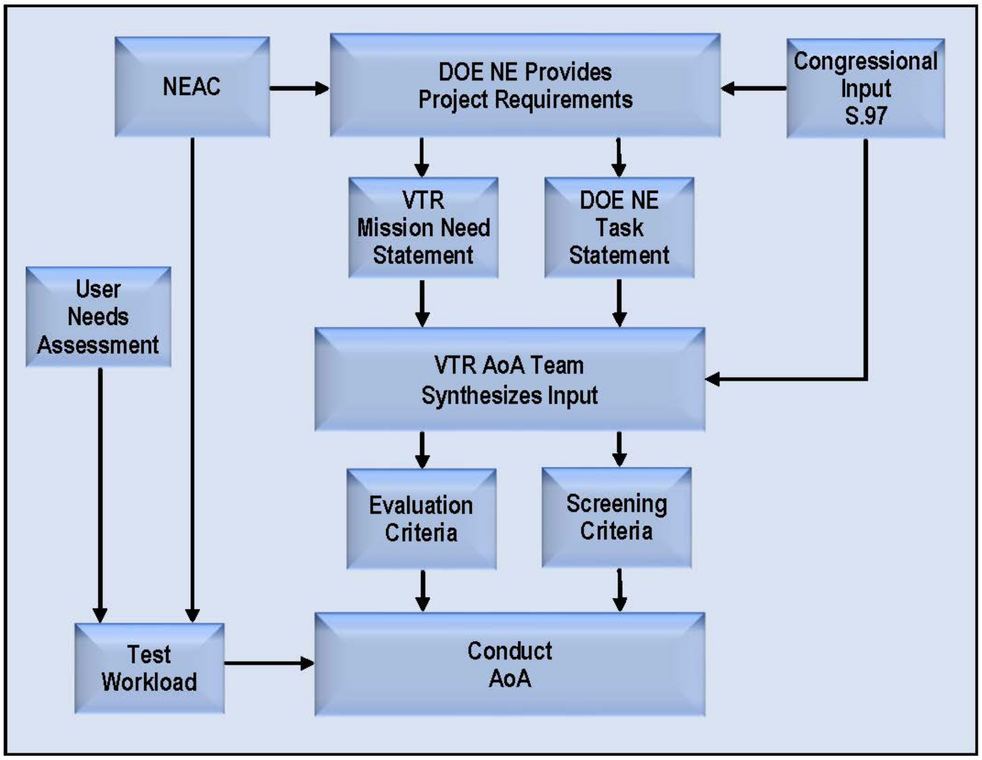

Figure 3-1. Approach to Conduct the AoA

3.2 Assumptions and Constraints

3.2.1 Principal Assumptions

The following principal assumptions were applied in performing this AoA:

- Project Requirements will be derived from the MNS, the DOE NE Task Statement, and applicable Congressional language.
- Fuel feedstock material will be made available for any viable alternative. The cost for driver fuel is not included in the LCCEs; however, the fuel fabrication capabilities were considered and evaluated as part of the analysis.

- There will be adequate facilities/processes in place to handle spent nuclear fuel and radioactive materials/waste produced by the VTR mission. The costs of these activities are assumed to be approximately equivalent for all alternatives considered and are not captured in the LCCEs; however, the adequacy of these facilities was considered during the analysis.

- Alternatives that exist or will be constructed on DOE sites will be regulated by DOE.

- Alternatives that exist or will be constructed on non-DOE (other government or commercial sites) will be regulated by the Nuclear Regulatory Commission (NRC).

- The same quantifiable "testing load" will be used to evaluate all viable Alternatives, including the Status Quo. See Section 6.3 for a discussion of testing load.

- This AoA is independent of the NEPA analysis. A full independent NEPA analysis will be conducted.

- Sufficient funding will be provided annually to support the VTR Project (note: funding availability was addressed as a threat in the risk analysis).

3.2.2 Constraints

In addition to identifying key assumptions, the VTR AoA Team applied the following VTR Project constraints:

- Existing test missions such as those in progress at ATR or HFIR will continue and will limit the availability and capacity of those facilities to meet the VTR Mission Need.
- Site visits were limited to a select few DOE sites where existing test reactor facilities, that may potentially fulfill parts of the VTR Mission Need are located. Additionally, the Team visited one other "generic" DOE site without an operating reactor but a history of nuclear technology and infrastructure. The Savannah River Site was used for this purpose.
- The site visits were limited to an evaluation of how the site's technology and infrastructure could meet some or part of the approved mission need. A complete Siting Study was not conducted.

4 ALTERNATIVES IDENTIFIED AND DESCRIBED

4.1 Description of Alternatives

The VTR AoA Project Team developed an initial set of alternatives during its kickoff meeting. This was accomplished by VTR AoA Team deliberations resulting in a diverse range of possible alternatives having the potential to meet the mission need. The objective of this exercise was to capture a broad set of alternatives without any predefined preference. The result of this activity was a total of 19 discrete alternatives: eighteen potential alternatives and the Status Quo alternative. Table 4-1 lists the resulting set of potential alternatives.

Table 4-1. Versatile Test Reactor Alternatives

Alternative		Description
1	Status Quo	No new facilities, no major modifications to existing facilities.
Use Existing Facility		
2a	Modify ATR with Fast Flux Booster	The ATR is a light-water cooled reactor located at the Idaho National Laboratory (INL). Currently using "thermal flux absorber" on irradiation vehicles to maximize fast flux component to simulate fast reactor environment. Installation of a BFFL on one lobe proposed to increase the fast flux into the required range.
2b	Modify High Flux Isotope Reactor (HFIR) to accommodate 3/7-pin configurations	The HFIR is a light-water cooled reactor located at the ORNL. Currently using "thermal flux absorber" on irradiation vehicles to maximize fast flux component to simulate fast reactor environment. Highest Fast Flux of existing facilities 1.0E+15. Options to boost the fast flux have been considered, such as incorporating a 3- or 7-pin irradiation vehicle for insertion in the center flux trap have been proposed to boost the fast flux and increase the irradiation volume.
2c	Install Materials Test Station at Los Alamos Neutron Science Center (LANSCE)	The Materials Test Station (MTS) that has been proposed by Los Alamos National Laboratory (LANL) is a proton-accelerator-driven target/irradiation facility that uses neutrons generated by the spallation process to perform irradiations. The neutron spectrum is similar to that of a fast reactor. The existing MTS design was predicated on upgrades to the LANSCE accelerator that were proposed in 2008 but never installed.
2d	Modify Spallation Neutron Source (SNS) to increase Fast Flux	SNS is a pulsed accelerator-driven spallation neutron source used for "scientific" R&D. SNS would require modification(s) to existing target station or a new target station (possibly with a substantial fission blanket) to meet mission requirements.
2e	Modify a University Reactor	University facilities such as the University of Missouri Research Center and Massachusetts Institute of Technology Research Reactors are thermal spectrum reactors and would require shielding the thermal flux in any irradiations to simulate fast-spectrum conditions. Reactors are relatively low power (6 and 10 MWth, respectively). Other university research reactors have less capability than these two.

Table 4-1. Versatile Test Reactor Alternatives

Alternative		Description
2f	Modify National Institute of Standards and Technology (NIST) Reactor	The NIST/National Bureau of Standards Reactor (NBSR) is in Gaithersburg, MD. It is a 20 MWth thermal spectrum reactor "over- subscribed" by science and other user communities.
2g	Restart and Modify FFTF	The FFTF is a 400 MWth SFTR located at the Hanford Reservation. It operated from 1982 to 1992 and is currently shutdown and in a safe storage condition with all fuel and sodium removed and an argon cover gas applied to all systems.
2h	Restart and Modify Experimental Breeder Reactor No. 2 (EBR-II)	EBR-II was a SFR that operated from 1964 through 1994. It was first used to demonstrate a complete fast breeder reactor fuel cycle, then converted to a burner reactor and used to test fuels and materials for advanced liquid metal reactors. After shutdown it was decommissioned and placed in a safe storage condition with all fuel and sodium removed. A passivation layer of sodium bicarbonate was applied to exposed sodium surfaces, and an inert cover gas blanket applied to all systems. It was later filled with grout and concrete, making it incapable of operation.
3	Use Foreign Fast Flux Test Reactor(s)	There are many thermal spectrum test reactors throughout the world, but far fewer fast spectrum test reactors in operation. The NEAC Report describes the four fast test reactors that exist now in Russia, China, India and Japan. The JOYO fast flux research reactor in Japan was shut down for repairs following a 2007 incident and is currently undergoing regulatory review before restart.
Build New Fast Flux Test Reactor		
4a	Fusion-fission Hybrid Test Reactor	A Deuterium-Tritium (DT) fusion reactor driving a fission source for flux multiplication and fission spectrum generation – such as an externally driven compact torus driving a U/Pu fission core with irradiation test positions.
4b	Sodium-cooled Fast Spectrum Reactor (SFTR)	A sodium-cooled fast-spectrum reactor – custom designed to produce the desired flux in irradiation test positions.
4c	High Temperature Gas-cooled Thermal Spectrum Reactor (HTGR)	A high temperature gas-cooled thermal-spectrum reactor, such as a He-cooled graphite-moderated reactor – custom designed to provide higher flux in irradiation positions.
4d	Thermal Molten Salt Test Reactor (MSTR)	A thermal-spectrum molten salt-cooled reactor, with either solid or molten-salt fuel – custom designed for higher flux in irradiation positions.
4e	Molten Salt Fast Test Reactor (MSFTR)	A fast-spectrum molten salt-cooled reactor, probably with molten-salt fuel – custom designed for high flux in irradiation positions.
4f	Lead/Lead bismuth Fast Test Reactor (LFTR)	A fast-spectrum reactor cooled with either Pb or Pb/Bi eutectic – custom designed to produce the desired flux in irradiation test positions.
4g	Super Critical Water-cooled Reactor (SCWR)	An epithermal-spectrum reactor cooled with supercritical water – custom designed to produce the desired flux in irradiation test positions.

Table 4-1. Versatile Test Reactor Alternatives

Alternative		Description
4h	Gas-cooled Fast Reactor (GFR)	A fast-spectrum reactor cooled with He gas – custom designed to produce the desired flux in irradiation test positions.
4i	New Accelerator Driven System (ADS)	Several designs have been developed for a linear proton accelerator to generate a spallation neutron source that would drive a subcritical blanket and produce a very high fast flux. In FY2001 the Advanced Accelerator Applications (AAA) program started work on an Accelerator Driven Test Facility (ADTF) concept for various potential missions including tritium production, medical isotope production, transmutation of used nuclear fuel elements, and testing of advanced nuclear fuels and materials. The ADTF never achieved CD-0 and thus the design was not developed beyond the conceptual stage. There were many technical challenges in the development of accelerator and spallation source components that would need to be resolved. A preliminary project schedule was developed which included ten years for design and construction. A new ADS concept meeting VTR objectives may be possible, given sufficient time and funding.

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5 INITIAL SCREENING OF ALTERNATIVES

5.1 Screening Criteria

The AoA Team reviewed available background documentation including the MNS, DOE NE Task Statement, and Congressional language, to develop the initial screening criteria that must be met to satisfy the mission. These criteria were extracted from the most essential program requirements specified by the MNS, guidance from the Task Statement and direction from the Congressional language. The source of each of these criteria can be found in Appendix C – C.2. These criteria were used to screen potential alternatives to determine whether an alternative is viable or non-viable. If an alternative was unable to meet one or more of these criteria, or only partially meets one or more criterion without compensating potential advantages, then it was deemed non-viable and not evaluated further. Thus, it was critical to clearly identify which requirements are essential to fulfilling the mission need and those which may be considered desired attributes or used to differentiate among alternatives during the subsequent evaluation analysis. Using this rationale, the Screening Criteria were defined as shown in Table 5-1.

Table 5-1. Screening Criteria

Number	Criteria	Source
1	The alternative shall provide an *intense* fast neutron irradiation environment with *prototypic* spectrum to determine irradiation tolerance and chemical compatibility of reactor fuels, materials and coolants, with the *versatility* to address *diverse technology* options and sustained and adaptable testing environments.	MNS, S.97
2	The alternative shall facilitate testing that provides a fundamental understanding of materials performance, validation of models for more rapid future development, and engineering-scale validation of materials performance in support of licensing efforts.	MNS
3	The alternative shall enable focused irradiations, either long- or short-term, with heavily instrumented experimental devices, and the possibility to do in situ measurements and quick extraction of samples.	MNS
4	The alternative shall become operational on an accelerated schedule to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets.	MNS
5	The alternative shall provide a versatile reactor-based fast neutron source, which can operate as a national user facility.	S.97
6	The alternative shall have capacity for upgrades to accommodate new or expanded research needs.	S.97

The AoA Team performed an initial screening of all identified alternatives using the Screening Criteria of Table 5-1. If any of the alternatives did not have the potential to significantly or totally meet every criterion, then the alternative was screened out from further consideration and the screening rationale documented below in Table 5-2. No further analysis was conducted for alternatives that were screened out. Table 5-3 summarizes the results of applying the Screening Criteria shown in Table 5-1 to each of the 18 potential alternatives plus the Status Quo shown in Table 5-1. (Note that the Status Quo alternative is evaluated with the viable alternatives but not screened out.)

Table 5-2. Application of Screening Criteria to Alternatives

Number	Alternative	Meets Screening Criterion					
		1	2	3	4	5	6
1	Status Quo	NA	NA	NA	NA	NA	NA
2a	Modify ATR with Fast Flux Booster	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
2b	Modify HFIR	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
2c	Install Materials Test Station at LANSCE	No	Yes	Yes	Yes	No	Yes
2d	Modify SNS to increase fast flux	No	Yes	Yes	Yes	No	Yes
2e	Modify a University Reactor	No	Yes	Yes	Yes	Yes	Yes
2f	Modify NIST Reactor	No	Yes	Yes	Yes	Yes	Yes
2g	Restart and Modify FFTF	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
2h	Restart and Modify EBR-II	No	Yes	Yes	No	Yes	Yes
3	Use Foreign Fast Flux Test Reactor(s)	Yes	Yes	Yes	No	No	Yes
4a	Fusion-fission Hybrid Test Reactor	No	Yes	Yes	No	Yes	Yes
4b	SFTR	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
4c	HTGR	No	Yes	Yes	Yes	Yes	Yes
4d	Thermal MSTR	No	Yes	Yes	Yes	Yes	Yes
4e	MSFTR	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
4f	LFTR	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
4g	SCWR	No	Yes	Yes	No	Yes	Yes
4h	GFR	No	Yes	Yes	No	Yes	Yes
4i	New ADS	Yes	Yes	Yes	No	No	Yes

Note: No means that the alternative did not have the potential to significantly or fully meet the criterion.
*All new reactor alternatives will be evaluated for siting at both a DOE site and a non-DOE site.
= Alternative meets Screening Criteria 1 through 6 (or is included as Status Quo) – these advance to full evaluation.

5.2 Alternatives Not Viable

The Team applied the Screening Criteria listed in Table 5-1 to the entire set of 18 potential VTR alternatives other than the status quo. It was determined that 12 of the potential alternatives are not viable, and therefore these alternatives are not evaluated further in this AoA. The list of non-viable alternatives is presented in Table 5-3 along with the rationale or justification for their elimination from further analysis in this AoA.

Table 5-3. Alternatives Determined Not Viable and Screened Out

Alternative	Criteria for Screening Out	Reason for Elimination
2c. Install Materials Test Station at LANSCE	1, 5	The Materials Test Station was originally proposed in 2006/2007 Its ability to support a spent fuel element transmutation mission was predicated on major upgrades to the LANSCE accelerator at LANL which have not occurred. Screened out primarily for: 1) This accelerator based option does not provide a "versatile *reactor*-based source" (per S.97) for fast neutron testing; and 2) To provide the *versatility* for a larger test volume and a more fission relevant fast neutron spectrum, a high-power fission multiplying blanket would be needed, which would make it primarily a new reactor build, which has been found to be problematic in the past at this site.
2d. Modify SNS to increase Fast Flux	1, 5	Screened out for several reasons, primarily: 1) This accelerator-based option does not provide a "versatile reactor-based source" (per S.97) for fast neutron testing; and 2) This intense *pulsed* spallation source is not representative of a steady fast neutron test environment needed for a *versatile* test facility, unless a high-power fission multiplying blanket is added, which makes it essentially a new reactor build. The VTR mission would also require a new and dedicated target station since current SNS target facilities serve the neutron science community.
2e. Modify a University Reactor	1	University reactors are all thermal neutron spectrum systems with low to intermediate flux levels. To provide a fast neutron test environment the thermal flux must be shielded out. The remaining fast flux in these reactors is insufficient to address the major portion of the VTR mission need. Screened out primarily because they cannot provide "an *intense* fast neutron irradiation environment with *prototypic spectrum* to determine irradiation tolerance and chemical compatibility of reactor fuels, materials and coolants".
2f. Modify NIST	1	The NIST research reactor is a thermal neutron spectrum design and is focused primarily on thermal (and lower energy) neutron experimental capabilities. It is relatively low power and is therefore screened out primarily because it cannot provide an *intense* fast neutron irradiation environment to address "diverse technology options and sustained and adaptable testing environments". The NIST reactor is also heavily subscribed by the neutron science user community.
2h Restart and Modify EBR-II	1, 4	The EBR-II reactor is decommissioned and filled with grout and concrete, making it incapable of operation. It was designed, built and operated as a power reactor demonstration facility. Screened out primarily on: 1) it cannot be recovered; and 2) cannot provide sufficient fast neutron irradiation environment (flux and volume) to address "*diverse technology* options and sustained and adaptable testing environments".
3. Use Foreign Fast Flux Test Reactors(s)	4, 5	Primarily screened out because this alternative does not "regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets" (per S.97). In addition, a foreign test reactor cannot "operate as a (U.S.) national user facility".

Table 5-3. Alternatives Determined Not Viable and Screened Out

Alternative	Criteria for Screening Out	Reason for Elimination
4a. Fusion-fission Hybrid Test Reactor	1, 4	The most likely 'near-term' fission-fusion system would be a 'driven' compact toroidal design with a substantial fast fission blanket (to provide a representative spectrum). Due to space constraints and magnet requirements in the center of the torus, the fission blanket is typically peripheral and the current compact fusion-fission hybrid designs cannot provide both extensive experimental irradiation volume and high fast-fission spectrum simultaneously to address the desired mission objectives. The current immature state of development for this type of reactor cannot ensure that a system can provide "*diverse technology* options and sustained and adaptable testing environments". Nor can it meet the accelerated schedule screening criterion 4.
4c. HTGR	1	The HTGR is a lower power-density thermal-spectrum design that cannot provide a significant fast neutron flux, and thus is not consistent with the VTR mission objectives. It is screened out primarily because it cannot provide "an *intense* fast neutron irradiation environment with *prototypic spectrum* to determine irradiation tolerance and chemical compatibility of reactor fuels, materials and coolants".
4d. Thermal MSR	1	The thermal MSR is inherently a lower power-density thermal-spectrum design that cannot provide a significant fast neutron flux, and thus is not consistent with the VTR mission objectives. It screened out primarily because it cannot provide "an *intense* fast neutron irradiation environment with *prototypic spectrum* to determine irradiation tolerance and chemical compatibility of reactor fuels, materials and coolants".
4g. SCWR	1, 4	The epithermal SCWR design does not operate with a prototypic fast reactor spectrum and requires very high core pressures requiring a massive high pressure boundary, which makes it very difficult to insert and recover test articles. It is screened out primarily on: 1) it cannot provide "an *intense* fast neutron irradiation environment with *prototypic spectrum* to determine irradiation tolerance and chemical compatibility of reactor fuels, materials and coolants, with the *versatility* to address diverse technology options and sustained and *adaptable* testing environments." and 2) In addition, the current state of development for this type of reactor cannot ensure that a system can provide "*diverse technology* options and sustained and adaptable testing environments".
4h. GFR	1, 4	A GFR that offers the high core power density necessary for high fast flux irradiation would operate at high temperatures, high gas pressures and high gas flow rates – which imply a significant high-pressure boundary, making it challenging to insert and recover test articles and thus it much less versatile than low pressure test reactors. It is screened out because: 1) It cannot provide "an *intense* fast neutron irradiation environment with *prototypic spectrum* to determine irradiation tolerance and chemical compatibility of reactor fuels, materials and coolants, with the *versatility* to address diverse technology options and sustained and *adaptable* testing environments." and 2) the current immature state of development for this type of reactor cannot ensure that it can "become operational on an accelerated schedule".

Table 5-3. Alternatives Determined Not Viable and Screened Out

Alternative	Criteria for Screening Out	Reason for Elimination
4i. New ADS	4,5	A new ADS could be designed to meet the intense high fast neutron flux requirements of the VTR over a very limited test volume and would require a large fission blanket to simultaneously meet flux, spectrum and irradiation volume objectives. There are also many technical challenges associated with both the linear proton accelerator and the SNS that would need to be resolved before construction could start. The technical immaturity of this concept would preclude its availability on an accelerated schedule to meet the VTR requirement to regain U.S. technology leadership and competitiveness in the advanced reactor markets. The ADS is also not a reactor-based system as required by S.97 language.

5.3 Viable Alternatives

After applying the Screening Criteria in Table 5-1 to the potential alternatives in Table 5-2, the VTR AoA Team determined that six alternatives are viable. Table 5-4 provides a list of these Alternatives along with a summary description. The Status Quo alternative is also included for completeness and comparison. More detailed descriptions of each alternative, together with relevant advantages/disadvantages, can be found in Appendix D.

Table 5-4. Viable Alternatives for Evaluation

Alternative	Description
Base Case (Status Quo)	No new facilities, no major modifications to existing facilities. Limited fast flux capability in the U.S. HFIR at ORNL currently has highest fast flux. ATR has less. Both test reactors have a large thermal flux component which is not representative of fast reactors, so testing results would be of limited value, although there has been some success in utilizing a thermal neutron absorber on the irradiation vehicle to improve the fast-to-thermal flux ratio. Sufficient damage accumulation in low fast flux environment takes many years (20 to 50). Extremely limited DOE use of foreign fast test reactors due to cost, transportation and political issues. Industry vendors who need fast flux test capability will continue to use DOE user facilities with long wait time for results, propose demonstration plant to be used as a test facility ("license by test protocol"), or try to get into foreign fast test reactors at their own expense.

Table 5-4. Viable Alternatives for Evaluation

Alternative	Description
Modify ATR by addition of BFFL	The ATR is a light-water cooled reactor located at the INL. The reactor's primary "customer" is the U.S. Navy, but over the past several years it has been used by the AFC of the DOE NE FCRD program to irradiate a broad spectrum of fuels and cladding materials of interest, as well as by other NE programs. The reactor is typically operated at a power level in the range of 110 to 120 MWth and has a maximum thermal flux of 1.0E+15 n/cm^2-s, and maximum fast flux of 5.0E+14 n/cm^2-s. There has been an interest in utilizing the ATR to support the testing of advanced fuels and materials for improved resource utilization and waste management missions, as well as to support advanced reactor developers. The absence of a domestic facility to provide the prototypic neutron testing environment required to support advanced reactor development and licensing was evident. To respond to this need, which included a fast neutron flux of 2E+15 n/cm^2-s the AFC/ATR developed and implemented an irradiation capsule design with a "thermal flux absorber" (e.g., cadmium) to minimize the thermal component of the flux to approximate a fast spectrum; and proposed (but did not implement) a Boosted Fast Flux Loop (BFFL) to increase the fast flux into the required range. This alternative assumes implementation of the BFFL.
Modify High Flux Isotope Reactor (HFIR) to accommodate 3/7-pin configurations	The HFIR is a light-water cooled reactor located at the ORNL. The reactor has a power level of 85 MWth and associated maximum thermal and fast fluxes of 3.0E+15 and 1.0E+15 n/cm^2-s, respectively. The primary application of the HFIR is neutron scattering and isotope production (e.g. medical, Pu238, …). It has been used by the AFC of the DOE NE Fuel Cycle Research and Development (FCRD) program to irradiate fuels and cladding materials of interest, as well as by other NE and non-NE programs. Irradiations designed to approximate a fast spectrum also use a "thermal flux absorber", e.g., Eu2O3, to minimize the thermal component of the flux. Options to boost the flux to the desired target may be feasible, such as incorporating a 3- or 7-pin irradiation vehicle for insertion in the center flux trap have been proposed to boost the fast flux and increase the irradiation volume. There is infrastructure on site to support many/most of the irradiation and PIE requirements of ongoing programs and the VTR mission.
Modify and Restart FFTF	The FFTF is a deactivated fast test reactor located at the Hanford Reservation in Washington. It is a 400 MWth sodium-cooled fast reactor that used mixed oxide driver fuel and operated from 1982 through 1992. It was used to test fuels (Including metal fuels) and materials for fast reactors and is potentially capable of being reactivated to meet the fast neutron irradiation requirements of the VTR project. The nearby dormant FMEF could also be reactivated to provide support for fuel fabrication, although significant modifications would be necessary to manufacture metal fuels. It could also support pre- and post-irradiation examination of test fuels and materials. There are significant technical, political, and experimental challenges that would have to be addressed if this option were selected as the preferred alternative, including component age-related material degradation, repairs to and recertification of systems modified to support deactivation, upgrades to meet current codes and standards including seismic, and upgrades to meet potential user experimental needs.

Table 5-4. Viable Alternatives for Evaluation

Alternative	Description
SFTR	A new SFTR based on proven technologies built and operated in the past is proposed as a viable alternative for the VTR. The reactor performance requirements can be met, and the experimental user needs can be incorporated into a properly designed SFTR technology-based test reactor, probably in the 250 – 400 MWth range. Liquid sodium has a high thermal conductivity and heat capacity and is compatible with steels and metal alloy fuels. Coolant purification technology and passive safety features have been demonstrated on large scale. The inherent reactivity of sodium requires an inert atmosphere for refueling and maintenance. The experience and lessons learned from the design, construction and operation of several SFTRs, research reactors and commercial reactors around the world can be used to minimize the technical, cost and schedule risks of this technology.
LFTR	A Pb or Pb-Bi-cooled-fast test reactor would be a new fast spectrum reactor cooled by either lead or lead-bismuth eutectic. The test reactor could be leveraged off any one of several conceptual designs for LFR power reactors, modified to incorporate test irradiation locations in the core to accommodate both static and dynamic experiments. An LFTR could be amenable to a high power density core and could achieve the desired irradiation conditions with a reactor in the 250-400 MWth range. Either pure Pb or Pb-Bi eutectic could be used for coolant. The preferred fuel for highest flux would probably be U/Pu-nitride. A pool-type design could facilitate experiment access, with in-vessel heat exchangers and above-pool access to experimental channels. Pb coolants have advantages in high thermal capacity, low pressure operation, hard neutron spectrum, high thermal margin to voiding and lack of chemical reactivity. Challenges include new fuel and core materials, and corrosion control. No heavy metal cooled reactors have been built in the U.S., but a number have been tested and fielded abroad, although none were high-flux irradiation test reactors.
MSFTR	A Molten Salt-Cooled-FTR would be a fast spectrum reactor cooled/fueled by molten salt. Options could include both a solid-fuel salt-cooled concept or more likely a molten salt fueled concept (allows greater flexibility in accommodating test articles due to absence of solid fuel assemblies) – to achieve high power density and high flux for irradiation. The reactor could be leveraged off any one of several conceptual designs for MSFTR power reactors, modified to increase flux and to incorporate test irradiation locations in the core to accommodate both static and dynamic experiments. Fast spectrum MSFTR designs are amenable to high power density cores and could achieve the desired irradiation conditions with a reactor in the 250-400 MWth range. A typical fuel/coolant would be chloride salt loaded with dissolved U/Pu. A pool-type design could facilitate experiment access, with above-pool access to experimental channels. Molten salt fuel has advantages in thermal capacity, low pressure operation, ability to retain actinides and fission products, high thermal margin to voiding, transparency and low chemical reactivity. Challenges include new fuel and core materials, and proliferation/safeguard concerns for liquid fuel designs. Several thermal MSR test reactors have been built and there is both foreign and domestic interest in both thermal and fast MSR concepts.

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6 EVALUATION CRITERIA

6.1 Evaluation Criteria

The VTR AoA Team facilitated group discussions focused on developing the desired attributes (i.e., evaluation/selection) to be used in determining the effectiveness of each alternative in meeting the mission need. These criteria were developed independent of identifying the potential alternatives and reflect the desired attributes of the project directly in support of the mission and associated requirements. In this report, each criterion is described with a rationale for why it was chosen, along with a reference to how it supports one or multiple mission and project requirements. The source of each of these criteria can be found in Appendix C – C.2. The detailed desired attributes (i.e., final evaluation criteria) that were developed by the VTR AoA Team are presented in Table 6-1.

Table 6-1. Evaluation Criteria

No.	Desired Attribute	Additional Description	Source
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users	Provides a high peak neutron flux (neutron energy > 0.1 MeV) with a prototypic fast reactor neutron energy spectrum. Target fast flux: ≥ 4 x 10^{15} n/cm^2-s	MNS, S.97
2	Provides high neutron dose rate for materials testing [quantified as dpa]	Provides a combination of fast flux and experimental duty cycle that enables accelerated damage testing. Target irradiation capability: > 30 dpa/year (for Fe based alloys).	MNS
3	Provides an irradiation length that is typical of fast reactor designs	Allows irradiation of prototypical length fuel elements. Target testing length: L≥0.6 meters.	MNS
4	Provides a large irradiation volume within the core region	Includes sufficient versatile test space for a diverse mix of future test needs. Target testing volume ≥ 7 L.	MNS, S.97
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	Potential for standard or flexible test positions, closed loops, rabbits and capability for Na, Pb, Pb-Bi, He, Molten Salts loops.	MNS, S.97
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	Capability for in-situ and real-time measurements and flexible detector testing.	MNS
7	High technical confidence the facility can be available for testing as soon as possible	Uses proven technologies with high technology readiness level (TRL). Less technical risk based on prior industry experience or developmental efforts.	MNS
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and PIE	Easier access to existing research support and/or ability to add support as needed for future needs. If practical, avoids transportation through public roads.	MNS, S.97
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	Must be evaluated based on cost and schedule impact with consideration for using existing DOE infrastructure when available. Considers degree of necessary modifications or additions needed for fuel life-cycle management.	MNS
10	Provides capabilities that support experimental high-temperature testing	Provides the ability to test materials and fuels at representative temperatures for a diverse mix of future test needs.	S.97

Table 6-1. Evaluation Criteria

No.	Desired Attribute	Additional Description	Source
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	Includes ability to test with softened spectrum neutrons if needed (<0.1MeV).	S.97
12	Lower Capital Investment (Total Project Cost)	Lower design, construction, startup, and commissioning costs.	S.97
13	Lower Annual Operating and Maintenance Costs during operations	Based on O&M costs determined in life-cycle cost estimates.	S.97
14	Lower PV of life-cycle costs	Includes incremental program PV life-cycle costs including D&D.	S.97
15	Shortest schedule to initiate operations	Shortest schedule for completion of capital project, recognizing legislative target for start of operations by December 31, 2025.	S.97
16	Ease of meeting security requirements	Can accommodate or have access to facility(ies) that meets security requirements for nuclear materials and nuclear operations.	General AoA Criteria
17	Greater ease and confidence of compliance with codes, standards, regulations	Utilizes proven technologies, systems and processes, considered independent of a specific site.	General AoA Criteria
18	Higher confidence in stakeholder acceptance	Includes, but not limited to: Congress, Federal, State, Local and Industry interests.	General AoA Criteria
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	Supports diverse technology development and deployment	MNS
20	Adequate availability to meet user needs and minimum conflict with other existing missions (if any)	Consideration of existing mission of facilities and locations where new capability is to be provided.	General AoA Criteria

6.2 Evaluation Criteria Weights

Following the identification of the Evaluation Criteria, the VTR AoA Team, in conjunction with DOE NE SMEs, established the scale that was used to weight each attribute to reflect its relative importance to of the requirements. The weighting factors are non- linear. The most important attribute weighting is "5", while the next most important attribute weighting is "3." This adds emphasis to the highest attribute importance. Each weighting factor is used to establish relative weights (RW) and normalized relative weights (NRWs). Relative weights are established by taking the weight (5, 3, 2, and 1) associated with the importance level and dividing it by the total number of evaluation criteria (i.e., 20). For example, criteria with the highest importance have a relative weight of 0.25 (5÷20=.25). The NRW is accomplished by multiplying the RW for each criterion by 100 and dividing it by the total sum of all 20 relative weights (i.e., 3.80). For example, a relative weight of 0.25 is multiplied by 100 and divided by 3.80 to result in a normalized relative weight of 6.58. Table 6-2 details the weighting scale used in the evaluation of each attribute[3].

Table 6-2. Attribute Weighting Scale

Attribute Importance	Importance Ranking	Weighting Factor
Highest importance (borders on a requirement)	1	5
Very important (highly desirable)	2	3
Medium importance (desirable)	3	2
Lowest importance	4	1

Changing the criteria after the identification of alternatives and subsequent scoring presents challenges to maintaining the integrity of the AoA process in not predefining a desired outcome. Thus, the VTR AoA Team obtained concurrence on the Evaluation Criteria from the federal government SMEs in advance of alternative development. The weights shown in Table 6-3 reflect the results of this process.

[3] The common convention in AoAs is to use the NRW. Therefore, the NRW is calculated and presented in Table 6-3.

Table 6-3. Weighted Attributes

No.	Desired Attribute	Importance	Weight	Relative Weight	Normalized Relative Weight (NRW)
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users	1	5	0.25	6.58
2	Provides high neutron dose rate for materials testing [quantified as dpa]	1	5	0.25	6.58
3	Provides an irradiation length that is typical of fast reactor designs	1	5	0.25	6.58
4	Provides a large irradiation volume within the core region	1	5	0.25	6.58
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	1	5	0.25	6.58
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	2	3	0.15	3.95
7	High technical confidence with the facility can be available for testing as soon as possible	1	5	0.25	6.58
8	Expedites experiment life cycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	1	5	0.25	6.58
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	4	1	0.05	1.32
10	Provides capabilities that support experimental high-temperature testing	1	5	0.25	6.58
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	3	2	0.1	2.63
12	Lower Capital Investment (Total Project Cost)	2	3	0.15	3.95
13	Lower Annual Operating and Maintenance Costs during operations	3	2	0.1	2.63
14	Lower PV of lifecycle costs	2	3	0.15	3.95
15	Shortest schedule to initiate operations	2	3	0.15	3.95
16	Ease of meeting security requirements	4	1	0.05	1.32
17	Greater ease and confidence of compliance with codes, standards, regulations	1	5	0.25	6.58
18	Higher confidence in stakeholder acceptance	2	3	0.15	3.95
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	1	5	0.25	6.58
20	Adequate availability to meet user needs and minimum conflict with other existing missions (if any)	1	5	0.25	6.58
	Total			**3.80**	**100.00**

6.3 Testing Workload

The Evaluation Criteria outlined in Section 6.1 include desired quantitative or adequately descriptive targets for fast neutron flux, annual dpa rate, sample length, sample volume and potential test environments. However, several of the Evaluation Criteria also imply a desired testing workload or throughput capacity related to available irradiation time, range of environmental test conditions, sample types, and quantities that have not been provided in any quantitative or descriptive sense useable for comparison. These 'testing workload capabilities' are implied by terms such as: 'sufficient to enable research for an optimal base of prospective users', 'space for a diverse mix of future test needs', 'flexibility in testing configuration' and 'supports diverse technology development'. The ability to measure and compare these capabilities is important to the conduct of the AoA.

In the absence of such targets for testing capacity, the AoA Team developed a representative 'Testing Workload' – from available documents, such as the MNS, NEAC reports, industry workshop reports, historical testing workloads for irradiation facilities and informal discussion with managers for materials and fuels D&D. This representative Testing Workload includes:

- Test availability for decades (40+years)
- Simultaneous medium to long term (years to decades) irradiation time of prototypic length fuel rods, lead test assemblies or components in prototypic coolant environments – quantity '1 to 10'
- Simultaneous medium to long term (years to decades) irradiation time of small fuel samples (rodlets, pellets, etc.) – quantity 'tens'
- Medium to long term (years to decades) irradiation time of small material test samples (swelling, creep, embrittlement, etc.) in controlled environments – quantity 'hundreds'
- Short term (hours to months) irradiation time of small material samples (such as via 'rabbits') – quantity 'tens to hundreds per year'
- In-core and /or ex-core testing of detectors – quantity '1 to 10'

This working representation of a Testing Workload was used to compare alternatives against several of the Criteria.

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7 COST AND SCHEDULE ESTIMATES

7.1 Cost Estimates Overview

LCCEs were developed for each of the six VTR Project viable alternatives. Additionally, an LCCE was developed for Alternative 1 – Status Quo. The life cycle costs include all upfront capital costs, operations, maintenance, periodic major upgrades over the operating life, and end-of-life D&D, including appropriate escalation allowances. The LCCEs are only intended to be used to support the VTR AoA for comparing each alternative's life cycle cost and are not considered budget quality estimates.

The basis and assumptions used for the LCCEs and the calculations of TPC and PV for each alternative are described in Appendix E. Appendix E also discusses how these estimates were developed in accordance with the best practices for developing and managing capital program costs found in the *GAO Cost Estimating and Assessment Guide*.

The estimated capital project costs for each of the VTR Project alternatives were time-phased using the alternative-specific summary level project development schedules discussed in Section 7.5 and depicted in Appendix F. The time-phasing of capital costs used to calculate the total TPC, including escalation allowance, is based on dates that represent an average of the two schedules presented for each alternative. No capital investment is assumed to be needed for Alternative 1 – Status Quo.

All alternatives were compared using life cycle estimates that span an assumed 40-year operational life. The actual timing of that operational life varies by alternative, beginning in the year following the point in time when the CD-4 milestone is scheduled to be approved for each alternative. For the Status Quo alternative, the operational life cycle was assumed to begin in FY2026.

7.2 Cost Estimate Approach

The basis and approaches used to develop the cost estimates for each alternative are described and presented in Appendix E. In general, the estimates were developed as follows:

- For Alternatives 2, 3 and 4, which involve modifications of existing facilities, the capital cost estimates are based on prior studies, reports and cost estimates [6, 14, 15, 16]. Although these estimates generally date to the 2007 time period, the costs were consistently escalated to FY2019 using a rate that is accepted as reasonable within DOE for that time period.

- For the SFTR alternative (Alternative 5), the capital cost estimate is based on the recent Independent Cost Review (ICR) completed by DOE's Office of Project Management (PM): *Independent Cost Review of the Versatile Test Reactor Project, Critical Decision-0, Approve Mission Need*, December 2018[8, 10]. The point estimate generated by the ICR Team was believed to provide the most valid data point for the SFTR. It was subsequently adjusted slightly with costs added for safety basis efforts and potential M&O oversight/support, consistent with the assumptions used for the other alternatives. Costs were time-phased using the schedules developed for the alternative (an average of the aggressive and nominal schedules) and appropriate escalation allowances were added.
- The costs for the LFTR (Alternative 6) and MSFTR (Alternative 7) were developed by factoring the SFTR costs based on AoA Team SME expertise and judgement.

- For all alternatives, a consistent set of parameters were used to estimate (or, in the case of the new reactor alternatives, to break-out) the costs for project management/administration, engineering/design, and start-up/commissioning (based on or in addition to the estimated procurement/construction costs) to facilitate both cost estimate development and the time-phasing of estimated costs for escalation and PV calculations.
- Operational period costs were estimated based on assumed staff sizes and annual costs per full-time equivalent (FTE). The assumptions were derived from feedback obtained during the site visits conducted by the AoA Team as well as the current budgets and staffing data provided by the HFIR (ORNL) and ATR (INL) Teams and the experience of the FFTF.
- Fuel fabrication costs are considered in a generic manner consistent with likely fuel needs for each alternative, and not as an explicit cost factor – because the fuel characteristics and quantities for each alternative cannot be known prior to design studies. Fuel fabrication cost is not captured explicitly for each alternative because sufficient and acceptable information is not available to support a defensible basis of estimate for all alternatives. However, the cost estimate for auxiliary facilities that could be used to support fuel fabrication are addressed in Appendix E, Section E.2.1.
- The costs associated with managing spent nuclear fuel have not been estimated due to the lack of clarity regarding spent fuel characteristics, quantities, and ultimate treatment/disposal path.

All capital project estimates include appropriate allowances for contractor Management Reserve (MR) and DOE Contingency. However, the distinction as to which category those allowances will be managed during project execution was not considered in developing the AoA estimates. Rather, a total allowance that is based on an assessment/analysis of both estimate uncertainties and risks has been added to the estimates.

The full set of assumptions and parameters used to develop the alternative estimates can be found in Appendix E.

7.3 Cost Estimate Results

Table 7-1 presents the results of the LCCEs for each alternative, in terms of both "as-spent" (i.e., escalated to time of expenditure) dollars and PV which is the most appropriate value to be used for alternative comparisons.

Table 7-1. Life Cycle Cost Estimate Results ($M)

Cost Estimate Summary		
Alternative	**As-Spent**	**PV**
Alternative 1 – Base Case / Status Quo	2,756	1,035
Alternative 2 – Modified ATR	6,654	2,505
Alternative 3 – Modified HFIR	2,680	1,128
Alternative 4 – Modify and Restart FFTF	16,774	6,705
Alternative 5 – SFTR	20,559	9,995
Alternative 6 – LFTR	27,432	11,287
Alternative 7 – MSFTR	28,159	11,747

The alternative cost estimates are broken down by major element in Figure 7-1 and Table 7-2 in As-Spent $'s, and in Figure 7-2 and Table 7-3 in terms of PV.

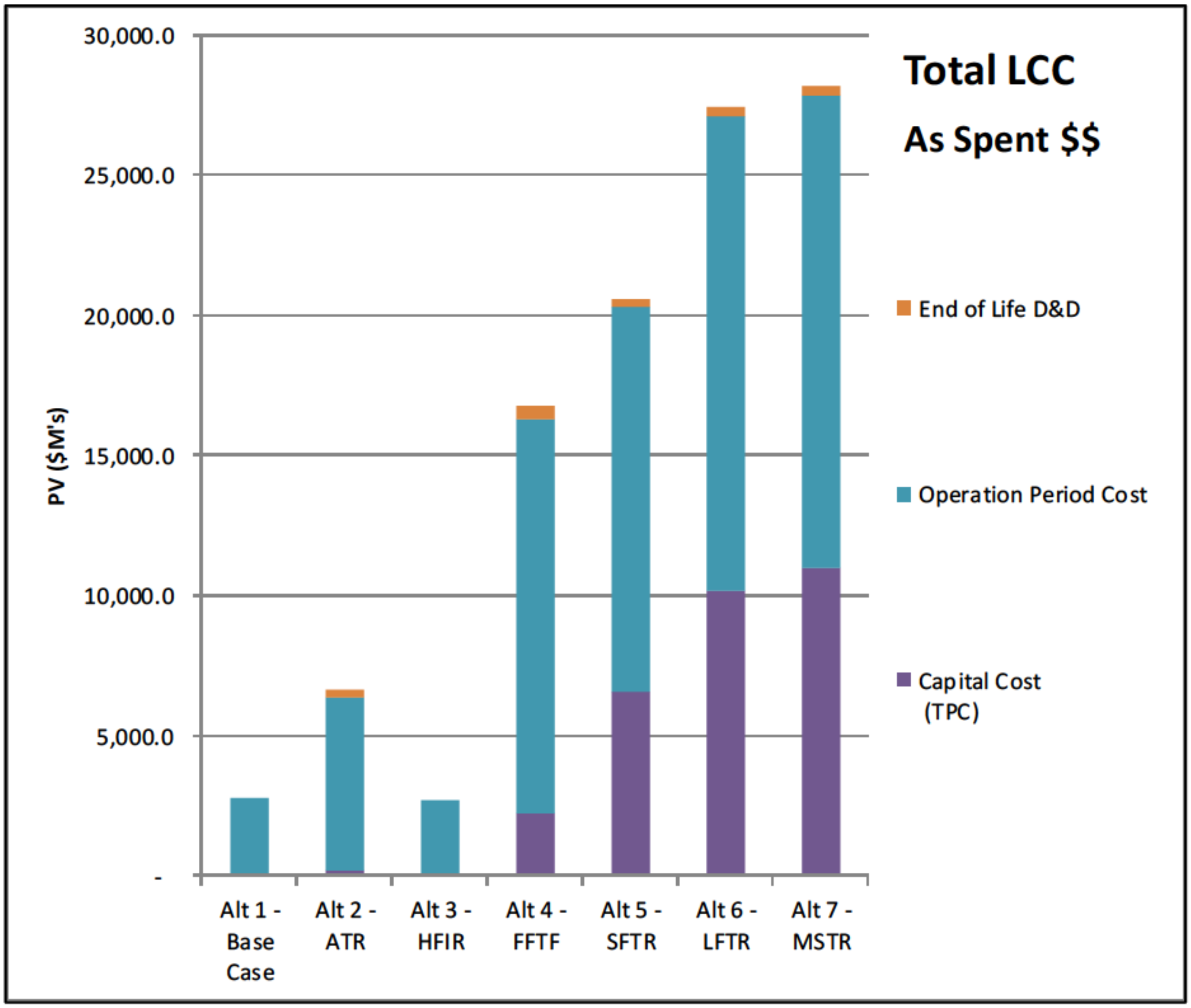

Figure 7-1. Alternative LCC in As-Spent $'s

Table 7-2. Life Cycle Cost Estimate Breakdown – As-Spent ($M)

Alternative	Capital Costs (TPC)	Operations Period Costs	D&D	Total LCC
Alternative 1 – Base Case / Status Quo	–	2,756	–	2,756
Alternative 2 – Modified ATR	190	6,206	258	6,654
Alternative 3 – Modified HFIR	76	2,603	–	2,680
Alternative 4 – Modify and Restart FFTF	2,240	14,077	457	16,774
Alternative 5 – SFTR	6,579	13,698	282	20,559
Alternative 6 – LFTR	10,145	16,930	357	27,432
Alternative 7 – MSFTR	11,004	16,798	357	28,159

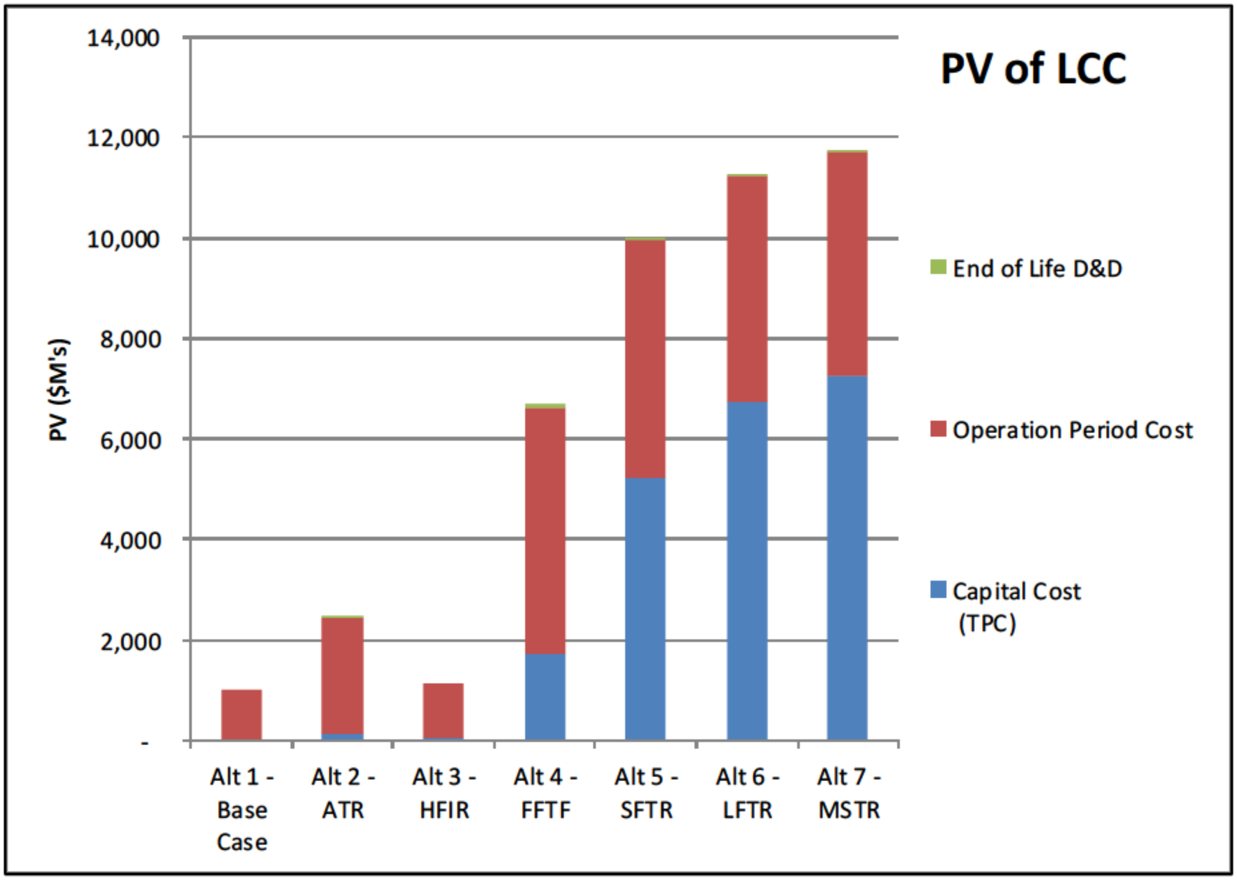

Figure 7-2. Alternative LCC PV

Table 7-3. Life Cycle Cost Estimate Breakdown – PV ($M)[1]

Alternative	Capital Costs (TPC)	Operations Period Costs	D&D	Total PV
Alternative 1 – Base Case / Status Quo	–	1,035	–	1,035
Alternative 2 – Modified ATR	156	2,308	41	2,505
Alternative 3 – Modified HFIR	66	1,062	–	1,128
Alternative 4 – Modify and Restart FFTF	1,746	4,890	68	6,705
Alternative 5 – SFTR	5,212	4,741	42	9,995
Alternative 6 – LFTR	6,742	4,504	42	11,287
Alternative 7 – MSFTR	7,243	4,462	42	11,747

[1] PV calculation uses Office of Management and Budget (OMB) nominal discount rate applied to escalated, as-spent dollars.

There is uncertainty associated with several of the assumptions and key parameters used for this analysis. All estimates used in developing the LCC are Class 5 estimates; therefore, a large range is expected in the accuracy of those estimates based on the data available at this time. The ranges presented in Table 7-4 were used to establish cost ranges for each of the five alternatives. The range for Capital Cost (TPC) and D&D is based on DOE G 413.3-21 for a Class 5 estimate, i.e., from –50% to +100%. However, because of the large degree of uncertainty associated with modifying existing facilities, combined with the lack of current cost estimates to accomplish that effort and, in the case of the FFTF, knowledge as to current facility conditions, the ranges used for the alternatives involving existing facility modifications have been assumed to be even broader. Because operational period costs are based on assumed staffing sizes and staff costs per FTE, a narrower range has been assumed for those cost estimates.

Table 7-4. VTR AoA Life Cycle Cost Range Summary

WBS/LCC Element	Modified Facilities		New Reactors	
	Low Range, %	High Range, %	Low Range, %	High Range, %
Capital Cost (TPC)	-50%	150%	-30%	100%
Operation Period Cost	-30%	50%	-30%	50%
D&D of New Facilities (EOL)	-50%	100%	-50%	100%

Figure 7-3 presents the estimated PV of the LCC for each alternative based on the above assumed ranges. Figure 7-4 presents the estimated Initial TPC for each alternative based on the above assumed range for capital costs. The high range values for the capital costs for Alternatives 6 and 7 also include an allowance for a potential pilot plant that may be needed to confirm the viability of the reactor technology and provide a basis for the design and licensing of the test reactor. The values that lead to these results, including the LCC by element, are provided in Appendix E.

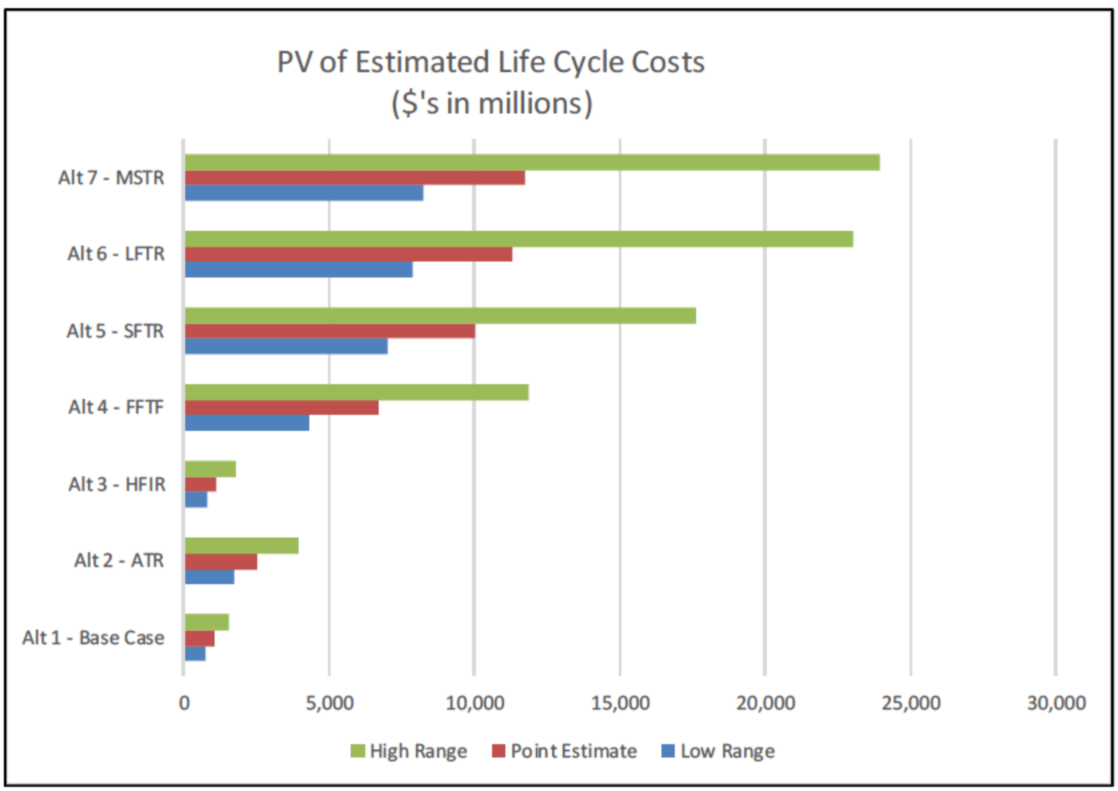

Figure 7-3. Range of PV of LCC for VTR Alternatives

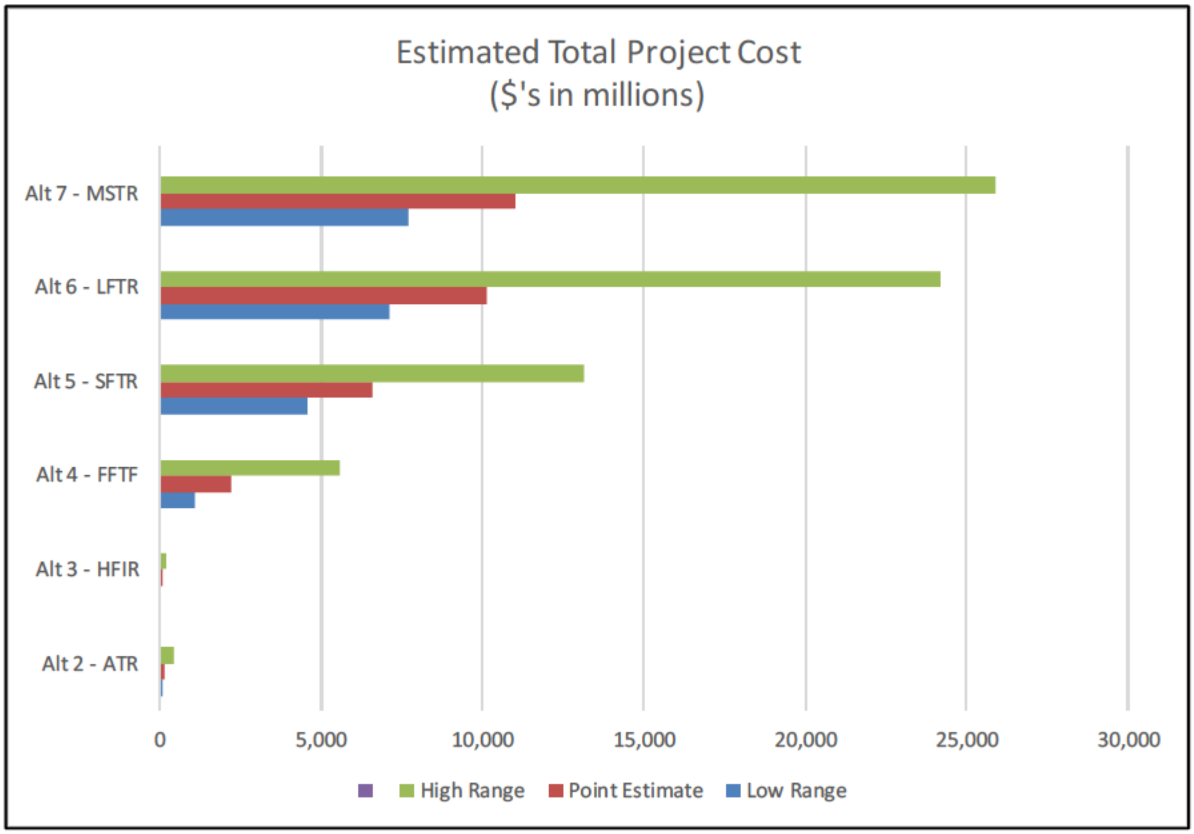

Figure 7-4. Range of Initial TPC for VTR Alternatives

7.4 Cost Sensitivity

The VTR alternatives being considered and compared fall into two groups: those that make use of existing DOE reactor facilities and those that involve the construction of a new test reactor at some potential site. The evaluation of these alternatives is largely dependent on the technical criteria that have been established and the degree to which the existing facilities can be modified to accomplish the stated VTR mission. The construction of a new reactor may not be the most attractive alternative from either an initial capital cost or life cycle cost perspective. Although potentially less costly than the construction of a new reactor, the restart and use of the FFTF may provide the most technical benefit of the alternatives that do not involve construction of a new reactor. However, that alternative also is expected to be significantly costlier than the alternatives that make use of the ATR or HFIR. The FFTF alternative also has many potential risks and uncertainties associated with it, as discussed elsewhere in this report.

The costs that have been excluded from the LCCES for each alternative (due to lack of basis for estimation) relative to fuel supply/fabrication and spent nuclear fuel treatment/disposal will not materially impact the comparison of the three sets of alternatives evaluated (use of existing facilities, restart and use of FFTF, or construction of new reactor). However, it is possible those excluded costs, if estimated and included for each of the new reactor alternatives, could have an impact on the comparison of those three alternatives. However, such analysis of the three new reactor alternatives requires further detailed development of conceptual design basis for each of those alternatives that is beyond the scope of this AoA.

Key estimating assumptions should be considered during a sensitivity analysis, as recommended by the GAO best practices and as contemplated when the AoA Estimate Plan was developed. However, given the set of alternatives under consideration, the AoA Team has determined that there are no significant assumptions used for the cost estimates developed for this AoA that may potentially impact the comparison of either initial capital or life cycle costs for the alternatives. This is because the assumptions were applied consistently across all alternatives and any variation in those factors or methodologies would have a similar impact on each alternative and not affect the overall ranking of alternatives from a cost perspective.

The one exception that does warrant consideration is the potential to perform the PV calculations using the Office of Management and Budget's (OMB's) recommended "Real" discount rate that is applied to current year (i.e., non-escalated) expenditures, as compared to the use of the nominal discount rate used for the results shown in Table 7-3. Because the assumed escalation rate used for the capital project costs is higher than the rate implied by the OMB discount rates (difference between nominal and real rates), an alternative PV calculation will tend to negate the potential impacts of lengthier schedules to implement the new reactor technology alternatives that are expected to take longer to reach initial operations (see Schedule discussion in Section 7.5). This can be seen in the results of such an alternative PV analysis, as shown in Table 7-5, which demonstrates less difference in the estimated costs for the 3 new reactor alternatives. These results also reflect the cost benefit of expenditures further out in time being less costly from a PV perspective (for example, the D&D of the LFTR and MSFTR, as compared to the SFTR which is assumed to start/end operations at an earlier point in time).

Table 7-5. Results of PV Calculation Based on Real Discount Rate ($M)

Alternative	Capital Costs (TPC)	Operations Period Costs	D&D	Total PV
Alternative 1 – Base Case / Status Quo	–	1,078	–	1,078
Alternative 2 – Modified ATR	146	2,406	27	2,579
Alternative 3 – Modified HFIR	64	1,104	–	1,168
Alternative 4 – Modify and Restart FFTF	1,595	5,110	44	6,749
Alternative 5 – SFTR	4,804	5,204	27	10,036
Alternative 6 – LFTR	5,677	4,636	25	10,338
Alternative 7 – MSFTR	6,071	4,662	25	10,757

7.5 Schedule Analysis

7.5.1 Approach

The VTR AoA Team supported the development of two schedules for each of the six alternatives in Table 5-4, resulting in a total of twelve schedules. These schedules are of importance to Selection Criteria 15 in Table 6-1 and Screening Criterion 4 in Table 5-1, both of which stem from the MNS that recommends NE proceed with developing a VTR facility on track for completion before 2026.

A summary of the schedule estimates is provided in Figure 7-5, and each individual schedule, along with their basis, are provided in Appendix F.

Because several of the alternative technologies have been analyzed previously, schedule estimates for those technologies already exist. Those estimates that were developed previously were utilized during the development of the schedule estimates shown here to the extent that they were applicable and up to date.

Changes that have occurred since the development of the existing schedule estimates were accounted for via discussion with the technical experts on the VTR AoA Team.

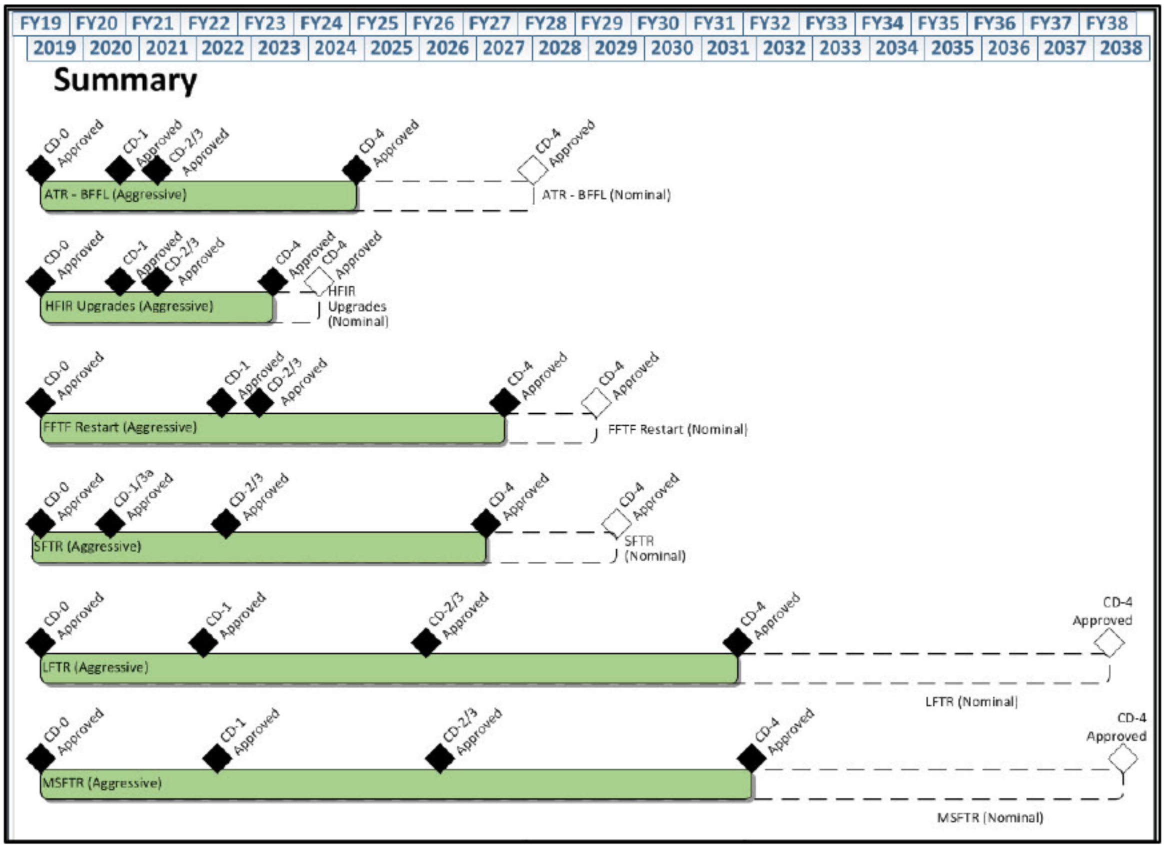

Figure 7-5. Schedule Estimate Summary

An aggressive and a nominal length schedule were developed for each alternative. This approach provided additional insight when comparing alternatives. Normalization based on estimated effort was also performed across design phases where sufficient schedule detail was not available from the sites. For additional information on this, see Appendix F.

7.5.2 Key Assumptions

When developing the schedule estimates, the following key assumptions were made:

1. All of the schedules (nominal and aggressive) assume that the critical decision (CD) process, as outlined in DOE O 413.3B, would be tailored for simultaneous approval of CD-2 and CD-3.

2. The LFTR and MSFTR alternatives are known to require extensive R&D efforts, and it is assumed that they will also require development of a pilot plant in the nominal case.

3. It is assumed that the NEPA process will not influence critical path for the purposes of this comparative analysis. This assumption was based on direction provided by the DOE Office of Nuclear Energy.

4. The schedules were developed using Primavera (P6) and are represented in this report using Visio diagrams for readability purposes.

7.5.3 Results

For the purposes of comparing alternatives, the completion date suggested by the MNS (FY2026) was used as a marker to signify expediency. The only three schedules that were estimated for completion on or before 2026 were HFIR Upgrades Aggressive (May 2023) and Nominal (March 2024), and ATR BFFL Aggressive (November 2024). The reason for these early completion dates is the relatively short design and construction activities due to the nature of performing an upgrade on a functional and licensed facility.

The next earliest CD-4 date was estimated to be achieved by the SFTR Aggressive schedule in February of 2027. This schedule was estimated for completion before most of the other large facility fabrication and restart efforts because the CD approval process has been tailored to allow for concurrent CD 2/3a approval, which would allow for an early start on long lead procurements. The SFTR Aggressive is followed relatively closely by the FFTF Aggressive schedule completion date of June 2027 and more distantly by ATR BFFL Nominal (December 2027), FFTF Nominal (Feb 2029), and SFTR Nominal (June 2029). Both the MSFTR and LFTR alternatives are estimated to take the longest amount of time to complete by a large margin in both the aggressive (2031 timeframe) and nominal cases (2038 timeframe). This is due to the need for significant R&D efforts in the aggressive case and the assumption that pilot plants will be required in the nominal case.

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8 ALTERNATIVE EVALUATION

8.1 Risk Assessment

8.1.1 Risk Assessment Process Overview

After identifying and describing the scope for seven alternatives (including the Status Quo or "do nothing") the VTR AoA Team initiated a risk assessment process comprised of several steps consistent with DOE and GAO guidance. First, an initial set of risks (i.e., threats and opportunities) were identified for consideration and applicability to all alternatives. All VTR AoA Team members participated in multiple rounds or iterations of open deliberations comparable to a modified Delphi technique in order to establish applicability and descriptions for the set of risks. Next, scores and their associated rationale were developed for each risk and each alternative in a similar manner, as all VTR AoA Team members offered their expert opinion and several iterations of open discussions were conducted to arrive at VTR AoA Team concurrence. Finally, risk mitigation handling strategies for moderate and high threats were developed and agreed upon by all VTR AoA Team members by applying the aforementioned modified Delphi technique.

8.1.2 Risk Assessment Results

The VTR AoA Team identified 34 potential risks associated with the overall effort: 28 threats (negative risks) and 6 opportunities (positive risks). Each alternative was evaluated in relation to all threats and opportunities. The risk analysis recognizes that certain risks (i.e., threats T-1 through T-18) are applicable to all seven alternatives. In contrast, other risks (i.e., threats T-19 through T-28) are location-driven and therefore are applicable to the site-specific alternatives only (i.e., ATR, HFIR, and FFTF). To avoid risk score bias, site-specific risks are not addressed for the (new) technologies for the VTR mission (i.e., SFTR, LFTR, and MSFTR) because they would be assigned an artificial risk level/score being site-neutral.

Risks vary between alternatives and can influence the selection of the preferred alternative. Therefore, the VTR AoA Team refined and further defined the detailed descriptions of the threats and opportunities throughout this evaluation process to a pre-conceptual level to remove ambiguities and improve understanding to ensure that the risk to each alternative is captured correctly. Detailed descriptions of the risks are included in Appendix G. Prior to performing the qualitative risk evaluation by alternative, the VTR AoA Team identified the risk matrix to determine the risk level based on probability of occurrence and the consequence level. Figures 8-1 and 8-2 show the Risk Analysis Matrix used to review threats and opportunities, respectively. These figures are consistent with the Qualitative Risk Analysis Matrix contained in the DOE *Risk Management Guide* (DOE G 413.3-7A) which was used to identify the risks as "Low," "Moderate," or "High".[4]

[4] The greater granularity depicted in Figure 3 on page 18 in the *DOE Risk Management Guide* –i.e., Very Low and Very High–is "suggested only" and not necessary to perform the VTR AoA.

		Consequences of Occurrence		
		Low	**Moderate**	**High**
Cost		Minimal or no consequence. Minimal or no impact to project or life-cycle costs	Marginally increases life-cycle costs	Significantly increases life-cycle costs
Schedule		Minimal or no impact to project schedule	Marginal impacts to project schedule	Significant impacts to project schedule
Likelihood of Occurrenc	Low (<25%)	Low	Low	Moderate
	Moderate (25% to 75%)	Low	Moderate	High
	High (>75%)	Moderate	High	High

Figure 8-1. Risk Analysis Matrix–Threats

		Consequences of Occurrence		
		Low	**Moderate**	**High**
Cost		Minimal or no consequence. Minimal or no impacts to life-cycle costs	Marginally increases life-cycle costs	Significantly increases life-cycle costs
Schedule		Minimal or no impact to project schedule	Marginal impacts to project schedule	Significant impacts to project schedule
Likelihood of Occurrenc	Low (<25%)	Low	Low	Moderate
	Moderate (25% to 75%)	Low	Moderate	High
	High (>75%)	Moderate	High	High

Figure 8-2. Risk Analysis Matrix–Opportunities

The VTR AoA Team rated the threats and opportunities and assigned qualitative values in accordance with the process identified in DOE G 413.3-7A, *Risk Management Guide*. A combined risk level score is used consisting of three levels: Low, Moderate, and High. This combined risk-level score is derived from a combination of two factors: the likelihood (or probability) of occurrence and the consequence (for threats) or benefit (for opportunities). The resulting risk level is the potential impact on the alternative. The results are shown in Tables 8-1 through 8-3. Presented in Table 8-1 are risk levels for 18 threats that impact all seven VTR mission alternatives. In contrast, Table 8-2 shows the risk levels for 10 threats that impact alternatives due to their respective locations (Alternatives 5, 6 and 7are not included since they are not evaluated for a specific site). Presented in Table 8-3 are opportunity levels for all seven VTR mission alternatives.

Table 8-1. List of Threats and Levels for All Alternatives

Alternative Risk	Brief Description	1 Status Quo	2 ATR	3 HFIR	4 FFTF	5 SFTR	6 LFTR	7 MSFTR
Threats								
T-1	Inability to establish sufficient operating workforce of cleared, trained personnel having relevant experience with the technology delays design and operations.	Low	Low	Low	Low	Low	Moderate	Moderate
T-2	Available funding delays the project start/completion.	Low	Low	Low	Moderate	High	High	High
T-3	Design Basis Threat changes impact facility design, construction, and operations.	Low	Low	Low	Low	Low	Low	Low
T-4	Environmental/NEPA reviews delay project implementation.	Low	Low	Low	High	Moderate	Moderate	Moderate
T-5	Project accidents during construction delay project completion.	Low	Low	Low	Moderate	Moderate	Moderate	Moderate
T-6	Community or other stakeholders' concerns, lawsuits, and/or other legal proceedings delay project start.	Low	Low	Low	Moderate	Moderate	Moderate	Moderate
T-7	Labor disputes lead to work slowdowns or stoppages delaying construction and operations.	Low	Low	Low	Low	Moderate	Moderate	Moderate
T-8	Construction materials or equipment availability delays project or adds costs.	Low	Low	Low	Moderate	Moderate	Moderate	Moderate
T-9	Program requirements change impacting cost and schedule.	Low	Low	Low	Low	Moderate	Moderate	Moderate
T-10	Facility degradation results in premature mission failure.	Low	Low	Low	High	Moderate	High	High
T-11	Changes to safety requirements require project re-design.	Low	Low	Low	Moderate	Moderate	Moderate	Moderate
T-12	External event impacts VTR Project construction or operations.	Low	Low	Low	Low	Low	Low	Low
T-13	Nuclear material quantity changes facility mission, thereby impacting cost and schedule.	Low	Low	Low	Low	Low	Low	Low
T-14	Additional space requirements for certain material delay project design and execution.	Low	Low	Low	Low	Low	Low	Low
T-15	IAEA requirements impact design and delays project start with additional impacts on operations.	Low	Low	Low	Low	Low	Low	Low
T-16	Project design issues during work (construction/modifications/repairs) result in more work than planned causing cost increases and schedule delays.	Low	Low	Low	High	Moderate	Moderate	Moderate
T-17	Facility design has greater potential for containment failure.	Low	Low	Low	Moderate	Low	Low	Low
T-18	Ability to develop technology within planned schedule.	Low	Low	Low	Moderate	Moderate	High	High

Table 8-2. List of Site-Specific Threats and Levels for Site-Specific Alternatives

Site Risk	Brief Description	Alternative 1 Status Quo	2 ATR	3 HFIR	4 FFTF	5 SFTR	6 LFTR	7 MSFTR
Threats								
T-19	Weather events cause delays that impact construction.	Low	Low	Low	Low	Site TBD	Site TBD	Site TBD
T-20	Inability to acquire sufficient workforce delays construction.	Low	Moderate	Low	Low	Site TBD	Site TBD	Site TBD
T-21	Ongoing site operations delay project completion.	Low	Low	Moderate	Low	Site TBD	Site TBD	Site TBD
T-22	Security requirements delay project completion.	Low	Low	Low	Low	Site TBD	Site TBD	Site TBD
T-23	Unforeseen site or existing facility conditions delay or add to construction work.	Low	Low	Low	Moderate	Site TBD	Site TBD	Site TBD
T-24	Uncertainty in site planning delays project implementation.	Low	Low	Moderate	Low	Site TBD	Site TBD	Site TBD
T-25	Longevity of agreements impact continued operations.	High	Moderate	High	Low	Site TBD	Site TBD	Site TBD
T-26	Existing facilities require more work than planned to meet applicable codes and standards impacting cost and schedule.	Low	Low	Low	Moderate	Site TBD	Site TBD	Site TBD
T-27	Inability to establish staff for performing post-irradiation examination (PIE) of fuels, materials and detectors.	Low	Low	Moderate	Low	Site TBD	Site TBD	Site TBD
T-28	Onsite operations interfere with VTR operations.	High	Moderate	High	Low	Site TBD	Site TBD	Site TBD

Table 8-3. List of Opportunities and Levels for All Alternatives

Oppor-tunities	Brief Description	Alternative						
		1	2	3	4	5	6	7
		Status Quo	ATR	HFIR	FFTF	SFTR	LFTR	MSFTR
Opportunities								
O-1	Operational efficiencies from new construction/upgrades yield better throughput.	Low	Low	Low	High	High	High	High
O-2	Improved political environment reduces schedule.	Low	Low	Low	Moderate	High	High	High
O-3	Existing facilities have more capability (i.e., space) than initially expected.	Low	Moderate	Moderate	Moderate	Site TBD	Site TBD	Site TBD
O-4	Improved construction logistics yields schedule savings.	Low	Low	Low	Low	Moderate	Moderate	Moderate
O-5	Domestic or foreign industrial partnering support yields cost savings.	Low	Moderate	Moderate	Moderate	High	High	High
O-6	Leveraging safety documentation prepared for existing facility yields cost and/or schedule savings.	Low	Moderate	Moderate	Moderate	Site TBD	Site TBD	Site TBD

A composite risk rating for each alternative is based on its calculated score using the following numerical values:

- High Threat [Low Opportunity] = 5
- Moderate Threat [Opportunity] = 3
- Low Threat [High Opportunity] = 1

Totaling these scores for the 28 threats and 6 opportunities results in a total risk score for each alternative. These (absolute) risk scores for all alternatives are presented in Table 8-4. Despite its relatively low risk level, the Status Quo fails to meet the mission need and therefore is not viable; its inclusion in the risk analysis is for completeness only.

Table 8-4. Composite Risk Scores

	Alternative						
	1	2	3	4	5	6	7
	Status Quo	ATR	HFIR	FFTF	SFTR	LFTR	MSFTR
Scores and Levels for Technology-Related Risks Impacting All Alternatives							
Risk Score (Threats Only) for All Alternatives, T-1 through T-18 Only	18	18	18	44	42	48	48
Risk Level	**Low**	**Low**	**Low**	**Moderate**	**Moderate**	**High**	**High**
Risk Score for All Alternatives, T-1 through T-18 and all Technology-Related Opportunities, O-1, O-2, O-4.	38	36	36	56	48	54	54
Risk Level	**Moderate**	**Low**	**Low**	**High**	**Moderate**	**High**	**High**
Scores and Levels for Risks Impacting Site-Specific Alternatives Only							
Risk Score (Threats Only) for Site-Specific Alternatives; T-19 through T-28 Only	18	16	24	14	Site TBD	Site TBD	Site TBD
Risk Level	**Moderate**	**Moderate**	**High**	**Low**			
Risk Score for Site-Specific Alternatives; T-19 through T-28 and all Site-Specific Opportunities, O-3, O-6.	28	22	30	20	Site TBD	Site TBD	Site TBD
Risk Level	**High**	**Moderate**	**High**	**Low**			

The composite scores and levels for all risks impacting all alternatives offer the most useful information. It indicates that among the existing facilities, Alternative 2 (i.e., ATR) provides the most favorable risk score and level. However, if new technology and associated construction is a consideration, then Alternative 5 (i.e., SFTR) has the lowest risk among the three alternatives (i.e., SFTR, LFTR, and MSFTR). Considering the 18 technology-related risks only, threats T-1 through T-18, Alternative 2 (i.e., ATR) and Alternative 3 (i.e., HFIR) had the lowest overall (and identical) scores. Considering only site-specific risks, Alternative 4 (i.e., FFTF) had the lowest risk score followed by Alternative 2 (i.e., ATR).

Threat No. 2, *Available funding delays the project start/completion*, was rated high for the relatively newer, more advanced and more costly technologies only. Threat No. 4, *Environmental/NEPA reviews delay project implementation*, is rated high for Alternative 4 only, which is consistent with waste management conditions at the Hanford Reservation. Two Threats, No. 4, *Environmental/NEPA reviews delay project implementation,* and No. 16, *Project design issues during work (construction/modifications/ repairs) result in more work than planned causing cost increases and schedule delays*, are rated high for one viable alternative only—Alternative 4—principally due to environmental management issues at the Hanford Reservation and facility condition uncertainty of the FFTF. Additional information on the risk analysis is contained Appendix G. It includes risk detail descriptions, information on numerical scoring results for the risk levels that are in the summary levels shown in Table 8-4 above, score rationale, and mitigation handling strategy for moderate and high level risks, and rationale for opportunities.

8.2 Alternative Scoring

The VTR AoA Team evaluated the viable alternatives using the weighted analysis matrix described in Section 6 and rated how completely each alternative met each evaluation criterion. The scoring system used is summarized in Table 8-5. The AoA Team did not assess relative weighting of threats and opportunities, and composite scores reflect an equal weighting.

Table 8-5. Evaluation Scoring System

Evaluation Criteria	Score
Fully meets the criterion	1.00
Generally meets the criterion	0.50
Somewhat meets the criterion	0.30
Barely meets the criterion	0.10
Does not meet the criterion at all	0.00

Table 8-6 presents the results of applying a score value to each evaluation criteria for each alternative. The rationale for scoring each alternative against each criterion is documented in Appendix H.

Table 8-6. Weighted Evaluation Scoring System

	Evaluation Criteria	Evaluation Score Value							
		Import-ance	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users.	1	0.0	0.3	0.1	1.0	1.0	1.0	1.0
2	Provides high neutron dose rate for materials testing [quantified as dpa]	1	0.1	0.3	0.3	1.0	1.0	1.0	1.0
3	Provides an irradiation length that is typical of fast reactor designs	2	1.0	1.0	0.5	1.0	1.0	1.0	1.0
4	Provides a large irradiation volume within the core region	1	0.1	0.1	0.1	1.0	1.0	1.0	1.0
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	1	0.1	0.3	0.3	1.0	1.0	1.0	1.0
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	4	0.5	0.5	0.5	1.0	1.0	1.0	1.0
7	High technical confidence the facility can be available for testing as soon as possible	1	0.1	0.3	0.1	0.3	0.3	0.1	0.1
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	3	0.5	1.0	0.5	0.5	1.0	1.0	1.0
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	2	1.0	1.0	1.0	0.3	1.0	0.3	0.5
10	Provides capabilities that support experimental high-temperature testing	3	0.3	0.3	0.3	1.0	1.0	1.0	1.0
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	2	1.0	1.0	1.0	1.0	1.0	1.0	1.0
12	Lower Capital Investment (Total Project Cost)	2	1.0	0.5	0.5	0.3	0.1	0.1	0.1
13	Lower Annual Operating and Maintenance Costs during operations	4	1.0	0.5	1.0	0.3	0.3	0.3	0.3
14	Lower present value of life cycle costs	1	1.0	0.5	1.0	0.3	0.1	0.1	0.1
15	Shortest schedule to initiate operations	2	1.0	0.5	1.0	0.3	0.3	0.1	0.1
16	Ease of meeting security requirements	1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
17	Greater ease and confidence of compliance with codes, standards, regulations	1	1.0	1.0	1.0	0.3	1.0	0.1	0.1
18	Higher confidence in stakeholder acceptance	1	0.0	0.1	0.1	0.3	1.0	0.1	0.1
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	1	0.0	0.1	0.1	0.5	1.0	1.0	1.0
20	Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)	2	0.0	0.3	0.1	0.5	1.0	1.0	1.0

To calculate one criterion score for an alternative, the NRW (from Table 6-3) is multiplied by the selected value from Table 8-6. For example, if the criterion NRW is 6.58 and the alternative value score is 0.5 (i.e., somewhat meets the criterion), then the score would be 3.29 for that criterion. The criteria scores for each alternative are totaled to create the final score for the alternative. These calculations and total Evaluation Scores for each alternative are summarized in Table 8-7.

Table 8-7. Evaluation Score for Alternatives

Evaluation Criteria	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	0.00	1.97	0.66	6.58	6.58	6.58	6.58
2	0.66	1.97	1.97	6.58	6.58	6.58	6.58
3	6.58	6.58	3.29	6.58	6.58	6.58	6.58
4	0.66	0.66	0.66	6.58	6.58	6.58	6.58
5	0.66	1.97	1.97	6.58	6.58	6.58	6.58
6	1.97	1.97	1.97	3.95	3.95	3.95	3.95
7	0.66	1.97	0.66	1.97	1.97	0.66	0.66
8	3.29	6.58	3.29	3.29	6.58	6.58	6.58
9	1.32	1.32	1.32	0.39	1.32	0.39	0.66
10	1.97	1.97	1.97	6.58	6.58	6.58	6.58
11	2.63	2.63	2.63	2.63	2.63	2.63	2.63
12	3.95	1.97	1.97	1.18	0.39	0.39	0.39
13	2.63	1.32	2.63	0.79	0.79	0.79	0.79
14	3.95	1.97	3.95	1.18	0.39	0.39	0.39
15	3.95	1.97	3.95	1.18	1.18	0.39	0.39
16	1.32	1.32	1.32	1.32	1.32	1.32	1.32
17	6.58	6.58	6.58	1.97	6.58	0.66	0.66
18	0.00	0.39	0.39	1.18	3.95	0.39	0.39
19	0.00	0.66	0.66	3.29	6.58	6.58	6.58
20	0.00	1.97	0.66	3.29	6.58	6.58	6.58
Total	**42.76**	**47.76**	**42.50**	**67.11**	**83.68**	**71.18**	**71.45**
Total Rounded	**43**	**48**	**43**	**67**	**84**	**71**	**71**

The total Evaluation Score for each alternative determines its relative rank. The ranking for all Alternatives is presented in Table 8-8.

Table 8-8. Alternative Evaluation Score Ranking

Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
6	5	7	4	1	3	2

8.3 Sensitivity Analysis

In addition to the cost sensitivity analysis evaluated as part of the LCCE development (PV discount rate variation only) (see Section 7.4), the AoA process requires an assessment of the sensitivity of benefit and effectiveness estimates for each alternative. Consistent scoring/evaluation methodologies were applied for each alternative yielding no key factor or assumption that, if varied, may alter the scoring and ranking of each alternative. However, the AoA Team has found during past AoAs that the most important area to assess in terms of sensitivity is the criteria weightings that have been assigned and used to score and compare each alternative. Accordingly, the AoA Team assessed four scenarios to determine the influence of Evaluation Criteria weighting on overall alternative ranking. The following scenarios have been considered:

- Scenario 1 – The cost and schedule related Evaluation Criteria (numbers 12, 13, 14 and 15) were changed from "Very Important" to "Highest Importance". This reflects a priority for minimal cost and shortest schedule.
- Scenario 2 – All Evaluation Criteria were made to be "Highest Importance". This reflects a priority to address all criteria derived from the Mission Need.
- Scenario 3 – Technical performance related criteria, previously rated as "Highest Importance" were downgraded to "Very Important" (Criteria numbers 1, 2, 3, 4, 5, 7, 8, 10, 19, and 20) and the cost and schedule related Evaluation Criteria (numbers 12, 13, 14, and 15) were changed to "Highest Importance". This reflects a priority for maximum technical performance.
- Scenario 4 – The weights assigned were changed to be linear by changing the weight assigned to "Highest Importance" to 4 (and the others remained at 3, 2, or 1). This assesses weighting bias for high performance.

Table 8-8 shows the ranking of the alternatives using the calculated Evaluation Criteria scoring for each of the above scenarios, as compared to the base case scores derived from the criteria scoring shown in Table 8-5. As can be seen in Table 8-9, under all scenarios, Alternative 5, the use of a new sodium-cooled fast reactor (i.e., SFTR), scored the highest as evaluated by the AoA Team. The scoring calculation spreadsheets can be found in Appendix H.

Table 8-9. Evaluation Criteria Scoring Sensitivity Analysis Results

	Ranking of Alternatives				
	Base Case	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Alternative 1 Status Quo	6	5	5	5	6
Alternative 2 Modified ATR	5	6	6	7	5
Alternative 3 Modified HFIR	7	7	7	6	7
Alternative 4 FFTF	4	4	4	2	4
Alternative 5 SFTR	1	1	1	1	1
Alternative 6 LFTR	3	3	3	4	3
Alternative 7 MSFTR	2	2	2	3	2

There is a range of potential benefits to be derived from the development and deployment of a VTR, as described in the Mission Need Statement (Appendix A). A frequent objective in an AoA is to quantify these benefits, and if possible to provide a net present value (NPV) for each alternative. However, due to the R&D nature of the VTR mission – and the characteristics of the alternatives, the VTR AoA Team determined that it was not found possible to properly quantify the benefits or provide a NPV. The rationale for this includes:

- Benefits from construction and long-term operation of a VTR cannot be monetized, as the nature and monetary value of the future R&D and its associated results cannot be known in advance.

- Lacking the ability to monetize benefits, the VTR AoA Team considered whether performance potential against the mission need could be quantified as a benefit for comparison of alternatives. The three custom designed new-build alternatives were assumed to fully meet the mission need, and the existing reactor alternatives would meet differing portions of the mission need, with significant uncertainties. There is no basis for quantifying the future benefit of these different portions of the mission need to allow a quantitative comparison.

- Cost and schedule estimates vary significantly and have large uncertainty ranges.

Similarly, there is no basis for combining the differing aspects of this analysis into a rolled-up ‘combined score’ for each alternative that would allow a ranking of alternatives. Therefore, this analysis stopped at providing comparative values for each alternative on:

- Performance against the mission need criteria
- Life cycle cost and capital cost
- Schedule range
- Risk

This information is provided as input to the project management for consideration in selection of a preferred alternative.

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9 CONCLUSIONS

This independent AoA was conducted for the VTR Project to provide an assessment of potentially feasible approaches to meeting the project mission need. Criteria were developed for screening potential alternatives, and a broader set of performance criteria, and cost, schedule and risk categories were developed to assess the viable alternatives. The results of this study are intended to support decisions, as no recommendation is provided. Data collected as a result of visits to specific DOE sites is applied to support our findings.

A summary of the results of the analysis for the seven alternatives (Status Quo and 6 viable alternatives) are presented in Table 9-1.

Table 9-1. VTR Project AoA Results

Alternative	Evaluation Score (Higher Better)	Technology-Related Risk Score* (Lower Better)	Site-Specific Risk Score* (Lower Better)	Life Cycle Costs (LCC) Present Value PV ($B)	Capital Cost (TPC) ($B)	Schedule Range (CD-4)
Alternative 1 Status Quo	43	18	18	$0.7 to $1.6	Not Applicable	Not Applicable
Alternative 2 Modified ATR	48	18	16	$1.7 to $3.9	$0.1 to $0.5	FY25 to FY28
Alternative 3 Modified HFIR	43	18	24	$0.8 to $1.8	$0.04 to $0.2	FY23 to FY24
Alternative 4 FFTF	67	44	14	$4.3 to $11.8	$1.1 to $5.6	FY27 to FY29
Alternative 5 SFTR	84	42	Site TBD	$7.0 to $17.6	$4.6 to $13.2	FY27 to FY29
Alternative 6 LFTR	71	48	Site TBD	$7.9 to $23.0	$7.1 to $24.2	FY31 to FY38
Alternative 7 MSFTR	71	48	Site TBD	$8.2 to $23.9	$7.7 to $25.9	FY31 to FY38

The LCCEs are only intended to be used to support the VTR AoA for comparing each alternative's life cycle costs and are not considered budget quality estimates.

**Risk scores include threats only (no opportunities).*

***The approved cost range from the Approval of CD-0, Approve Mission Need, for the Versatile Test Reactor Project, is $3.0B to $6.0B with a schedule range of 2026 to 2028. This represents the Department of Energy formal position on cost and schedule of the VTR.*

Based on the results of their analysis, the VTR AoA Team concludes:

- The Status Quo alternative does not meet the mission need.
- As shown in Table 9-1, Alternative 5, which requires the construction of a new SFTR, scored highest in terms of the Evaluation Criteria. These criteria appropriately weigh performance factors as well as relative cost and schedule for each identified viable alternative. A sensitivity analysis demonstrated that even if the relative weights of the Evaluation Criteria are modified, the SFTR alternative maintained its top ranking.
- There is a lower risk potential, as well as lower costs and faster implementation schedules, if existing facilities (HFIR and ATR) are used to meet mission need. However, those alternatives do not achieve the full suite of performance criteria identified in the MNS.
- There is the potential for upgrading both the ATR and the HFIR facilities to better support the VTR mission (a potential hybrid alternative). Looking at the scores, the costs, risks and performance would be additive, and the schedules would be parallel. The incremental performance of these two thermal spectrum reactors compared to any of the fast spectrum reactors would not result in substantially improved scoring, as the largest performance increase would be in the ATR fast flux booster. Additionally, the combined cost and risk would not result in substantially worsened scoring, as the cost is dominated by the ATR booster and risk is dominated by HFIR mission conflict. Thus, it was determined that the combined upgrades would not result in a significantly improved alternative.
- As expected, the new reactor alternatives have potentially higher initial capital costs and life cycle costs, as well as potentially longer implementation schedules, than do the alternatives that involve use/modification of existing facilities. However, these higher costs will need to be incurred if the full suite of performance criteria identified in the MNS are to be met.
- The analysis of estimated capital costs and project schedules was based on an assumed availability of annual funding as needed to support an optimum and possible project schedule. This results in very high annual funding levels being necessary over the project schedule for the new reactor alternatives (approaching $1B per year for the new SFTR alternative and even higher for the other reactor technology alternatives) that could be even higher if the high range cost estimates are considered. In the event that actual annual funding levels are limited, there would be longer project execution schedules and correspondingly higher project costs.

A few observations arise from the results of this study:

- The performance of the existing thermal spectrum test reactors was lacking for a fast neutron irradiation mission. There is some capability, and that can be improved, but they inherently do not have the level of potential for this mission as a fast spectrum reactor.
- Existing facilities have cost and schedule advantages over any new reactor alternative but have more limited performance and have the risk of mission conflicts.
- FFTF is an intermediate case of an existing but long-shuttered high-performance irradiation test facility that has significant uncertainties regarding technical requirements for restart, stakeholder acceptance and long-term operation that add risk. These significant uncertainties have been evaluated during this AoA; however, the degree of the “unknown unknowns” with respect to risk in meeting the mission need could only be determined by conducting significantly more detailed studies.
- A new test reactor could best meet mission needs with lower risk, but with potentially higher costs and longer schedules.

- Any of the four fast spectrum test reactor alternatives could meet the mission needs, and the comparison is one of maturity. The potential restart of FFTF is an issue of age, present condition and future longevity. A new SFTR is by intent based on current maturity. The LFTR and MSFTR suffer in the evaluation from lack of maturity, and the possibility that a technology demonstration facility might be needed to mitigate technology risk. Amongst the four fast spectrum reactors, the SFTR was evaluated to be a better alternative.
- The AoA Team visited four DOE sites that could support the VTR mission. Three sites (INL Hanford and ORNL) have existing reactors that are included among the alternatives evaluated. The fourth (SRS) does not have a reactor that could be used for the VTR mission but does have existing facilities that could support a VTR. SRS was included in the site visits to better understand the capabilities and availability of mission support facilities. Actual site selection(s) should also consider the results from a full NEPA evaluation and accompanying siting study. Local stakeholder and state government support (or lack thereof) would also need to be assessed in selecting a potential site or sites.
- While the VTR AoA effort was not a siting study, the VTR AoA Team also briefly explored the relative pros and cons of siting a new test reactor at a DOE site as compared to a non-DOE (not specifically specified) site. The VTR AoA Team believes that it would be preferable to use a DOE site that already includes some of the requisite support facilities needed for the VTR mission and an existing regulatory/security posture to accommodate a new VTR. These observations are further detailed in Appendix I.

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APPENDIX A VERSATILE TEST REACTOR (VTR) APPROVED MISSION NEED STATEMENT (MNS)

Mission Need Statement
for the
VERSATILE TEST REACTOR (VTR) PROJECT

A Major Acquisition Project

Office of Nuclear Technology Research and Development
Office of Nuclear Energy
U.S. Department of Energy

Date Approved:
December 2018

Mission Need Statement
for the Versatile Test Reactor (VTR) Project

Submitted by:

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Office of Nuclear Energy, DOE

Concurrence:

Date: 11/23/18

Dennis Miotla, Chief Operating Officer
Office of Nuclear Energy

Approval:

Date: 12/10/18

Ed McGinnis, Principal Deputy Assistant Secretary for Nuclear Energy
Office of Nuclear Energy, DOE

2

Table of Contents

1. STATEMENT OF MISSION NEED

The United States (U.S.) has been an international leader in the development and testing of advanced nuclear reactor technologies since the advent of nuclear power generation. The Department of Energy (DOE) and its predecessor organizations appropriately provided nuclear fuels and materials development capabilities and large-scale testing facilities in support of all currently deployed nuclear reactor technologies. However, the U.S. has not maintained a domestic fast neutron spectrum testing capability for over two decades. This gap in testing capability is severely crippling the U.S. ability to move forward in the development of next-generation nuclear reactors – many of which require a fast neutron spectrum for operation – and equally impacts the U.S. ability to regain technology leadership in this arena. In the meantime, development of next generation advanced reactors technologies is being actively pursued by DOE national laboratories, universities and industry in competition with similar efforts by international private and/or state supported nuclear technology providers.

Common to advanced nuclear reactor technology development is the urgent need for accelerated testing and qualification of advanced nuclear fuels, materials instrumentation and sensors.

The lack of a versatile fast neutron spectrum testing capability is a significant national strategic risk affecting the ability of DOE to fulfill its mission areas. This testing capability is essential for the U.S. to modernize its nuclear energy research and development (R&D) infrastructure for developing transformational nuclear energy technologies. Failure to develop this capability on an accelerated schedule will lead to further degradation of the U.S. ability to develop advanced nuclear energy technologies. If this capability is not available to U.S. innovators as soon as possible, the ongoing shift of nuclear technology primacy to other international states (e.g., China, the Russian Federation) will accelerate, and the opportunity will be missed to re-energize the U.S. nuclear industrial sector. Furthermore, independent of domestic deployment strategies, relinquishing U.S. leadership in advanced reactor technologies will have national security consequences as U.S. influence in global nuclear safety and security policies and their implementation will be severely diminished.

2. ALIGNMENT

The mission of the DOE is to advance the energy, environmental, and nuclear security of the U.S.; promote scientific and technological innovation in support of that mission; and ensure the environmental cleanup of the national nuclear weapons complex. The DOE's FY 2014-2018 Strategic Plan[1] calls out Strategic Objective 2 as:

> *Support a more economically competitive, environmentally responsible, secure and resilient U.S. energy infrastructure.*

The plan adds the following specificity:

> *DOE will continue to explore advanced concepts in nuclear energy that may lead to new types of reactors with further safety improvements and reduced environmental and nonproliferation concerns.*

The Office of Nuclear Energy's (NE) mission is to advance nuclear power to meet the nation's energy, environmental, and national security needs. To accomplish this mission, NE has established research objectives to resolve barriers in technical, cost, safety, security, and proliferation resistance through early-stage research, development, and demonstration to:

- Enhance the long-term viability and competitiveness of the existing U.S. reactor fleet.
- Develop an advanced reactor pipeline.
- Implement and maintain national strategic fuel cycle and supply chain infrastructure.

In support of these research objectives, the mission of the DOE NE Versatile Test Reactor (VTR) program is to provide leading edge capability for accelerated testing and qualification of advanced fuels and materials, enabling the U.S. to regain and sustain technology leadership in the area of current and future advanced reactor systems.

There is bi-partisan support, both in the U. S. House and in the Senate, for nuclear energy research and development (R&D) infrastructure in general and for the VTR concept in particular, accentuating the need for development of the VTR. The Nuclear Energy Research Infrastructure Act[2] (H.R. 4378) directs DOE to construct a versatile, reactor-based fast neutron source and authorizes $35M in FY 2018 and larger amounts in subsequent years. The Nuclear Energy Innovation Capabilities Act of 2017[3] (NEICA, S. 97, enacted into law in September 2018), directs the Secretary of Energy to determine the mission need for a versatile reactor-based fast neutron source operating as a national user facility.

3. CAPABILITIES GAP

3.1 Capability Gap

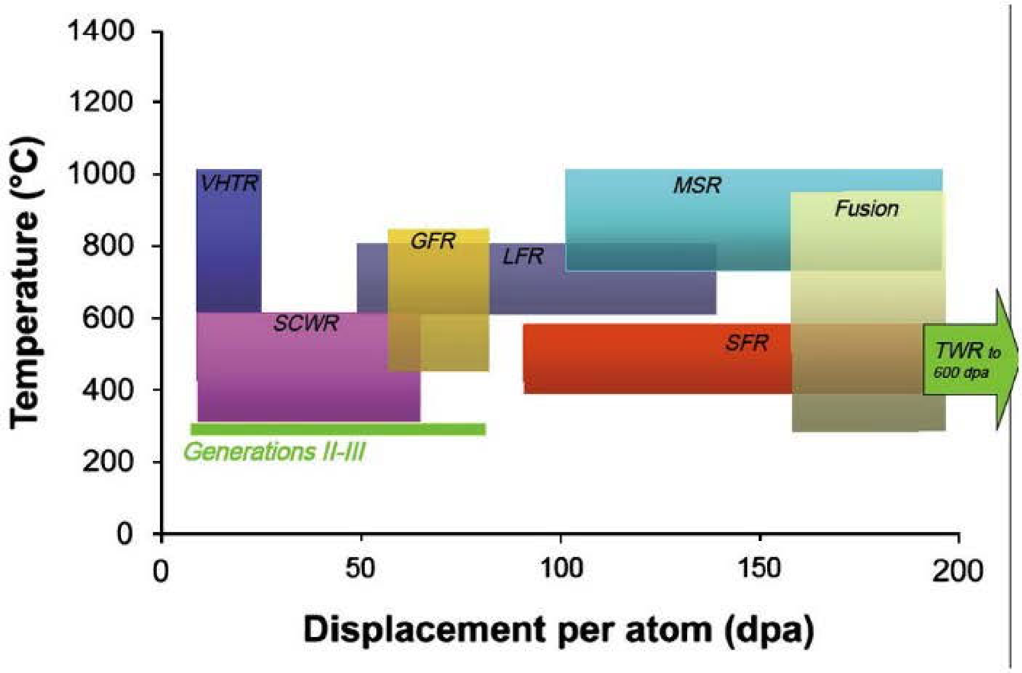
The capability gap addressed by this mission need statement is the current inability to effectively test advanced nuclear fuels and materials in a prototypic fast neutron spectrum irradiation environment at high neutron fluxes. Deployment of this complex testing capability is and has been historically recognized as a DOE mission.

Advanced nuclear fuels with long-life, high-burnup properties and reactor systems structural materials that can tolerate high burnups and high levels of radiation damage are needed for successful development and deployment of advanced nuclear reactor technology options. They are also useful for continued improvements in the existing light water reactor (LWR) fleet. As an example, the U.S. Nuclear Regulatory Commission and international regulatory authorities require comprehensive technical data obtained via prototypic irradiation testing prior to use of advanced nuclear fuels and materials. Furthermore, many Gen-IV concepts using coolants other than water may also require fast neutrons for the study of fuels and corrosion control.[4]

The nuclear industry, which has always provided safe, clean, reliable energy, needs innovation now more than ever before. It is likely that fast spectrum reactors will be deployed in the future as the current fleet of LWRs are decommissioned. Fast neutron spectrum nuclear reactors have the potential to significantly rely on inherent safety characteristics, operate for very long periods of time without refueling, and reduce the volume of newly generated nuclear waste.

Neutron damage rates are significantly higher for advanced fast neutron reactor systems than those for the current fleet of LWRs. This is because the magnitude of the fast neutron flux is much higher than that for thermal systems and because the fuels are designed for higher lifetime fluence. A water-cooled test reactor cannot support research and development of advanced reactor designs because it is not possible to achieve sufficiently high fast neutron flux (without thermal neutron contamination). This high neutron flux is needed for the development of any fast spectrum reactor system and acceleration of materials irradiations for both thermal and fast reactors.[4]

The required functional testing capability for development of advanced nuclear fuels and materials ranges from 20 displacements per atom (dpa) per year to over 500 dpa as shown in Figure 1.[4] Additionally, to create the prototypic environment needed to qualify advanced nuclear fuels and materials, the irradiation must be performed at elevated temperatures with a fast neutron spectrum (>0.1 million electron volts [MeV]) and with flowing coolants other than water. Current domestic irradiation testing facilities cannot provide a representative, timely irradiation testing environment, and access to very limited international testing facilities is precluded by political, transportation, technical, and cost issues.



Legend:

FUSION, fusion reactor; Generations II-III, advanced light-water reactor; GFR, gas-cooled fast reactor; LFR, lead-cooled fast reactor; MSR, molten salt reactor; SCWR, super-critical water-cooled reactor; SFR, sodium-cooled fast reactor; VHTR, very high temperature reactor; TWR, traveling wave reactor

Figure 1. Temperature/displacement damage (dose) windows for fission and fusion concepts.

6

NEAC Recommendation

In July of 2016, DOE NE chartered the Nuclear Energy Advisory Committee (NEAC) to independently determine the requirements and overall capabilities (e.g., neutron spectrum/spectra, testing environments, etc.) for a new irradiation test reactor and to perform a comparison with alternative facilities, methodologies, and approaches for meeting these needs and providing these capabilities. The NEAC conducted an independent study (including a user needs assessment) and confirmed that there was a need in the U.S. for fast neutron testing capabilities, but that there is no facility that is readily available domestically or internationally.[5] Subsequently, DOE-NE directed that a research and development (R&D) effort be initiated to create a versatile advanced test reactor (VTR) concept, with associated cost and schedule estimate, to enable a fully informed DOE acquisition decision at the end of three years.[6]

Industry Input

Currently, a number of private entities are working on developing fast reactors for future commercialization. After a series of workshops organized by the DOE's Gateway for Accelerated Innovation in Nuclear (GAIN), the commercial fast reactor development community organized a working group under the Nuclear Energy Institute (NEI). In addition to reactor developers, the NEI fast reactor working group (FRWG) also has active participation from the U.S. utilities, including Southern Company, Exelon, and Duke. The FRWG meets periodically to discuss common issues and make recommendations to DOE through GAIN in areas where federally funded programs can help resolve common challenges.

On February 13, 2017, the FRWG submitted a letter to DOE identifying its R&D priorities within the federally funded nuclear energy programs. Prominent in the list was the need for a fast neutron spectrum test reactor that can support technology development for multiple concepts in the areas of fuels, materials, and sensor development. The letter articulates the difficulties associated with relying on foreign fast-spectrum testing capabilities and the urgent need for domestic capabilities for these commercial efforts to move forward and to be commercially sustainable in the future.

There are industrial entities focusing on the next generation of sodium cooled fast reactors. Examples are Advanced Reactor Concepts (ARC), General Electric (GE) and TerraPower. Westinghouse is working on a lead-cooled fast reactor concept. General Atomics (GA) is working on a gas-cooled fast reactor concept. These are in the early R&D phase. The companies are exploring many innovative technologies, including fuels and materials, to be used in the final design.

There are also a number of liquid-fueled molten salt fast reactor designs being explored by the private sector. Examples include the TerraPower molten chloride fast reactor (MCFR) and the Elysium Industries molten chloride salt fast reactor (MCSFR). In addition, Oklo Inc. and Westinghouse are working on fast-spectrum, heat-pipe-cooled micro-reactor designs ($<$ 10 megawatt thermal [MWth]).

The information above is provided as a summary of wide-ranging interests in the field of fast reactor technology. The list of private entities is not meant to be all-inclusive; it only includes the companies represented in the FRWG. The maturity level of the design of each concept varies. Many of these companies aim to achieve the readiness for the first prototype/demonstration unit as quickly as possible (within the next 10-15 years). However, these companies also recognize that, to sustain long-term competitive advantage, a supporting research infrastructure will be necessary. Simply building the first prototype may not be sufficient to gain and sustain adequate market share nationally or globally. The corollary would be U.S. leadership in the LWR industry. Even though LWR technology has been available for many decades, the supporting research infrastructure has enabled an increase in the availability from 60% in the 1960s to more than 90% in the 2000s. There is still ongoing research in test reactors to improve the fuels and materials performance in LWRs.

Congressional Direction

Recognizing the importance of U.S. leadership in advanced reactor development in terms of economic competitiveness and national security implications, there are a number of nuclear-energy-related authorization bills that are being considered at various levels within the U.S. House and Senate. These bills directly or indirectly affect the VTR program. As of September 2018, the Nuclear Energy Research Infrastructure Act[2] (H.R. 4378) directs DOE to construct a versatile reactor-based fast neutron source. This bill authorizes $35M in FY 2018 and larger amounts in subsequent years. The bill has passed in the House and has been referred to the Senate Energy and Natural Resources Committee.

On the Senate side, the Nuclear Energy Innovation Capabilities Act of 2017[3] (NEICA, S. 97) enables civilian R&D of advanced nuclear energy technologies by private and public institutions and directs the Secretary of Energy to determine the mission need for a versatile reactor-based fast neutron source, which shall operate as a national user facility. This bill passed the Senate on March 7, 2018 and the House on September 13, 2018, and was signed by the President on September 28, 2018.

The bi-partisan support both in the House and in the Senate, for nuclear energy R&D infrastructure in general and for the VTR concept in particular, accentuates the need for development of the VTR.

3.2 Strategic Risk

The lack of a versatile fast neutron spectrum testing capability is a significant national strategic risk affecting the ability of DOE to fulfill its mission areas as described in Section 1. The LWR and advanced reactor communities, which are supported by several DOE program areas (e.g., small modular reactor technology development and licensing, LWR sustainability, advanced nuclear technology development) are key to providing a flexible portfolio of energy supply sources. This will ensure national security through energy independence and energy dominance and re-energize the U.S. nuclear industrial sector for domestic deployment of advanced reactors and for access to international markets. Failure to develop a versatile fast neutron spectrum testing capability on an accelerated schedule will lead to further degradation of the U.S. capability to develop advanced nuclear reactors, accelerate the ongoing shift of nuclear technology primacy to other international states (e.g., China, the Russian Federation), and fail to re-energize the U.S. nuclear industrial sector. This testing capability is essential for the U.S. to modernize its nuclear energy infrastructure for developing transformational nuclear energy technologies. Independent of domestic deployment strategies, relinquishing U.S. leadership in advanced reactor technologies will limit U.S. influence in global nuclear safety and security policies and their implementation.

An additional often misunderstood strategic risk is the potential loss of qualified human resources to provide the innovation required for developing advanced reactor designs and subsequent operation. The national commitment to pursue a new nuclear project of the importance of VTR will provide an inestimable incentive for students and young professionals to enter this essential profession and dedicate their careers to ensure international leadership for the United States.

3.3 Capability Requirements

The high-level capability requirements for the VTR are driven by the variety of user-needs.[7] Overall the requirements are developed with the following considerations:

- An intense neutron irradiation environment with prototypic spectrum to determine irradiation tolerance and chemical compatibility with other reactor materials, particularly the coolant.

- Testing that provides a fundamental understanding of materials performance, validation of models for more rapid future development, and engineering-scale validation of materials performance in support of licensing efforts.

- A versatile testing capability to address diverse technology options and, sustained and adaptable testing environments.

- Focused irradiations, either long- or short-term, with heavily instrumented experimental devices, and the possibility to do in situ measurements and quick extraction of samples.

- An accelerated schedule to regain and sustain U.S. technology leadership and to enable the competiveness of U.S-based industry entities in the advanced reactor markets. This can be achieved through use of mature technologies for the reactor design (e.g., sodium coolant in a pool-type, metallic-alloy fueled fast reactor) while enabling innovative experimentation.

A summary of preliminary requirements is provided in Table 1.[7]

Table 1. Preliminary requirements summary.

REQUIREMENT	TARGET
Provide a high peak neutron flux (neutron energy > 0.1 MeV) with a prototypic fast reactor neutron energy spectrum	$\geq 4 \times 10^{15}$ n/cm^2-s
Provide high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	> 30 dpa/year
Provide an irradiation length that is typical of fast reactor designs	0.6 m $\leq$ L $\leq$ 1 m
Provide a large irradiation volume within the core region	$\geq$ 7 L

REQUIREMENT	TARGET
Provide innovative testing capabilities through flexibility in testing configuration and testing environment (coolants) in closed loops	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salts loops
In addition to traditional measurement techniques, provide the ability to test advanced sensors and instrumentation for the core and test positions	In-situ and real-time measurements
Make the facility available for testing as soon as possible.	Use proven technologies with high technology readiness level (TRL). Operational by the end of FY2026.
Expedite experiment lifecycle by enabling easy access to support facilities for experiments fabrication and post-irradiation examination	If practical, avoid transportation through public roads.
Provide life-cycle management for the reactor driver fuel while minimizing cost and schedule impacts.	Must be evaluated based on cost and schedule impact with consideration for using existing DOE infrastructure with necessary modifications for fuel life-cycle management.

3.4 High-Level Interdependencies

Several ongoing DOE-NE programs will derive benefit from the development of this capability. A key consideration is that the development of the needed capability should support, be synergistic with, and minimize operational impacts to ongoing programs. The Office of Advanced Reactor Technologies sponsors research, development, and deployment activities through its Next Generation Nuclear Plant, Advanced Reactor Concepts, and Advanced Small Modular Reactor programs to promote safety, technical, economical, and environmental advancements of innovative Generation IV nuclear energy technologies.

The Fuel Cycle Technologies Program will benefit from development of this capability in two R&D campaigns. The Systems Analysis & Integration campaign has developed systematic, transparent, and objective processes to screen and evaluate a wide variety of proposed fuel cycles to identify potential solutions. It evaluates advanced reactor and other nuclear technologies from a nuclear energy system perspective. The Advanced Fuels campaign supports both existing and next-generation reactors by developing accident-tolerant LWR fuel and advanced proliferation-resistant fuels for sustainable fuel cycles.

The Light Water Reactor Sustainability Program is developing the scientific basis to extend existing nuclear power plant operating life beyond the current 60-year licensing period and ensure long-term reliability, productivity, safety, and security. The program conducts research and development projects in the following pathways: Materials Aging and Degradation

Assessment; Advanced Instrumentation, Information, and Control Systems Technologies; Risk-Informed Safety Margin Characterization; and Advanced Light Water Reactor Nuclear Fuels.

Nuclear Energy Advanced Modeling and Simulations (NEAMS) is developing advanced multi-physics and multi-scale modeling tools for advanced reactor fuels and materials. The proposed capability will be needed for the validation of these tools. Additionally, Nuclear Energy Enabling Technologies (NEET) is developing advanced online sensors for fuels and materials testing and reactor monitoring and control systems. The planned capability will also be instrumental in testing these advanced sensors and qualifying them for use in reactor applications.

3.5 Status of Existing Capabilities

The U.S. has not had a fast neutron spectrum testing facility for over two decades. The existing U.S. capability for testing nuclear fuels and materials is limited to water-cooled reactors providing thermal neutron spectrum testing capability. For over 50 years, water-cooled test reactors have been the workhorse of nuclear fuels and materials testing for thermal reactor systems.[4] The U.S. relies mostly on irradiations carried out in the Advanced Test Reactor (ATR) at Idaho National Laboratory (INL) and the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) for accelerated testing of radiation tolerance. These reactors are decades old and are called on for many other missions besides commercial nuclear power applications. These material test reactors produce damage rates of up to 10 dpa/yr, which is sufficient to support most thermal reactor development; however, they are already operating near full capacity. To attain peak doses typical of advanced fast reactors (200 to 500 dpa), using a water-cooled test reactor would take 20−50 years.[4] Thus, it is not feasible to attain the required peak dose in a reasonable amount of time using a water-cooled test reactor.

An evaluation of existing domestic and international thermal neutron spectrum and fast neutron spectrum irradiation facilities concluded that domestic thermal material test reactors have severely limited fast neutron capabilities. It also concluded that fast neutron facilities with the appropriate infrastructure exist today only in Russia and India. Concerns over political issues, transportation to and from the U.S., and equivalencies of quality assurance programs make those facilities difficult to rely upon.[4]

In summary, there is no existing capability that can be used to address the U.S. fast neutron spectrum testing gap.

4. POTENTIAL APPROACH

This capability gap can be addressed with a new fast neutron spectrum test facility based on sodium-cooled fast reactor (SFR) technology. With this approach, the new facility could be designed and built using mature SFR technology informed by more than a hundred cumulative years of SFR operating experience and associated lessons learned. This proposed approach would provide a test facility with versatile operational capabilities and maximum mission flexibility.

Several important considerations and constraints were identified for the development of viable alternatives:

- The anticipated operational lifetime of the capability is 40 - 60 years.[7]
- Availability of accessible pre-and post-irradiation preparation and examination facilities is a required analytical capability[7] and a potential constraint in the detailed analysis of alternatives to be conducted in support of Critical Decision (CD)-1. Proximity to existing fuel fabrication, experiment manufacturing, fuels and materials characterization, and post-irradiation examination capabilities provides for optimized benefit of the new capability. Easy access to these facilities reduces the transportation difficulties and accelerates the testing program.
- DOE regulation of the capability is required to minimize regulatory uncertainty and enable timely development, approval, and maintenance of the safety basis.
- Teaming with industry to identify and develop mitigations for supply chain challenges is essential to minimize the well-recognized issues associated with new nuclear facility builds and support re-energization and revitalization of the U.S. nuclear industry.
- If uranium is used solely or in combination with other fissile materials for reactor fuel, uranium enrichment levels will be limited to less than 20% to comply with international agreements.
- Congress has dictated that the initial target date for operational readiness for the fast neutron spectrum capability is FY 2026.[3] Mature technologies are required for a rapid deployment and reliable operations of an irradiation test reactor within this time frame.[4]

Fast neutron spectrum testing facilities using mature sodium-cooled fast reactor technologies have been successfully constructed and operated domestically and internationally (e.g., Experimental Breeder Reactor II [EBR-II], U.S.; Fast Flux Test Facility [FFTF], U.S.; and BOR-60, Russian Federation).[5] Existing and legacy test facilities present a wealth of knowledge for sodium-cooled fast neutron spectrum test reactor design, construction, and operation, and provide a history of prototypic test environments representative of the capability needs presented herein. However, as noted in the previous section, existing operating domestic irradiation testing facilities are not capable of filling the capability gap as described in this document, and international facilities are precluded from consideration due to several problematic issues in regard to access, transportation, and technical equivalencies. Furthermore, taking no action cannot meet the mission need for the reasons articulated in the previous section. Therefore, two potential approaches are identified to meet the mission need described in this document. These include construction of a new sodium-cooled fast neutron spectrum test reactor facility or refurbishment and reactivation of an existing decommissioned sodium-cooled fast neutron spectrum test facility (i.e., FFTF). Based on a preliminary analysis, refurbishment and reactivation of FFTF has been evaluated and was removed from consideration as a viable alternative for pre-conceptual planning activities.[8] This preliminary evaluation will be reviewed as part of an Independent Analysis of Alternatives required prior to CD-1.

As previously noted, a wealth of information exists for sodium-cooled fast reactors. The SFR has been under development by the U.S. government since the inception of nuclear electricity production in the 1950s. Experimental and demonstration facilities were built and operated starting in the early 1960s with EBR-II in Idaho and the Fermi-1 power plant in Michigan, both of which generated electricity. The FFTF is a deactivated 400 MWth SFR in Washington State that was used for materials irradiations.[4] There are no unusual nuclear safety issues, safeguards and security issues, nor major design process constraints associated with the execution of this mission need using a sodium-cooled fast reactor technology approach. DOE expectations for safety in design will be detailed as part of the CD-0 package submittal and a safety design strategy developed and approved in support of CD-1.

In February 2017, the Department of Energy Office of Nuclear Energy's (DOE-NE) Nuclear Energy Advisory Committee (NEAC) released a final report evaluating the needs and requirements for a new U.S. test reactor.[5] This report received unanimous approval by the NEAC members with the key recommendation of the report being that "DOE-NE proceed immediately with pre-conceptual design planning activities to support a new test reactor (including cost and schedule estimates)." Subsequently, DOE-NE directed that an R&D effort be initiated to create a Versatile Advanced Test Reactor (VTR) concept with an associated cost and schedule estimate that will enable a fully informed DOE acquisition decision at the end of three years.[6]

An initial evaluation of alternatives during the pre-conceptual design planning activity indicates, congruent with the conclusions of the test reactor options study[4] and the NEAC recommendation,[5] development of a well-instrumented sodium-cooled fast neutron spectrum test reactor in the 300 MWth power level range providing a flexible, reconfigurable testing environment for known and anticipated testing is the most practical and cost-effective strategy to meet the mission need and address constraints and considerations presented in this document. DOE will conduct an independent analysis of alternatives as part of the CD-1 process.

It is anticipated that the VTR, coupled with the existing supporting R&D infrastructure, will provide the basic and applied physics, materials science, nuclear fuels, and advanced sensor communities with a unique research capability to enable a comprehensive understanding of the multi-scale and multi-physics performance of nuclear fuels and structural materials to support the development and deployment of advanced nuclear energy systems.

5. RESOURCE AND SCHEDULE FORECAST

The cost range and schedule estimates in this section are based on current DOE laboratory and industry estimates for advanced reactor development and deployment, as well as legacy DOE construction data and lessons learned from similar fast neutron spectrum test reactors.

5.1 Cost Forecast

A rough-order-of-magnitude cost range has been developed[9] to acquire the capability to address the stated mission need. The cost range was generated using six independent approaches:

1. The 400 MWth FFTF design and construction effort in the 1970s with actual costs escalated to 2018 dollars and the equipment costs scaled using best engineering judgment.
2. A 1994 proprietary advanced conceptual design effort with estimated costs escalated to 2018 dollars and equipment costs scaled using best engineering judgment.
3. A reactor technologies capital cost estimation algorithm applied to the VTR design concept using best engineering judgment.
4. A 2008 proprietary advanced conceptual design effort estimated costs escalated to 2018 dollars and equipment costs scaled using engineering judgment.

5. An analogous reactor technology cost model developed for a LWR test reactor escalated to 2018 dollars and equipment costs scaled using engineering judgment.
6. An analogous reactor technology cost model developed for a high-temperature gas reactor escalated to 2018 dollars and equipment costs scaled using engineering judgment.

The cost range is comprehensive, covering the reactor, fuel, support facilities, construction cost, and startup costs. To ensure that all costs were accounted for, a representative DOE site was assumed to develop scope and cost estimates for a postulated specific location. The cost range for the test facility and support facilities is \$3.3B to \$4.5B, and it is anticipated that the peak annual funding need would be \$650M (2018 dollars). The top end of the range accounting for uncertainty in Hazard Category 1 nuclear reactor facility design and construction.

5.2 Schedule Forecast

A notional preliminary schedule of milestones for the VTR project, consistent with the funding profile in Section 5.3, is given below in Table 2.

Table 2. Notional preliminary milestone schedule for the VTR project.

Critical Decisions (CD)	***Fiscal Year***
CD-0, Approve Mission Need	*January 2019*
CD-1, Approve Alternative Selection and Cost Range *CD-3A, Approve Long-Lead Procurements*	*FY 2020*
CD-2/3, Approve Performance Baseline/Approve Start of Construction	*FY 2022*
CD-4, Approve Project Completion/Start of Operations	*FY 2026*

5.3 Funding Forecast

A five-year funding profile, developed for planning purposes only, is shown below in Tables 3a and 3b. The profile is based on the high end of the project cost estimate. Total estimated funding required for the effort to advance the project from CD-0 to CD-1 is \$120M.

Table 3a. Initial five-year funding profile estimate. Net Present Value FY-2018.

Fiscal Year	***FY19***	***FY20***	***FY21***	***FY22***	***FY23***	***Total ($M)***
OPC	65	55	20	40	110	290
TEC – PED Phase		85	380	235		700
TEC – Construction Phase		5	250	375	540	1170
Total Project Cost ($M)	65	145	650	650	650	2160

Table 3b. Initial five-year funding profile estimate (Escalated to year of execution using an annual escalation rate of 3.23%).

Fiscal Year	***FY19***	***FY20***	***FY21***	***FY22***	***FY23***	***Total ($M)***
OPC	65	55	25	45	125	315
TEC – PED Phase		90	405	260		755
TEC – Construction Phase		5	265	410	615	1,295
Total Project Cost ($M)	65	150	695	715	740	2,365

Legend: OPC, other project costs; TEC, total estimated cost; PED, project engineering and design

References

1. DOE/CF-0067, U. S. Department of Energy, Strategic Plan, 2014-2018.

2. H.R. 4378, "Nuclear Energy Research Infrastructure Act," 2018.

3. S.97, "Nuclear Energy Innovation and Capabilities Act," 2017.

4. INL/EXT-16-37867, ADVANCED DEMONSTRATION AND TEST REACTOR OPTIONS STUDY (pp., 26, 78, 79, 102, 134, 135)

5. Nuclear Energy Advisory Committee, *Assessment of Missions and Requirements for a New U.S. Test Reactor*, February 2017. (pg. 20)

6. Dr. John Herczeg, DOE NE-4, to Rick Provencher, Manager, DOE Idaho Operations Office, Fiscal Year (FY) 2017 Program Guidance – US Test Reactor R&D Initiative, United States Government Memorandum, March 6, 2017.

7. INL, *Versatile Irradiation Test Reactor User Needs Assessment*, INL/MIS-16-40582, January 2017 (pp. 1, 3).

8. Kemal O. Pasamehmetoglu, INL, to Dr. John Herczeg, DOE NE-4, "Contract No. DE-AC07-05ID14517 – Preliminary Evaluation of the FFTF Restart Alternative, Revision 1", CCN243271, August 22, 2018.

9. INL, *Cost Estimate Range for the Versatile Test Reactor for the Mission Need Document*, TEV-3508, September 2018.

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APPENDIX B OFFICE OF NUCLEAR ENERGY VTR AOA TASK STATEMENT

Task Statement for Analysis of Alternatives (AoA)
for the
Versatile Test Reactor (VTR) Project
11/1/18

A. Background[1]

Capability Gap

Advanced nuclear fuels with long-life and high-burnup properties and reactor systems structural materials that can tolerate high levels of radiation damage are needed for successful development and deployment of advanced nuclear reactor technology options and for continued improvements in the existing light water reactor (LWR) fleet. As an example, the U.S. Nuclear Regulatory Commission and international regulatory authorities require comprehensive technical data obtained via prototypic irradiation testing prior to use of advanced nuclear fuels and materials. Furthermore, Gen-IV concepts using coolants other than water may also require fast neutrons for the study of fuels and corrosion control.

For advanced fast neutron reactor systems, neutron damage rates are significantly higher than for the current fleet of light water reactors because the magnitude of the fast neutron flux is much higher than for thermal systems and the fuels are designed for higher lifetime fluence. A water-cooled test reactor cannot support research and development of advanced reactor designs because it is not possible to achieve sufficiently high fast neutron flux (without thermal neutron contamination) that is needed for the development of any fast spectrum reactor system and acceleration of materials irradiations for both thermal and fast reactors.

The required functional testing capability for development of advanced nuclear fuels and materials ranges from 20 displacements per atom (dpa) per year to over 600 dpa. Additionally, to create the prototypic environment needed to qualify advanced nuclear fuels and materials, the irradiation must be performed at elevated temperatures with a fast neutron spectrum (>0.1 million electron volts (MeV)) and with flowing coolants other than water. Current domestic irradiation testing facilities cannot provide a representative, timely irradiation testing environment, and access to very limited international testing facilities is precluded by political, transportation and technical issues.

In July of 2016, DOE NE chartered the Nuclear Energy Advisory Committee (NEAC) to independently determine the requirements and overall capabilities (e.g. neutron spectrum/spectra, testing environments, etc.) for a new irradiation test reactor and to perform a comparison with alternative facilities, methodologies, and approaches for meeting these needs and providing these capabilities. The NEAC conducted an independent study including a user needs assessment, and confirmed that there was a U.S. need for fast neutron testing, but no facility that was readily available domestically or internationally. Subsequently, DOE-NE directed that a research and development (R&D) effort be initiated to create a Versatile Advanced Test Reactor (VTR) concept with associated cost and schedule estimate that enables a fully informed DOE acquisition decision at the end of 3 years. The capability gap to be addressed by the VTR concept is the current inability to effectively test advanced nuclear fuels and materials in a prototypic fast neutron spectrum irradiation environment.

The lack of a versatile fast neutron spectrum testing capability is a significant national strategic risk affecting the ability of NE to fulfill its mission to advance nuclear power to meet the nation's energy, environmental, and national security needs. The light water reactor and advanced reactor communities, which are supported by several NE program areas (e.g., small modular reactors technology development and licensing, light water reactor sustainability, advanced nuclear technology development) are key to providing a flexible portfolio of energy supply sources to ensure national security through energy independence and energy dominance, and re-energize the U.S. nuclear industrial sector for domestic deployment of advanced reactors and for access to international markets.

Failure to develop a versatile fast neutron spectrum testing capability as soon as possible on an accelerated schedule will lead to further degradation of U.S. capability to develop advanced nuclear reactors and to continue to improve performance in the current light water reactor fleet, accelerate the on-going shift of nuclear technology primacy to other international states (e.g., China, Russian Federation, Republic of Korea), and fail to re-energize the U.S. nuclear industrial sector. This testing capability is essential for the U.S. to modernize its nuclear energy infrastructure for developing transformational nuclear energy technologies. Independent of the domestic deployment strategies, relinquishing U.S. leadership in advanced reactor technologies will limit U.S. influence in global nuclear safety and security policies and their implementation.

Mission and Objectives

The mission of the DOE NE VTR Project is to provide a leading edge capability for accelerated testing and qualification of advanced fuels and materials enabling the U.S. to regain and sustain technology leadership in the area of current and future advanced reactor system. To meet the mission need, the selected alternative must be a mature concept capable of providing a versatile experimental capability that enables an understanding of nuclear fuels and structural materials performance under irradiation environments representative of future advanced nuclear reactors.

The objectives of the VTR Project are to:

- Execute an efficient approach to development of a conceptual design, cost and schedule estimate, and acquisition approach that would enable a positive decision (CD-1) in 2020 towards 2026 operational startup for the new fast spectrum test reactor.
- Utilize strong industry, university, and laboratory engagement and interaction to ensure an optimum design and experiment capability.
- Utilize international engagement and collaborations to enhance experiment capability development.
- Engage with the NRC to inform licensing of future advanced reactor designs.

Functional Requirements

Per the GAO Best Practices for the Analysis of Alternatives (AoA) Process (GAO-16-22 Appendix I), the customer must define functional requirements (i.e. the general parameters that the selected alternative must have to address the mission need) based on the mission need without a predetermined solution. The customer defines the capabilities the AoA process seeks to refine through characterized gaps between capabilities in the current environment and the capabilities required to meet the stated objectives for the future environment.

The high-level capability requirements established for the VTR include:

- An intense neutron irradiation environment to determine irradiation tolerance and chemical compatibility with other reactor materials, particularly the coolant, is needed for development of new nuclear fuels and materials for use in nuclear reactors. The testing provides a fundamental understanding of materials performance, validation of models for more rapid future development, and engineering scale validation of materials performance in support of licensing efforts.
- A versatile testing capability to address diverse technology options and provide sustained, adaptable testing environments.
- A prototypic neutron energy spectrum to allow testing that is relevant to advanced nuclear reactors.
- Focused irradiations, either long or short term, with heavily instrumented experimental devices, and the possibility to do in-situ measurements and quick extraction of samples, for example with shuttle (rabbit-type) devices to support a science-based approach towards developing predictive fuels and materials modeling capabilities;
    - The final objective of that development is to create validated modeling and simulation tools that will substantially accelerate the development of innovative concepts in the future and shorten the overall nuclear fuels and materials development cycle.
- Develop the capability as soon as possible (goal of 2026 or as soon as practical) on an accelerated schedule to regain and sustain U.S. technology leadership and to enable the competiveness of the U.S based industries in the advanced reactor markets.
    - Use mature technologies for the reactor design (e.g. sodium coolant) while enabling innovative experimentation.

A user needs assessment was also performed to determine specific capabilities that will be required. A summary of preliminary requirements determined from the user needs assessment is provided in Table 1.

Table 1: Preliminary Requirements Summary

REQUIREMENT	TARGET VALUE
Provide a high peak neutron flux (neutron energy > 0.1 MeV) with a prototypic fast reactor neutron energy spectrum	$\geq 4 \times 10^{15}$ n/cm^2-s
Provide high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	> 30 dpa/year
Provide an irradiation length that is typical of fast reactor designs	< 1 m
Provide a large irradiation volume within the high neutron flux region	$\leq$ 7 L in the core region where mid-core neutron flux > 4×10^{15} n/cm^2-s
Provide innovative testing capabilities through flexibility in testing configuration and testing environment (coolants) in closed loops	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salts loops
In addition to traditional measurement techniques, provide the ability to test advanced sensors and instrumentation for the core and test positions	In-situ and real-time measurements
Make the facility available for testing as soon as possible by using proven technologies with high technology readiness level (TRL)	Operational by the end of FY2026
Expedite experiment lifecycle by enabling easy access to support facilities for experiments fabrication and post-irradiation examination	If practical, avoid transportation through public roads
Provide the capability to fabricate the metallic-alloy driver fuel needed for startup and refueling using existing DOE infrastructure with necessary modifications	Not specified must be measured based on $/ton of fuel fabrication

B. Federal Points of Contact

- Program Manager: BP Singh, NE-42: 301-903-3741
- Contracting Officer's Representative: Bob Rova, NE-4: 301-903-9096
- Task Monitor: Janelle Eddins, NE-42: 301-903-2475

C. Scope

The Office of Nuclear Energy is seeking support to complete the AoA for the VTR Project. Pursuant to DOE Order 413.3B, an Analysis of Alternatives must be completed as a requirement to obtain CD-1 approval. Although not required until CD-1, the AoA for the VTR Project is being conducted at prior to CD-0 approval to support the accelerated schedule. The AoA must be independent of the contractor organization responsible for managing the construction or constructing the capital asset project. The preferred alternative should provide the essential functions and capabilities at an optimum life-cycle cost, consistent with required cost, scope, schedule, performance and risk considerations.

The selected team (herein referred to as the AoA team) shall conduct an AoA to provide an analytical basis to be used by NE leadership to inform the future scope of work and associated budget required to meet the VTR Project mission. The AoA must be executed in accordance with *GAO 16-22 Appendix I: Best Practices for the Analysis of Alternatives Process* and should utilize the GAO 22 step best practices process. The life-cycle cost estimates must follow the GAO 12-Step Cost Estimating Guide and use a common cost element structure for all alternatives.

The purpose of the AoA is to:

- Meet the 413.3B requirements and to guide future decisions on the VTR Project.
    - Since this AoA is taking place prior to CD-0 approval, it is expected that the AoA will be updated after CD-0 is approved to support a CD-1 decision.
- Identify all viable options to meet mission needs. Explain why alternatives do or do not meet requirements. For alternatives that do meet the requirements, an explanation should be given on how well these alternatives meet the requirements.
- Provide an objective quantitative assessment of viable alternatives against mission need.
- Calculate the estimated full life cycle costs of each alternative.
- Identify the risks and mitigation strategies of all alternatives analyzed. Potential risks may include: programmatic, operational, schedule, cost, technical feasibility, procurement and resources.
- Provide a sound basis for the proposed design solutions, which will be developed as part of the conceptual design effort.

The AoA may:

- Use applicable previous analyses to the extent that they are analytically rigorous and objective.
- Screen the list of alternatives to elimate those alternatives that are not viable early in the process with consensus of the AoA team. Only those alternatives found viable are examined fully in the AoA process. All assumptions and reasons why an alternative is not considered viable must be fully documented.
    - Some possible criteria for eliminating alternatives are:
        - Inability to meet mission objective
        - Inability to meet threshold safety requirements
        - Inability to meet schedule requirements
        - Unacceptably high cost relative to other viable alternatives

The AoA shall not:

- Build a case for a preferred solution by attempting to validate a pre-selected option.
- Over-emphasize meeting particular requirement thresholds by automatically disqualifying alternatives instead of exploring what is needed to sufficiently mitigate the

gap and achieve an acceptable level of operational risk.
- Over-emphasize performance capability without adequately addressing cost and schedule risks.
- Focus on the best system, as opposed to the best value for the investment.
- Lack awareness of assumptions, data, and scenarios that unfairly skew the results toward a preferred alternative.

The AoA shall consider all feasible options. Each alternative must be responsive to the mission and must be technically achievable for the Office of Nuclear Energy. The AoA team shall define selection criteria based on the requirements and mission need established for the VTR Project, as discussed in Section A and documented in the draft VTR Mission Need Statement[1]. The AoA should include the following alternatives as a minimum starting point:
- Maintain the status quo
- Use, refurbishment, repair or upgrade of available facilities and infrastructure
- Construct and operate a fast spectrum versatile test reactor

The AoA shall consider the following assumptions:
- NEPA compliance is feasible, although not fully defined at this pre-conceptual stage
- Fissile supply will be available when needed
- Sufficient funding will be provided annually to support the VTR Project

All other assumptions used in the performance of the AoA should be clearly documented.

The AoA Team shall reach an in-depth understanding of DOE Capital Construction Policies, Critical Decision documentation, and requirements with input from DOE/NE stakeholders and the NE Project Manager. The AoA team should consist of members with a variety of necessary skill sets, specific knowledge, and abilities to successfully execute the study including the following staff:
- Project management and engineering Subject Matter Experts (SMEs) familiar with DOE AoA requirements, risk management, cost estimating and scheduling
- Fast Reactor and other Nuclear Technology SMEs as needed
- SMEs with knowledge of the entire fuel cycle and system integration expertise
- Nuclear Regulation SMEs
- Other technical and administrative support as coordinated with the NE Program Office

D. Deliverables and Schedule

Expected deliverables are described in Table 2 below. All deliverables should be consistent with GAO-16-22: Appendix 1: Best Practices for the Analysis of Alternatives Process, GAO 12-Step Cost Estimating Guide and DOE Order 413.3B and subordinate Policies and Guides. Any additional technical guidance and direction will be provided by the VTR Project Manager as needed.

Table 2: Deliverables and Schedule

Requirement	Deliverable	Due date	Qty	Frequency	Format
AoA team shall hold a kick-off meeting.	Summary of kick off meeting and Next Actions	1 week after the kick-off meeting	1 Final	1 Time	Hard Copy Document & Electronic
AoA team shall provide an AoA Study Plan for approval by NE.	Plan documenting proposed methodology, screening criteria, evaluation/weighting criteria, and preliminary list of alternatives.	Draft 2 weeks after kick-off meeting; Final 3 weeks after kick-off meeting	1 Draft 1 Final	Once each	Hard Copy Document & Electronic Format
AoA team shall provide a PowerPoint presentation to NE briefing the AoA Study Plan.	Presentation describing proposed methodology, screening criteria, evaluation criteria, metrics, weighting criteria, and preliminary list of alternatives	3 weeks after kick-off meeting, as requested by NE	1 Final	Once	Verbal Presentation & Electronic Format
AoA team shall provide a Final AoA Report describing the entire AoA process and results.	Final report describing the entire AoA process and results to include: Life cycle cost estimates, schedules, risk analysis, alternatives evaluation and sensitivity analysis	Draft 9 weeks after kick-off meeting Final 3 months after kick off meeting	1 Draft 1 Final	Once Each	Hard Copy Document & Electronic Format
AoA team shall provide a PowerPoint presentation to DOE/NE briefing the AoA Results.	Presentation describing the results of the AoA	3 months after kick-off meeting	1 Final	Once	Verbal Presentation & Electronic Format
AoA team Activities Report.	Bi-Weekly Conference calls including but not limited to: Outlining Activities, Accomplishments, Estimated Task Durations Against Actual Task Execution	As determined By Task Monitor and COR	6 conference calls	Bi Weekly	Conference calls

References:

1. Draft Mission Need Statement for the VTR Project, November 2018
2. NEAC Assessment of Missions and Requirements for a New US Test Reactor, February 2017
3. Independent Technical Review of the VTR, October 2018
4. GAO-16-22 Appendix I, October 2015
5. GAO Cost Estimating and Assessment Guide (12 Step), March 2009

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APPENDIX C CONGRESSIONAL DIRECTION AND SYNTHESIS OF REQUIREMENTS, GUIDANCE AND DIRECTION

C.1 SENATE BILL S.97, NUCLEAR ENERGY INNOVATION CAPABILITIES ACT OF 2017

S. 97

One Hundred Fifteenth Congress
of the
United States of America

AT THE SECOND SESSION

Begun and held at the City of Washington on Wednesday, the third day of January, two thousand and eighteen

An Act

To enable civilian research and development of advanced nuclear energy technologies by private and public institutions, to expand theoretical and practical knowledge of nuclear physics, chemistry, and materials science, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Nuclear Energy Innovation Capabilities Act of 2017".

SEC. 2. NUCLEAR ENERGY INNOVATION CAPABILITIES.

(a) NUCLEAR ENERGY.—Section 951 of the Energy Policy Act of 2005 (42 U.S.C. 16271) is amended to read as follows:

"SEC. 951. NUCLEAR ENERGY.

"(a) MISSION.—

"(1) IN GENERAL.—The Secretary shall carry out programs of civilian nuclear research, development, demonstration, and commercial application, including activities under this subtitle.

"(2) CONSIDERATIONS.—The programs carried out under paragraph (1) shall take into consideration the following objectives:

"(A) Providing research infrastructure to promote scientific progress and enable users from academia, the National Laboratories, and the private sector to make scientific discoveries relevant for nuclear, chemical, and materials science engineering.

"(B) Maintaining nuclear energy research and development programs at the National Laboratories and institutions of higher education, including infrastructure at the National Laboratories and institutions of higher education.

"(C) Providing the technical means to reduce the likelihood of nuclear proliferation.

"(D) Increasing confidence margins for public safety of nuclear energy systems.

"(E) Reducing the environmental impact of activities relating to nuclear energy.

"(F) Supporting technology transfer from the National Laboratories to the private sector.

"(G) Enabling the private sector to partner with the National Laboratories to demonstrate novel reactor concepts for the purpose of resolving technical uncertainty associated with the objectives described in subparagraphs (A) through (F).

S. 97—2

"(b) DEFINITIONS.—In this subtitle:

"(1) ADVANCED NUCLEAR REACTOR.—The term 'advanced nuclear reactor' means—

"(A) a nuclear fission reactor with significant improvements over the most recent generation of nuclear fission reactors, which may include—

"(i) inherent safety features;

"(ii) lower waste yields;

"(iii) greater fuel utilization;

"(iv) superior reliability;

"(v) resistance to proliferation;

"(vi) increased thermal efficiency; and

"(vii) the ability to integrate into electric and nonelectric applications; or

"(B) a nuclear fusion reactor.

"(2) COMMISSION.—The term 'Commission' means the Nuclear Regulatory Commission.

"(3) FAST NEUTRON.—The term 'fast neutron' means a neutron with kinetic energy above 100 kiloelectron volts.

"(4) NATIONAL LABORATORY.—

"(A) IN GENERAL.—Except as provided in subparagraph (B), the term 'National Laboratory' has the meaning given the term in section 2.

"(B) LIMITATION.—With respect to the Lawrence Livermore National Laboratory, the Los Alamos National Laboratory, and the Sandia National Laboratories, the term 'National Laboratory' means only the civilian activities of the laboratory.

"(5) NEUTRON FLUX.—The term 'neutron flux' means the intensity of neutron radiation measured as a rate of flow of neutrons applied over an area.

"(6) NEUTRON SOURCE.—The term 'neutron source' means a research machine that provides neutron irradiation services for—

"(A) research on materials sciences and nuclear physics; and

"(B) testing of advanced materials, nuclear fuels, and other related components for reactor systems.".

(b) NUCLEAR ENERGY RESEARCH PROGRAMS.—

(1) IN GENERAL.—Section 952 of the Energy Policy Act of 2005 (42 U.S.C. 16272) is amended—

(A) by striking subsection (c); and

(B) by redesignating subsections (d) and (e) as subsections (c) and (d), respectively.

(2) CONFORMING AMENDMENT.—Section 641(b)(1) of the Energy Policy Act of 2005 (42 U.S.C. 16021(b)(1)) is amended by striking "section 942(d)" and inserting "section 952(c)".

(c) ADVANCED FUEL CYCLE INITIATIVE.—Section 953(a) of the Energy Policy Act of 2005 (42 U.S.C. 16273(a)) is amended by striking ", acting through the Director of the Office of Nuclear Energy, Science and Technology,".

(d) UNIVERSITY NUCLEAR SCIENCE AND ENGINEERING SUPPORT.—Section 954(d)(4) of the Energy Policy Act of 2005 (42 U.S.C. 16274(d)(4)) is amended by striking "as part of a taking into consideration effort that emphasizes" and inserting "that emphasize".

S. 97—3

(e) DEPARTMENT OF ENERGY CIVILIAN NUCLEAR INFRASTRUCTURE AND FACILITIES.—Section 955 of the Energy Policy Act of 2005 (42 U.S.C. 16275) is amended—

(1) by striking subsections (c) and (d); and

(2) by adding at the end the following:

"(c) VERSATILE NEUTRON SOURCE.—

"(1) MISSION NEED.—

"(A) IN GENERAL.—Not later than December 31, 2017, the Secretary shall determine the mission need for a versatile reactor-based fast neutron source, which shall operate as a national user facility.

"(B) CONSULTATIONS REQUIRED.—In carrying out subparagraph (A), the Secretary shall consult with the private sector, institutions of higher education, the National Laboratories, and relevant Federal agencies to ensure that the user facility described in subparagraph (A) will meet the research needs of the largest practicable majority of prospective users.

"(2) ESTABLISHMENT.—As soon as practicable after determining the mission need under paragraph (1)(A), the Secretary shall submit to the appropriate committees of Congress a detailed plan for the establishment of the user facility.

"(3) FACILITY REQUIREMENTS.—

"(A) CAPABILITIES.—The Secretary shall ensure that the user facility will provide, at a minimum, the following capabilities:

"(i) Fast neutron spectrum irradiation capability.

"(ii) Capacity for upgrades to accommodate new or expanded research needs.

"(B) CONSIDERATIONS.—In carrying out the plan submitted under paragraph (2), the Secretary shall consider the following:

"(i) Capabilities that support experimental high-temperature testing.

"(ii) Providing a source of fast neutrons at a neutron flux, higher than that at which current research facilities operate, sufficient to enable research for an optimal base of prospective users.

"(iii) Maximizing irradiation flexibility and irradiation volume to accommodate as many concurrent users as possible.

"(iv) Capabilities for irradiation with neutrons of a lower energy spectrum.

"(v) Multiple loops for fuels and materials testing in different coolants.

"(vi) Additional pre-irradiation and post-irradiation examination capabilities.

"(vii) Lifetime operating costs and lifecycle costs.

"(4) DEADLINE FOR ESTABLISHMENT.—The Secretary shall, to the maximum extent practicable, complete construction of, and approve the start of operations for, the user facility by not later than December 31, 2025.

"(5) REPORTING.—The Secretary shall include in the annual budget request of the Department an explanation for any delay in the progress of the Department in completing the user facility by the deadline described in paragraph (4).

S. 97—4

"(6) COORDINATION.—The Secretary shall leverage the best practices for management, construction, and operation of national user facilities from the Office of Science.".

(f) SECURITY OF NUCLEAR FACILITIES.—Section 956 of the Energy Policy Act of 2005 (42 U.S.C. 16276) is amended by striking ", acting through the Director of the Office of Nuclear Energy, Science and Technology,".

(g) HIGH-PERFORMANCE COMPUTATION AND SUPPORTIVE RESEARCH.—Section 957 of the Energy Policy Act of 2005 (42 U.S.C. 16277) is amended to read as follows:

"SEC. 957. HIGH-PERFORMANCE COMPUTATION AND SUPPORTIVE RESEARCH.

"(a) MODELING AND SIMULATION.—The Secretary shall carry out a program to enhance the capabilities of the United States to develop new reactor technologies through high-performance computation modeling and simulation techniques.

"(b) COORDINATION.—In carrying out the program under subsection (a), the Secretary shall coordinate with relevant Federal agencies as described by the National Strategic Computing Initiative established by Executive Order 13702 (80 Fed. Reg. 46177 (July 29, 2015)), while taking into account the following objectives:

"(1) Using expertise from the private sector, institutions of higher education, and the National Laboratories to develop computational software and capabilities that prospective users may access to accelerate research and development of advanced nuclear reactor systems and reactor systems for space exploration.

"(2) Developing computational tools to simulate and predict nuclear phenomena that may be validated through physical experimentation.

"(3) Increasing the utility of the research infrastructure of the Department by coordinating with the Advanced Scientific Computing Research program within the Office of Science.

"(4) Leveraging experience from the Energy Innovation Hub for Modeling and Simulation.

"(5) Ensuring that new experimental and computational tools are accessible to relevant research communities, including private sector entities engaged in nuclear energy technology development.

"(c) SUPPORTIVE RESEARCH ACTIVITIES.—The Secretary shall consider support for additional research activities to maximize the utility of the research facilities of the Department, including physical processes—

"(1) to simulate degradation of materials and behavior of fuel forms; and

"(2) for validation of computational tools.".

(h) ENABLING NUCLEAR ENERGY INNOVATION.—Subtitle E of title IX of the Energy Policy Act of 2005 (42 U.S.C. 16271 et seq.) is amended by adding at the end the following:

"SEC. 958. ENABLING NUCLEAR ENERGY INNOVATION.

"(a) NATIONAL REACTOR INNOVATION CENTER.—There is authorized a program to enable the testing and demonstration of reactor concepts to be proposed and funded, in whole or in part, by the private sector.

"(b) TECHNICAL EXPERTISE.—In carrying out the program under subsection (a), the Secretary shall leverage the technical expertise of relevant Federal agencies and the National Laboratories in order to minimize the time required to enable construction and operation of privately funded experimental reactors at National Laboratories or other Department-owned sites.

"(c) OBJECTIVES.—The reactors described in subsection (b) shall operate to meet the following objectives:

"(1) Enabling physical validation of advanced nuclear reactor concepts.

"(2) Resolving technical uncertainty and increasing practical knowledge relevant to safety, resilience, security, and functionality of advanced nuclear reactor concepts.

"(3) General research and development to improve nascent technologies.

"(d) SHARING TECHNICAL EXPERTISE.—In carrying out the program under subsection (a), the Secretary may enter into a memorandum of understanding with the Chairman of the Commission in order to share technical expertise and knowledge through—

"(1) enabling the testing and demonstration of advanced nuclear reactor concepts to be proposed and funded, in whole or in part, by the private sector;

"(2) operating a database to store and share data and knowledge relevant to nuclear science and engineering between Federal agencies and the private sector;

"(3) developing and testing electric and nonelectric integration and energy conversion systems relevant to advanced nuclear reactors;

"(4) leveraging expertise from the Commission with respect to safety analysis; and

"(5) enabling technical staff of the Commission to actively observe and learn about technologies developed under the program.

"(e) AGENCY COORDINATION.—The Chairman of the Commission and the Secretary shall enter into a memorandum of understanding regarding the following:

"(1) Ensuring that—

"(A) the Department has sufficient technical expertise to support the timely research, development, demonstration, and commercial application by the civilian nuclear industry of safe and innovative advanced nuclear reactor technology; and

"(B) the Commission has sufficient technical expertise to support the evaluation of applications for licenses, permits, and design certifications and other requests for regulatory approval for advanced nuclear reactors.

"(2) The use of computers and software codes to calculate the behavior and performance of advanced nuclear reactors based on mathematical models of the physical behavior of advanced nuclear reactors.

"(3) Ensuring that—

"(A) the Department maintains and develops the facilities necessary to enable the timely research, development, demonstration, and commercial application by the civilian nuclear industry of safe and innovative reactor technology; and

"(B) the Commission has access to the facilities described in subparagraph (A), as needed.

"(f) REPORTING REQUIREMENTS.—

S. 97—6

"(1) IN GENERAL.—Not later than 180 days after the date of enactment of the Nuclear Energy Innovation Capabilities Act of 2017, the Secretary, in consultation with the National Laboratories, relevant Federal agencies, and other stakeholders, shall submit to the appropriate committees of Congress a report assessing the capabilities of the Department to authorize, host, and oversee privately funded experimental advanced nuclear reactors as described in subsection (b).

"(2) CONTENTS.—The report submitted under paragraph (1) shall address—

"(A) the safety review and oversight capabilities of the Department, including options to leverage expertise from the Commission and the National Laboratories;

"(B) options to regulate privately proposed and funded experimental reactors hosted by the Department;

"(C) potential sites capable of hosting privately funded experimental advanced nuclear reactors;

"(D) the efficacy of the available contractual mechanisms of the Department to partner with the private sector and Federal agencies, including cooperative research and development agreements, strategic partnership projects, and agreements for commercializing technology;

"(E) the liability of the Federal Government with respect to the disposal of low-level radioactive waste, spent nuclear fuel, or high-level radioactive waste (as those terms are defined in section 2 of the Nuclear Waste Policy Act of 1982 (42 U.S.C. 10101));

"(F) the impact on the aggregate inventory in the United States of low-level radioactive waste, spent nuclear fuel, or high-level radioactive waste (as those terms are defined in section 2 of the Nuclear Waste Policy Act of 1982 (42 U.S.C. 10101));

"(G) potential cost structures relating to physical security, decommissioning, liability, and other long-term project costs; and

"(H) other challenges or considerations identified by the Secretary.

"(3) UPDATES.—Once every 2 years, the Secretary shall update relevant provisions of the report submitted under paragraph (1) and submit to the appropriate committees of Congress the update.

"(g) SAVINGS CLAUSES.—

"(1) LICENSING REQUIREMENT.—Nothing in this section authorizes the Secretary or any person to construct or operate a nuclear reactor for the purpose of demonstrating the suitability for commercial application of the nuclear reactor unless licensed by the Commission in accordance with section 202 of the Energy Reorganization Act of 1974 (42 U.S.C. 5842).

"(2) FINANCIAL PROTECTION.—Any activity carried out under this section that involves the risk of public liability shall be subject to the financial protection or indemnification requirements of section 170 of the Atomic Energy Act of 1954 (42 U.S.C. 2210) (commonly known as the 'Price-Anderson Act').".

(i) BUDGET PLAN.—Subtitle E of title IX of the Energy Policy Act of 2005 (42 U.S.C. 16271 et seq.) (as amended by subsection (h)) is amended by adding at the end the following:

S. 97—7

"SEC. 959. BUDGET PLAN.

"(a) IN GENERAL.—Not later than 1 year after the date of enactment of the Nuclear Energy Innovation Capabilities Act of 2017, the Secretary shall submit to the Committee on Energy and Natural Resources of the Senate and the Committee on Science, Space, and Technology of the House of Representatives 2 alternative 10-year budget plans for civilian nuclear energy research and development by the Secretary, as described in subsections (b) through (d).

"(b) BUDGET PLAN ALTERNATIVE 1.—One of the budget plans submitted under subsection (a) shall assume constant annual funding for 10 years at the appropriated level for the civilian nuclear energy research and development of the Department for fiscal year 2016.

"(c) BUDGET PLAN ALTERNATIVE 2.—One of the budget plans submitted under subsection (a) shall be an unconstrained budget.

"(d) INCLUSIONS.—Each alternative budget plan submitted under subsection (a) shall include—

"(1) a prioritized list of the programs, projects, and activities of the Department to best support the development of advanced nuclear reactor technologies;

"(2) realistic budget requirements for the Department to implement sections 955(c), 957, and 958; and

"(3) the justification of the Department for continuing or terminating existing civilian nuclear energy research and development programs.".

(j) REPORT ON FUSION INNOVATION.—

(1) IN GENERAL.—Not later than 180 days after the date of enactment of this Act, the Secretary of Energy shall submit to the Committee on Energy and Natural Resources of the Senate and the Committee on Science, Space, and Technology of the House of Representatives a report identifying engineering designs for innovative fusion energy systems that have the potential to demonstrate net energy production not later than 15 years after the start of construction.

(2) INCLUSIONS.—The report submitted under paragraph (1) shall identify budgetary requirements that would be necessary for the Department of Energy to carry out a fusion innovation initiative to accelerate research and development of the engineering designs identified in the report.

(k) CONFORMING AMENDMENTS.—The table of contents for the Energy Policy Act of 2005 is amended by striking the item relating to section 957 and inserting the following:

SEC. 3. ADVANCED NUCLEAR ENERGY LICENSING COST-SHARE GRANT PROGRAM.

(a) DEFINITIONS.—In this section:

(1) COMMISSION.—The term "Commission" means the Nuclear Regulatory Commission.

(2) PROGRAM.—The term "program" means the Advanced Nuclear Energy Cost-Share Grant Program established under subsection (b).

(3) SECRETARY.—The term "Secretary" means the Secretary of Energy.

S. 97—8

(b) ESTABLISHMENT.—The Secretary shall establish a grant program, to be known as the "Advanced Nuclear Energy Cost-Share Grant Program", under which the Secretary shall make cost-share grants to applicants for the purpose of funding a portion of the Commission fees of the applicant for pre-application review activities and application review activities.

(c) REQUIREMENT.—The Secretary shall seek out technology diversity in making grants under the program.

(d) COST-SHARE AMOUNT.—The Secretary shall determine the cost-share amount for each grant under the program in accordance with section 988 of the Energy Policy Act of 2005 (42 U.S.C. 16352).

(e) USE OF FUNDS.—A recipient of a grant under the program may use the grant funds to cover Commission fees, including those fees associated with—

(1) developing a licensing project plan;
(2) obtaining a statement of licensing feasibility;
(3) reviewing topical reports; and
(4) other—
  (A) pre-application review activities;
  (B) application review activities; and
  (C) interactions with the Commission.

Speaker of the House of Representatives.

Vice President of the United States and
President of the Senate.

C.2 SYNTHESIS OF APPENDIX A, APPENDIX B, AND APPENDIX C.1

As discussed in Chapter 3 of the VTR AoA Report, DOE NE provided the approved MNS, the NE Task Statement and the S.97 Nuclear Energy Innovation Capabilities Act (S.97 NEICA). From these three documents, the AoA Team synthesized the requirements, DOE NE guidance and the Congressional direction into Screening Criteria and Evaluation Criteria to conduct the AoA. Figure C-1 outlines this approach.

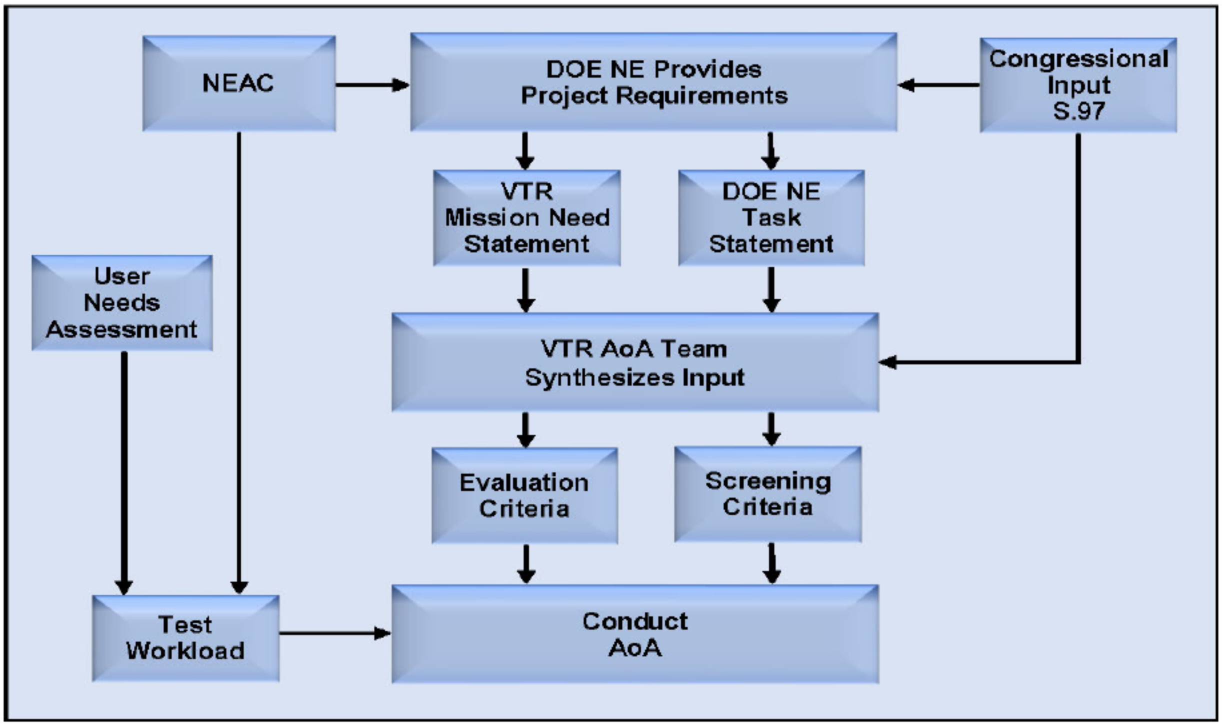

Figure C-1. VTR AoA Team's Synthesis of DOE NE Requirements, DOE NE Guidance, and Congressional Direction

The Specific references for each of the Screening Criteria can be found in Table C-1.

Table C-1. Screening Criteria References

Screening Criteria	References
SC #1	MNS Section 3.3. Capabilities and S 97 NEICA of 2017
SC #2	MNS Section 3.3 Capabilities
SC #3	MNS Section 3.3 Capabilities
SC #4	MNS Section 3.3 Capabilities
SC#5	S.97 NEICA of 2017 Section (C) (1) (A)
SC #6	S.97 NEICA of 2017 Section (C) (3) (A) (ii)

The specific references for each of the Evaluation Criteria can be found in Table C-2.

Table C-2. Evaluation Criteria References

Evaluation Criteria	References
EC #1	MNS Section 3.3 Capabilities and S.97 NEICA of 2017 Section (C) (3) (B) (ii)
EC #2	MNS Section 3.3 Capabilities
EC #3	MNS Section 3.3 Capabilities
EC #4	MNS Section 3.3 Capabilities and S.97 NEICA of 2017 Section (C) (3) (B) (iii)
EC #5	MNS Section 3.3 Capabilities and S.97 NEICA of 2017 Section (C) (3) (B) (v)
EC #6	MNS Section 3.3 Capabilities
EC #7	MNS Section 3.3 Capabilities
EC #8	MNS Section 3.3 Capabilities and S.97 NEICA of 2017 Section (C) (3) (B) (vi)
EC #9	MNS Section 3.3 Capabilities
EC #10	S.97 NEICA of 2017 Section (C) (3) (B) (i)
EC #11	S.97 NEICA of 2017 Section (C) (3) (B) (iv)
EC #12	S.97 NEICA of 2017 Section (C) (3) (B) (vii)
EC #13	S.97 NEICA of 2017 Section (C) (3) (B) (vii)
EC #14	S.97 NEICA of 2017 Section (C) (3) (B) (vii)
EC #15	S.97 NEICA of 2017 Section (C) (4)
EC #16 – 20	General AoA Considerations

APPENDIX D ALTERNATIVE DESCRIPTIONS

Following the initial screening of alternatives, a more functional description was prepared for the Status Quo and the six viable alternatives. This provided the VTR AoA Team with a common basis for understanding and comparing the alternatives and facilitated a discussion of strengths and challenges that might be important for discrimination of the alternatives. These descriptions were refined as appropriate as additional information was obtained during this analysis, with each revision considered by the team for consistency. The final working descriptions are discussed below.

D.1 Status Quo Alternative Description

D.1.1 Summary

The base case (Status Quo) implies no new facilities are constructed and no major modifications are made to existing facilities. There is currently no fast spectrum reactor operational in the United States and the primary source for fast spectrum testing is in a limited number of high flux, thermal spectrum reactors using thermal neutron absorbers to filter out the thermal flux and use the remaining fast flux for testing. This represents very limited fast flux testing capability, leaving the VTR mission need fundamentally unfilled. This is a basic conclusion of a recent study of the Nuclear Energy Advisory Committee that recommended pursuing a VTR mission (reference). Several existing thermal test reactors would continue to provide limited testing capacity. HFIR at ORNL currently has the highest fast flux available. ATR at INL has somewhat less but has a larger test volume. Both test reactors have a primarily thermal flux which must be filtered out, leaving a spectrum that is not entirely representative of fast reactors. Sufficient damage accumulation to test fast reactor fuels and materials using these limited fast flux environments takes many years (20 to 50+). There has been, and might continue to be, extremely limited DOE use of foreign fast test reactors. This is limited due to cost, transportation and political issues, as well as the age and test volume of those facilities. Industry vendors who need fast flux test capability will continue to use the DOE user facilities with long wait times for results, or they may propose that an initial demonstration plant be used as a test or research facility ('license by test protocol' or research reactor class 104(c)). Industry would also try to partner with foreign nations to use their facilities, which could potentially result in the effective export of advanced U.S. nuclear energy technology to potentially hostile foreign nations.

D.1.2 Rationale for Consideration

In general, a 'no action' or 'Status Quo' alternative is required in all Analyses of Alternatives for comparison to the potentially viable alternatives for meeting the mission need – although, the Status Quo alternative does not meet the mission need. This description of the Status Quo will explore what fraction of the mission need might be met with modest extensions of existing facilities and practices, without significant capital investment.

D.1.3 Features of the Status Quo

The United States currently does not have any major fast-neutron irradiation test facilities. Research, development and deployment of advanced nuclear energy systems requires new fuels, materials and components that will operate in a fast-neutron environment. Without adequate irradiation capabilities U.S. researchers are limited to a set of unsatisfactory options for testing of fuels, materials, other components, detectors, etc., including:

- **Use of the limited space in existing thermal neutron reactors** along with filters such as cadmium sheaths or rare earth absorbers to stop the low energy neutrons and irradiate samples in the remaining fast neutrons. The fast flux available in these facilities is inadequate for the full range of testing required. The two most capable facilities for this are ATR and HFIR, but both have existing thermal neutron missions that constrain the available capacity. Several University or industrial reactors can also be used with thermal neutron filtering, but the remaining fast flux is even lower.

- **Use of an accelerator-based spallation source.** The most capable spallation sources (such as FMIT) have been decommissioned and the proposed replacements have not been built (such as MTS). These could have useful fast flux, but over very limited test volume unless a large fission blanket is used. Such sources typically have a limited duty cycle – and meet only a small fraction of the mission need.
- **Go overseas to foreign fast research reactors to buy irradiation time.** There are a few such reactors (such as in Russia, China, India, Japan), with limited volume and remaining lifetime (or not yet operational). Efforts in the past to use this approach have proven difficult, costly and lengthy. In addition, partnering with foreign test facilities (that are all government controlled) could risk exporting advanced U.S. technology R&D to potentially adversarial and/or competitive nations.
- **Substitute numerical simulation for testing.** Some benefit can be gained from advanced modeling, but even the best simulations require physical data to build and validate their models, and only experiments can discover unexpected phenomena.
- **Bypass some of the testing** by attempting to construct one or more technology demonstration or prototype reactors through the use of the NRC 'License by Test' approach or use of a research Class 104(c) license. This has proven to be uncertain, expensive and lengthy, and would continue to offer uncertain success.
- **Wait for foreign R&D to bear fruit**, and either buy or copy their designs if and when they become commercially available. This does not support U.S. technology leadership.
- **Limit future technologies to those fuels, materials and systems that have been tested in the past.** This prevents development of advanced technologies and leaves the United States out of the future nuclear energy and technology market.

D.1.4 Pros/Cons of the Status Quo

Potential advantages include:

- There are no major construction costs – only ongoing experimental costs and modest modification of existing facilities.
- The Status Quo is currently implemented – by default.

Potential disadvantages include:

- Inability to meet any significant fraction of the mission need.
- Inability to support and enable U.S. nuclear technology development.
- Continued stagnation of domestic nuclear energy technology.
- Loss of world leadership in nuclear technology.
- Potential export of U.S. nuclear innovation to other nations.

Table D-1 summarizes some of the capabilities of the Status Quo to support VTR mission needs.

Table D-1. Comparison of Status Quo Capabilities to VTR Targets

VTR Requirement	VTR Target	Status Quo Capability
Peak fast flux	≥4.5×1015 n/cm2-s	~1.0×1015 n/cm2-s
dpa rate	> 30 dpa/year	6 – 10 dpa/year
Irradiation length	0.6m – 1.0m	0.6m – 1.0m (reduced flux)
Irradiation volume	≥ 7 Liters	< 1 liter (highest flux), several liters (reduced flux) dependent on availability
Test flexibility	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salt Loops	Closed loops, maybe rabbits
Test advanced I&C	Test advanced sensors and instruments	Some instrumented testing.
Available soon	Operational by end of FY2026	Currently exists.
Easy access to experiment fabrication and PIE	Avoid shipping off of a controlled site	Adequate – varies by site.
Provide life cycle management for driver fuel while minimizing cost and schedule impacts	Evaluate based on cost and schedule impact with consideration for using existing DOE infrastructure with necessary modifications for fuel life-cycle management	Assume current ability.

D.2 Advanced Test Reactor (ATR) + Boosted Fast Flux Loop (BFFL) Alternative Description

D.2.1 Summary

The Advanced Test Reactor (ATR) is a light-water cooled research and test reactor located at the Idaho National Laboratory (INL). The reactor's primary "customer" is the U.S. Navy. It is also used by industry, universities and various NE programs, most notably, the Advanced Fuels Campaign (AFC) of the DOE NE Fuel Cycle Research and Development (FCRD) program to irradiate a broad spectrum of fuels and cladding materials of interest. The reactor is typically operated at a power level in the range of 110 to 120 MWth (250 MWth maximum) and has a maximum thermal flux of $1.0\text{x}10^{15}$ n/cm^2-s, and maximum fast flux of $5.0\text{x}10^{14}$ n/cm^2-s. The irradiations address both thermal and fast spectrum concepts with Accident Tolerant Fuels a prime example of the former. To approximate a fast spectrum environment, the AFC/ATR developed and implemented an irradiation capsule design with a "thermal flux absorber" (e.g., cadmium) to minimize the thermal component of the flux. In addition, a Boosted Fast Flux Loop (BFFL) was proposed in the past (but not implemented) to increase the fast flux into the range of ~$1\text{x}10^{15}$ n/cm^2-s[6]. This alternative considers the ATR with the BFFL implemented in the future. There is infrastructure on site to support many/most of the irradiation and PIE requirements of the ongoing programs, and the VTR mission.

D.2.2 Rationale for Consideration as Potentially Viable Alternative

- Operating, domestic test reactor.
- High-power and high-flux (primarily thermal).
- National Science User Facility (NSUF) – experienced in accommodating the needs of multiple users.
- Multiple irradiation locations.
- Capabilities for "large" dimension/volume irradiation samples.
- Boosted Fast Flux Loop (BFFL) "extensively studied" to boost fast flux into range required for fast-spectrum reactors; fast flux increased from 5.0E+14 to ~1.0E+15 n/cm^2-s.
- Used for many years by Advanced Fuels Campaign (AFC) to irradiate fuels and materials for thermal- and fast-spectrum reactors.
- Use of cadmium (Cd) shielded irradiation baskets to approximate fast-spectrum performance has been successful (INL-EXT-17-41677) in providing useful information on expected fuel behavior in a fast spectrum based on irradiations in a thermal reactor:

  "The analyses and comparisons presented in this report show that ATR irradiations performed using cadmium shrouding are sufficiently prototypic that they can be used with confidence in the development and testing of fast reactor fuels."
- Currently studying use of reduced diameter fuel rodlets to increase the power density and hence accelerate the burnup in simulations of fast-spectrum conditions.
- Infrastructure available on INL site for fabrication and characterization of irradiation samples and subsequent PIE.
- Experienced in receiving and shipping samples between sites.
- With proper maintenance, the ATR has many decades of useful life remaining. Naval Reactors has indicated that they want to use it until at least 2085.
- BFFL option is much less expensive than a new test reactor. Last estimated cost range (2009) was $50-$75M.
- BFFL option could be implemented by 2026. Last estimated schedule (2009) was seven years.

D.2.3 Features of the ATR-BFFL

Figure D-1 shows a cross-section of the Advanced Test Reactor and the large number of potential locations for irradiation samples both within the core (flux traps) and in the reflector. As noted above, various users, including NE programs and the AFC have been irradiating fuel and materials samples in the ATR for many years.

"The Boosted Fast Flux Loop (BFFL) project was initiated to determine the basic feasibility of designing, constructing, and installing in a host irradiation facility, an experimental vehicle that can replicate with reasonable fidelity the fast-flux test environment needed for fuels and materials irradiation testing for advanced reactor concepts. The BFFL was originally called the Gas Test Loop (GTL) project."

Figure D-2 shows the BFFL located in one of the core lobes of the ATR, and some details for one of the concepts. The analyses performed for the initial GTL/BFFL design concept showed that with a lobe power of 45 MW and a reactor power of 140 MW. "The peak fast flux for the configuration analyzed is approximately 1.07×10^{15} n/cm^2-s (E > 0.1 MeV) and exceeds 1×10^{15} n/cm^2-s in a 27 cm tall section about the core mid-plane".

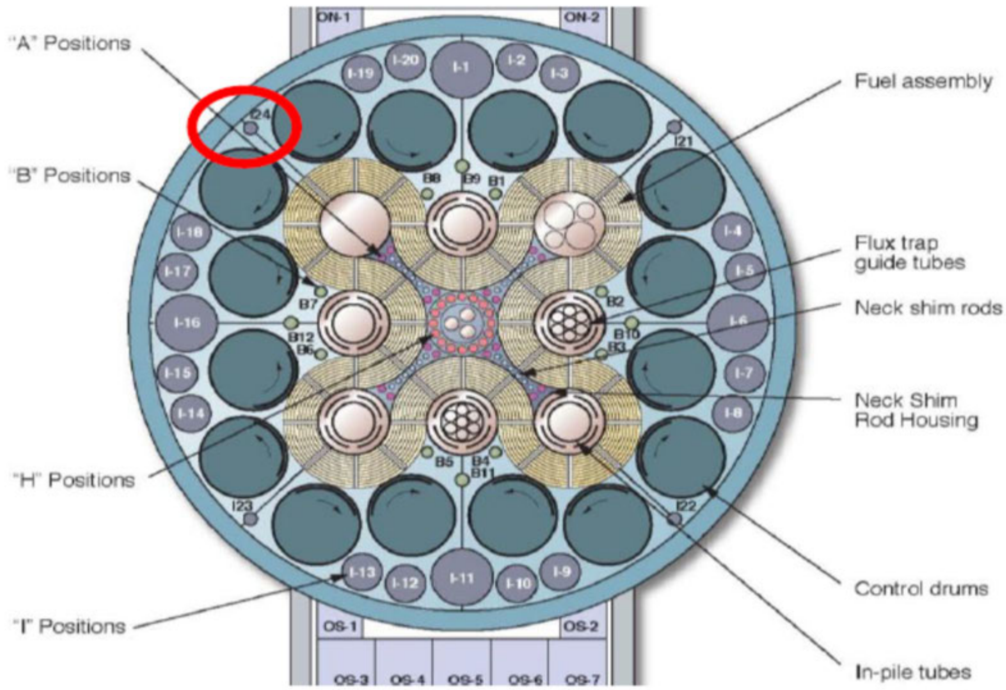

Figure D-1. Cross-section of ATR Showing Irradiation Locations

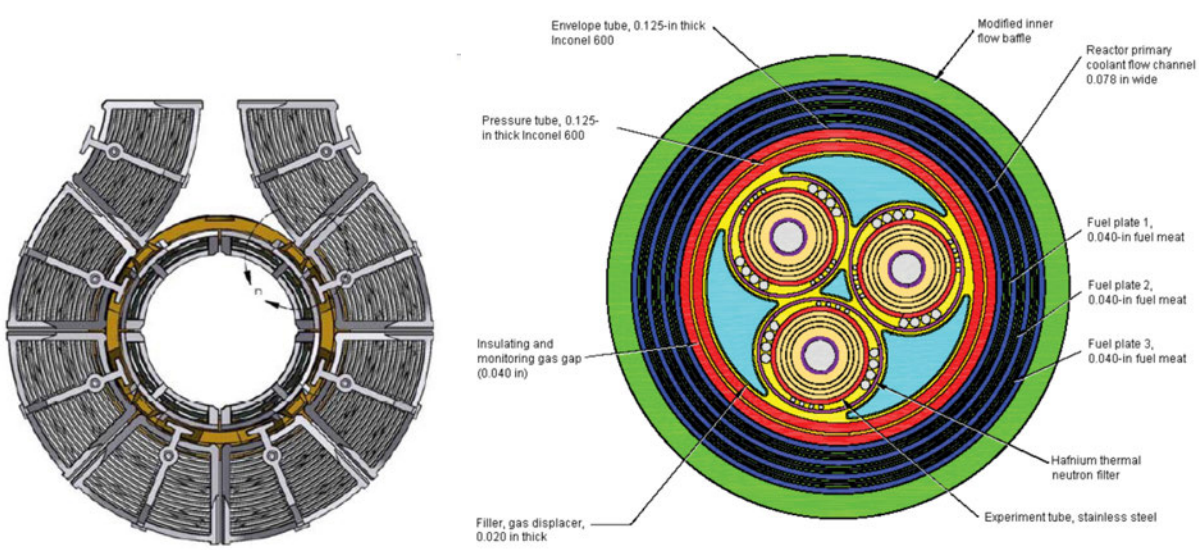

Figure D-2. BFFL in ATR Lobe (left) and Detail of BFFL (right)

D.2.4 Pros/Cons of ATR-BFFL for VTR Mission

Potential Advantages: see "Rationale" above.

Potential Disadvantages Include:

- Thermal-spectrum reactor – use of "thermal-flux absorber" while relatively successful (see above) is not prototypic; issues include fast-to-thermal flux ratio, radial fission distribution, burnup of Cd or Hf shield, damage accumulation for cladding, etc.
- Maximum fast flux achievable is only 1E15 n/cm^2-s, which is a factor of 4 less than the required VTR fast flux. This will result in many more irradiation cycles per experiment.
- No work/progress on BFFL concept since ~2009.
- Potential competition with main mission (Navy), impact on ATF program irradiations, NSUF commitments, and upcoming Pu-238 production mission for NASA. There is potential for schedule conflicts for BFFL installation, however, it is likely that the installation would be done in concurrence with a scheduled CIC or required extended maintenance.
- Potential operating issues with BFFL due to significant increase in power in affected lobe versus other lobes. This could adversely affect other experiments in the reactor, including Naval Reactors experiments.
- The higher power required to achieve a decent fast flux also means the booster fuel will burn up more quickly than other ATR fuels. It will also accelerate the degradation of the beryllium reflector material. This will mean more frequent shutdowns of ATR for refueling and maintenance and lessen the number of cycles achievable per year, decreasing operational efficiency.
- Booster fuel in current design uses HEU, which could cause additional proliferation and security concerns beyond the current ATR HEU fuel.
- Depending on what fuel is used for the BFFL (e.g., U_3Si_2), a fuel qualification program may be required. In addition, no full-length booster fuel plates were ever fabricated by BWXT, the ATR fuel supplier and projected booster fuel supplier.
- BWXT is struggling to meet current ATR fuel fabrication requirements. INL manager stated that without BWXT, booster fuel will need to be fabricated at MFC, possibly requiring a new fuel fabrication line and equipment plus additional security.
- Because of other ATR customer needs, the only position considered feasible for a BFFL is the northeast flux trap in ATR. Only three test trains of 1-inch diameter and maximum 61 cm length each can be inserted at a time. The resultant test volume available is a little more than 1L each, much less than the desired 7L for VTR.

Table D-2 summarizes some of the capabilities of ATR with BFFL to support VTR mission needs.

Table D-2. Comparison of ATR-BFFL Capabilities to VTR Targets

VTR Requirement	VTR Target	ATR / BFFL Capability
Peak fast flux	≥4.5×1015 n/cm2-s	1.0×1015 n/cm2-s*
dpa rate	> 30 dpa/year	6 – 10 dpa/year
Irradiation length	0.6m – 1.0m	0.4* - 1.2 m
Irradiation volume	≥ 7 Liters	1.0×1015 n/cm2-s = 0.6 L* Plus larger volumes at reduced flux: 3.7-5.0×1014 n/cm2-s 30 locations x 0.2 L
Test flexibility	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salt Loops	Likely in closed & rabbits Unknown if in BFFL
Test advanced I&C	Test advanced sensors and instruments	Assume – YES
Available soon	Operational by end of FY2026	No work on BFFL beyond Final Report September 2009
Easy access to experiment fabrication and PIE	Avoid shipping off of a controlled site	Assume – YES
Provide life cycle management for driver fuel while minimizing cost and schedule impacts	Evaluate based on cost and schedule impact with consideration for using existing DOE infrastructure with necessary modifications for fuel life-cycle management	Assume – YES

*For BFFL, others for highest flux irradiation positions (A-16 holes, H-14 holes) see Figure D-1.

D.3 HFIR with 3/7 Pin Configuration Alternative Description

D.3.1 Summary

The High Flux Isotope Reactor (HFIR) is a light-water cooled reactor located at the Oak Ridge National Laboratory (ORNL). The reactor has a power level of 85 MWth (100 MWth maximum power) and associated maximum thermal and fast fluxes of 3.0×10^{15} and 1.0×10^{15} n/cm^2-s, respectively. The primary application of the HFIR originally focused on isotope production, but the current focus is neutron scattering, and isotope production (e.g., Pu238 and medical) In addition to other users (LWRS, NEET, NEUP, NSUF, and others). It has been used by the Advanced Fuels Campaign (AFC) of the DOE NE Fuel Cycle Research and Development (FCRD) program to irradiate fuels and cladding materials of interest in rabbits in the core/reflector for short-term irradiations and in irradiation locations in the reflector/pool. Irradiations designed to approximate a fast spectrum use a "thermal flux absorber", e.g., Eu_2O_3, to minimize the thermal component of the flux. Options to boost the flux and volume available for irradiations were considered in 2007. The possibility of utilizing flux-boosting pins or plates was acknowledged by ORNL in 2006/2007 but never explicitly evaluated. This current AoA notes these possible enhancements, but has no design basis for detailed analysis.

D.3.2 Rationale for Consideration as Potentially Viable Alternative

In 2007 ORNL proposed the use of the HFIR to support the testing of fuels and materials for fast spectrum systems.

The HFIR possesses the following desirable attributes:

- Operating, domestic, test reactor.
- High-power and high-flux (highest domestic fast flux 1.0x10^{15} n/cm^2-s).
- National Science User Facility (NSUF).
- Multiple irradiation locations.
- Capabilities to insert/remove samples while reactor is operating.
- Used for many years by Advanced Fuels Campaign (AFC) to irradiate fuels and materials for thermal- and fast-spectrum reactors using a "thermal flux absorber" for the latter.
- Infrastructure available on ORNL site for fabrication and characterization of irradiation samples and subsequent PIE.
- Capabilities to fabricate UO_2, UN, UC, and TRISO fuels.
- Experienced in receiving and shipping samples between sites.
- The Reactor Vessel is "good to at least 2050" assuming 10 cycles per year (based on historic funding actually ~6-8 cycles per year).
- Core "consumables" (e.g., internal components, control plates) are replaced on a routine basis. The permanent beryllium reflector is scheduled to be replace in 2023 during routine maintenance outage. This will "ensure safe, reliable, and efficient operations…beyond 2050".

D.3.3 Features of the HFIR with 3/7 Pin Configuration

Figure D-3 shows a plan view of the High Flux Isotope Reactor and the large number of potential locations for irradiation samples both within the core (flux trap) and in the reflector. As noted above, the AFC has been irradiating fuel and materials samples in the HFIR. The HFIR is also a National Scientific User Facility (NSUF) and has experience in performing irradiations of fuels and materials for a variety of customers.

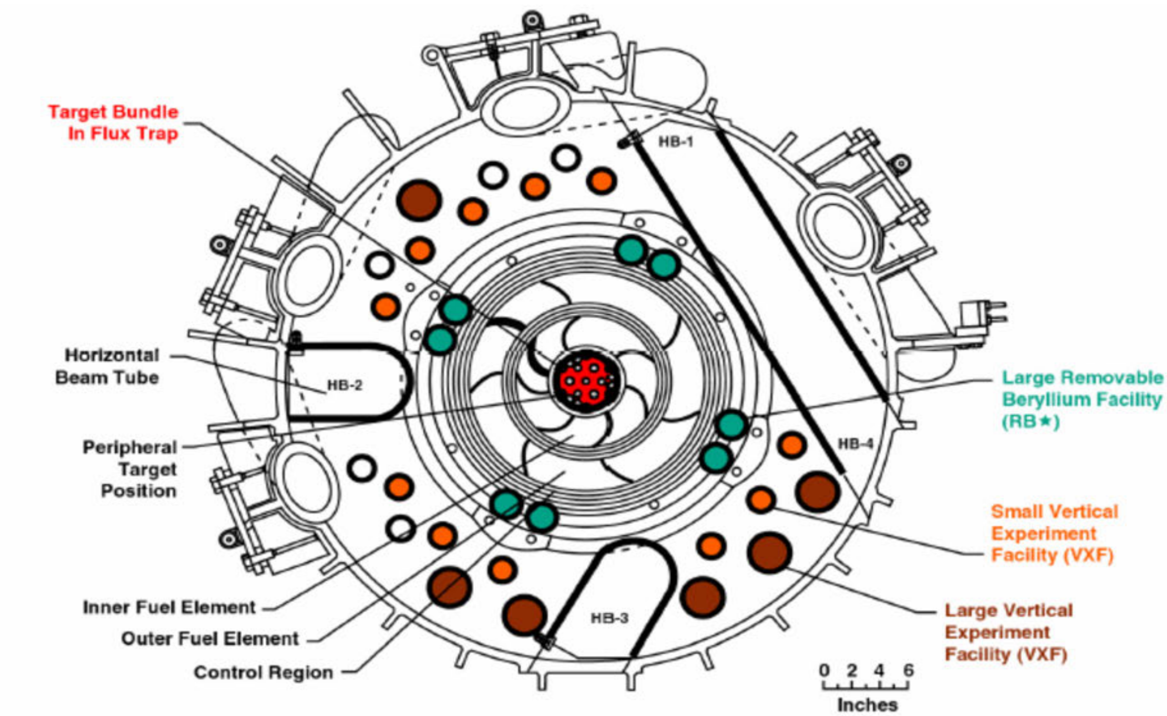

Figure D-3. Plan View of HFIR Showing Experiment Irradiation Locations

<u>Experiment facilities available include:</u>

1. Four horizontal beam tubes, which originate in the beryllium reflector.
2. The hydraulic tube irradiation facility, located in the very high flux region of the flux trap, which allows for insertion and removal of samples while the reactor is operating.
3. Thirty target positions in the flux trap each have 7 capsule locations, which contain trans-plutonium production rods and materials irradiations (two of these positions can accommodate instrumented targets).
4. Six peripheral target positions located at the outer edge of the flux trap.
5. Numerous vertical irradiation facilities of various sizes located throughout the beryllium reflector.
6. Two pneumatic tube facilities in the beryllium reflector, which allow for insertion and removal of samples while the reactor is operating for neutron activation analysis.

In ~2007, the HFIR proposed a 1-pin target bundle in the “flux trap” (cf. Fig. D-3). This approach allowed the use of HFIR capabilities as-is, and in this way was essentially an "experiment design" rather than a new facility or facility upgrade. Subsequently, in order to increase the irradiation volume and fast flux, ORNL proposed a 3/7-pin target bundles (cf. Figure D-4). This approach would require a modest redesign and replacement of three components: the target basket, the target tower, and the quick opening hatch, and would negatively impact the cycle length.

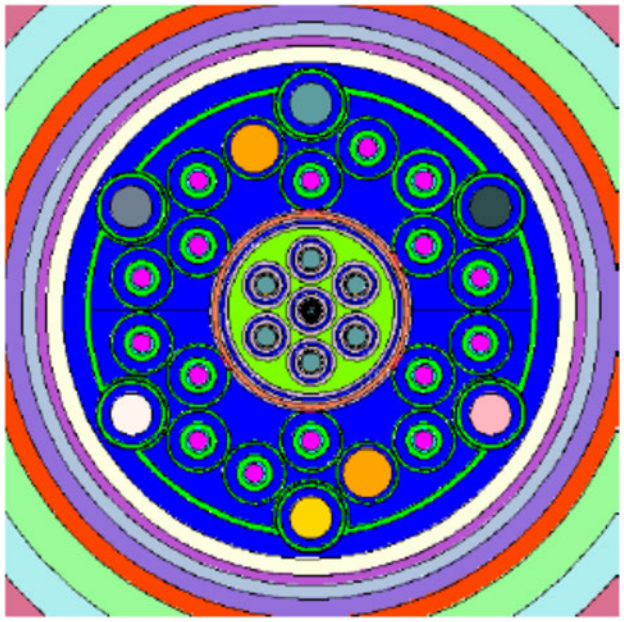

Figure D-4. Proposed 7-pin Irradiation Concept Located in the HFIR Flux Trap Region

To address fast-spectrum irradiation objectives, use of a "thermal flux absorber", e.g., Eu_2O_3, on the irradiation capsule was also proposed and analyzed. The 3/7-pin designs achieve a fast flux of ~1.0 – 2.0x10^{15} n/cm^2-s. As noted by ORNL in 2006/2007: "Achieving a higher value would require the addition of flux boosters in adjacent target locations and would represent possible improvements on this design, which were not considered at this time."

Utilization of HFIR to support irradiation studies approximating the conditions in a fast-spectrum system under the obvious constraint that HFIR is a thermal reactor, have continued with the implementation of the use of the "thermal absorber" approach.

D.3.4 Pros/Cons of HFIR with 3/7 Pin Configuration for VTR Mission

Potential Advantages: see "Rationale" above

Potential Disadvantages Include

- Thermal-spectrum reactor – use of "thermal-flux absorber" while successful (INL-EXT-17-41677) is not prototypic; issues include fast-to-thermal flux ratio, radial fission distribution, burnup of thermal absorber, etc.

- No work/progress subsequent after 2006/2007 on exploring potential options to enhance the capabilities of HFIR to meet higher flux/volume objectives than achievable with the 3/7-pin option, e.g., a flux booster. These proposed options would require modifications to HFIR, and negatively impact cycle length and other missions. Detailed studies would be required to evaluate and plan/design these proposed modifications. (It is likely that the 3/7-pin option can be implemented within the framework of regular refueling/maintenance/etc. shutdowns and would not require a dedicated long-term shutdown).

- HFIR is currently heavily used to support its primary missions: neutron scattering and isotope production - which impacts its availability for VTR-related missions. Also, a planned approximately 9-month outage to replace the permanent beryllium reflector in 2023 will affect near-term availability. Implementation of the 3/7-pin flux enhancement may create additional schedule conflicts.
- ORNL has capabilities to fabricate many ceramic fuels as noted earlier, but metallic test fuels would have to be produced elsewhere. PIE on sodium-bonded metallic fuels requires inert hot cell environment which is currently not available – there is potential to modify an existing or dormant hot cell to provide this capability.

Table D-3 summarizes some of the capabilities of HFIR with the 3/7 pin capability to support VTR mission needs. The major deficiencies noted relate to the achievable maximum fast flux, dpa/year, and the irradiation volume and flexibility – all not unexpected since HFIR is a thermal spectrum reactor and was designed and built to support a different purpose(s). In addition to the fundamental limitation of this being a thermal spectrum reactor, there is the potential that non-proliferation concerns may require the use of LEU versus the current HEU which could slightly lower flux performance.

Table D-3. Comparison of HFIR Capabilities to VTR Targets

VTR Requirement	VTR Target	HFIR / 3/7 Pin Capability
Peak fast flux	≥4.5×1015 n/cm2-s	1.0-2.0×1015 n/cm2-s
dpa rate	> 30 dpa/year	11 – 14 dpa/year
Irradiation length	0.6m – 1.0m	~50 cm
Irradiation volume	≥ 7 Liters	~0.01 L (single-pin flux trap experiment), ~4.6 L (using all 8 RB positions) Modified flux trap with 3-pin or 7-pin configuration likely over 1 Liter but actual volume unknown
Test flexibility	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salt Loops	Closed loops, maybe rabbits.
Test advanced I&C	Test advanced sensors and instruments	Instrumented testing supported in RB positions, might be supported in flux trap with modifications
Available soon	Operational by end of FY2026	1-pin experiments (current HFIR) could be by FY2022 3-pin or 7-pin experiments (modified HFIR) unknown, maybe FY2024
Easy access to experiment fabrication and PIE	Avoid shipping off of a controlled site	Can avoid public roads for all experiment fabrication and PIE transportation except metal fuel fabrication
Provide life cycle management for driver fuel while minimizing cost and schedule impacts	Evaluate based on cost and schedule impact with consideration for using existing DOE infrastructure with necessary modifications for fuel life-cycle management	HFIR successfully manages full life cycle of its own driver fuel, which would provide substantial cost and schedule savings for DOE compared to building a new facility

D.4 FFTF Alternative Description

D.4.1 Summary

The FFTF is a deactivated fast test reactor located at the Hanford Reservation in the state of Washington. It is a 400 MWth sodium-cooled fast reactor that used mixed oxide driver fuel and operated from 1982 through 1992. It is currently shutdown, deactivated, and in a safe storage condition with all fuel and sodium removed and an argon cover gas applied to all systems. It was used to test fuels and materials for fast reactors and is potentially capable of being reactivated to meet the fast neutron irradiation requirements of the VTR project. The nearby deactivated Fuels and Materials Examination Facility (FMEF) and Maintenance and Storage Facility (MASF) could also be reactivated, refurbished and equipped to provide support for fuel fabrication, pre- and post-irradiation examination of test fuels and materials. There are significant technical and experimental challenges that would have to be addressed if this option were selected as the preferred alternative, including component age-related material degradation, repairs to and recertification of systems modified to support deactivation, upgrades to meet current codes and standards including seismic, and upgrades to meet potential user experimental needs.

D.4.2 Rationale for Consideration as a Potentially Viable Alternative

The construction of FFTF was completed in 1978 and initial operation began in 1980. The FFTF operated successfully as a national research facility between 1982 and 1992 to test advanced nuclear fuels, materials, components, plant operations and maintenance protocols, and reactor safety designs for the fast breeder reactor programs. During this time, the FFTF also produced a wide variety of medical and industrial isotopes, made tritium for the U.S. fusion research program, and conducted cooperative international research work. After shutdown, FFTF was defueled and systems maintained in hot standby for almost two decades while new potential missions were being assessed. Finally, FFTF completed deactivation activities (sodium removal, cooldown, application of argon cover gas) and was placed in a long-term, low-cost surveillance and maintenance condition in 2009. If FFTF technical issues can be resolved and if it can be reactivated and refurbished at a reasonable cost, it would be able to provide the high fluxes and test irradiation capabilities needed by the VTR program, with only testing longevity currently unknown.

D.4.3 Features of the FFTF

- 400 MWth sodium cooled fast test reactor.
- Loop design with three loops, each containing a primary and secondary coolant pump, an intermediate heat exchanger, and secondary dump heat exchanger.
- Peak fast flux – 4.6×10^{15} n/cm^2-sec.
- Low pressure (133 psig); inlet temp – 680°F; outlet temp – 980°F.
- Test irradiation locations in core – 91.
- Irradiation locations in reflector – 108.
- Designed for up to four closed loops (one built but not utilized).
- MOX fueled, SS cladding, 0.23 in. OD pin; 217 pin fuel assembly.
- The Interim Examination and Maintenance (IEM) cell located inside the FFTF containment boundary has the capability to clean sodium from and conduct nondestructive examination of test assemblies and core components in an inert gas environment.

The Hanford site has two major facilities that could support FFTF:

- The Fuels and Materials Examination Facility (FMEF) is a ~175,000 square foot Category One structure constructed in the early 1980s. FMEF was planned to support the U.S. fast breeder reactor program and was designed specifically to manufacture large quantities of uranium-plutonium oxide fuels and to disassemble and inspect irradiated fuel assemblies. The facility has never been used and is uncontaminated. Significant refurbishment and installation of equipment for fuel fabrication, test article fabrication and assembly, and post-irradiation examination would be required before it could be used to support FFTF restart. If metal fuel is selected for VTR, these costs would be higher because FMEF was planned to support oxide fuel fabrication only.
- The Maintenance and Storage Facility (MASF) is a multi-purpose service center completed in 1982 that supported FFTF during its operational life. The main building contains a 28,000 square foot area serviced by a 60-ton overhead bridge crane. Half of this area is serviced by a 200-ton crane, is 105 feet high and contains floor space for repairs and maintenance of large equipment. It has below-grade shielded hot cells for sodium cleaning of fuel assemblies and experiments. It also has a large shielded enclosure that contains two shielded decontamination rooms. These can be used for both remote and hands-on cleaning of small equipment items and tools that are contaminated with radioactive material. Some refurbishment of MASF would be required before it could be used to support future FFTF operations. MASF is currently being used for other DOE missions but might be available for future VTR support.

During the period that the FFTF operated at power, there were no significant failures of any system. The FFTF utilized three Heat Transport Systems (Figure D-5).

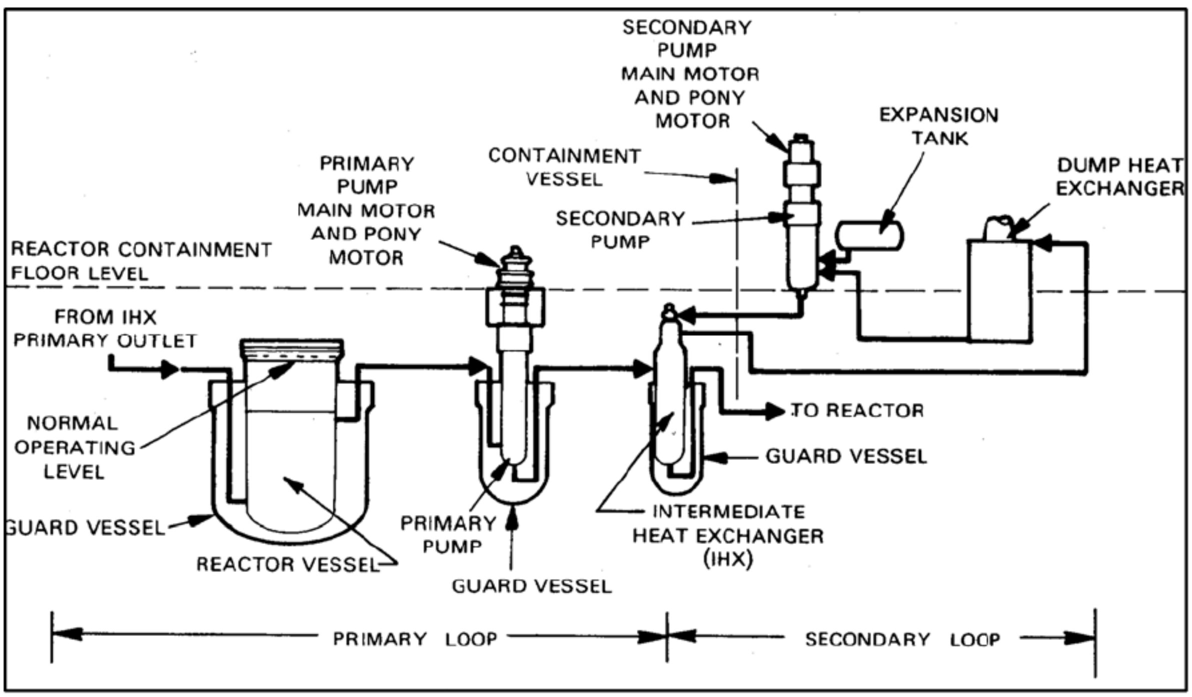

Figure D-5. FFTF Heat Transport System (one of three)

D.4.4 Pros and Cons of FFTF for VTR Mission

The AoA Team reviewed several documents and discussed the pros and cons of FFTF restart for the VTR mission with representatives of DOE Richland (RL), DOE Office of River Protection (ORP), Pacific Northwest National Laboratory, and the Tri Cities Development Council (TRI-DEC). The most significant documents regarding the state of FFTF and its ability to be reactivated as a test reactor included the *Siting Study For Hanford Advanced Fuels Test & Research Center* (DE-FG07-07ID14798)[16] of April 30, 2007 performed by the Columbia Basin Consulting Group (CBCG) based in Richland, Washington, and the VTR Program Executive Director's letter to J. Herczeg, DOE NE (INL Letter CCN 243271 Rev. 1 dated August 22, 2018)[9]. These documents presented differing assessments of the material condition and safety of the FFTF systems. Further inspections and analyses of FFTF systems and components will be required to verify their actual conditions in order to determine if restart is viable, and if so to provide more accurate cost and schedule estimates. This activity alone could cost $10-15 million and take one to two years.

<u>Pros:</u>

- FFTF is an existing facility that has operated as a high flux fast spectrum materials and test reactor. It has some co-located and nearby support facilities that can be modified and refurbished to support the VTR mission.
- Designed for up to four closed loops (one built but not utilized).
- FFTF operated with MOX driver fuel but was also used to test full length metallic fuel assemblies with excellent results.
- Plant Configuration Control with full plant documentation has been rigorously maintained.
- The FFTF is a fully permitted facility.
- FMEF and the Secure Automated Fabrication (SAF) fuel line can be modified for advanced fuels fabrication and post irradiation examination.
- According to the CBCG report, FFTF could have been reactivated at a cost of approximately $500 Million (2007 dollars) and be ready to start up in approximately 60 to 66 months. However, the facility has been in dark shutdown for more than an additional decade, and many systems and procedures that were assumed to be adequate for restart in the CBCG report may require updating, refurbishment or replacement.
- The cost will depend on the extent of surveillances, replacements, and reanalysis but could be much higher, given the complications and age of the components.

<u>Cons:</u>

- FFTF reactor and support systems have accrued significant age-related degradation since termination of operations. The sodium was removed from the primary system several years ago and the system cooled down to ambient temperature and an argon cover gas applied. One potential concern is the exposure of sensitized austenitic stainless steels to stress corrosion cracking mechanisms during the surveillance and maintenance period which could lead to degradation or accelerated corrosion. The system piping and components will need to be inspected to determine whether there has been any significant corrosion or other degradation that could compromise the boundary. The external surfaces of the Decay Heat Removal System will also need to be inspected to determine if exposure to the weather has degraded them. This could result in extensive component replacement.

- Key FFTF reactor systems had consumed a significant percentage of duty cycles at termination of operations in 1992. This will require as a minimum re-analysis or could require major component replacement.
- The in-vessel refueling equipment must be inspected to determine if the sodium draining, cooldown and argon cover gas degraded the material condition or operability of any of the components.
- The control system and other electronics will require evaluation, and either refurbishment or replacement, including re-qualification.
- Significant subsurface geologic investigation, seismic reanalysis and physical upgrades to the nuclear island, balance-of-plant systems and facility structures with attendant safety basis revision may be required as evidenced by updated criteria for the Waste Treatment and Immobilization Plant (WTP) at the Hanford Site. The FFTF site was designed to withstand a maximum ground acceleration of 0.25g as determined in the 1970s, while the analyses for the WTP site provide peak acceleration values of 0.6g or greater after extensive site investigation and data re-analysis in 2005 through 2007. This could require extensive re-analysis and may require significant plant seismic upgrades.
- While the facility already exists, there are essentially no remaining staff onsite that have experience operating FFTF. New operators will have to be hired, trained and qualified.
- Upgrades to meet current codes and standards may be necessary, potentially including upgrades to provide functions commensurate with the expectations of the current regulatory climate versus that of the 1970s. Application of some of the new codes and standards would be negotiable, while others (such as fire protection) are often more difficult and will require meeting the requirement or specific exemptions and approvals if not met.
- Existing but aged security features and procedures may require updating.
- MASF is being used to support Hanford environmental cleanup activities, which are expected to continue for a number of years. New support facilities may be needed to support FFTF restart.
- Local and state permitting may be required for the FMEF as it has not previously been activated.
- Experimental facilities would require significant plant refurbishment and modifications to address the VTR mission. A rabbit system was designed but never installed. FFTF had a closed loop testing system installed, but it had never been placed on-line and would require a significant effort to put it into operation.
- A ¾-inch hole was drilled through a support plate inside the reactor vessel below the core support area to install a sodium drain pump for removing the sodium from the lower areas of the vessel. The loose metal chips from the drilling and the effect of alteration of the sodium flow path within the reactor vessel must be addressed.

Environmental and Legal Considerations:

The January 2001 *Nuclear Infrastructure Programmatic Environmental Impact Statement (NI PEIS)* included deactivation of FFTF as part of its Record of Decision (ROD)[12]. Pursuant to NEPA and CEQ regulations, the Secretary of Energy can amend the ROD provided the addressed issue was initially reviewed in the NI PEIS. The NI PEIS reviewed the status of the FFTF for continued operations, limited operations, and restart to full capacity. Amending the initial ROD from status of permanent deactivation to restart is within the parameters of the NI PEIS.

The December 2012 *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington* (*TC&WM EIS,* DOE/EIS–0391), included an updated analysis of alternatives for decommissioning of the FFTF and its auxiliary facilities. The preferred alternative announced in the December 2013 ROD was to entomb FFTF[13]. To date no action has been taken to dismantle FFTF as higher priority tank closure and waste management activities have been the focus of DOE. A new NEPA review would be required to reverse the direction of this ROD.

Since all of the milestones in the Tri-Party Agreement among DOE, the Environmental Protection Agency (EPA), and the Washington State Department of Ecology (TPA)[19] associated with FFTF are predicated upon the permanent deactivation of FFTF, the treatment of all of them in the event of restart would be the same. Essentially, all milestones having to do with the deactivation of FFTF would have to be renegotiated.

Siting a new reactor at Hanford faces challenges and may not be viable, given the cleanup mission. Use of FMEF for fuel fabrication for a reactor at a different DOE site is feasible, considering that FRAMATOME operates an LWR fuel fabrication facility next to the Hanford site and there is little opposition from local residents and politicians. Since FMEF was originally designed to support oxide fuel fabrication for FFTF, additional modifications would be required to support metallic fuel fabrication.

Table D-4 summarizes some of the capabilities of FFTF to support VTR mission needs.

Table D-4. Comparison of FFTF Capabilities to VTR Targets

VTR Requirement	VTR Target	FFTF Capability
Peak fast flux	≥4.5×1015 n/cm2-s	4.6×1015 n/cm2-s
dpa rate	> 30 dpa/year	> 40 dpa/year
Irradiation length	0.6m – 1.0m	36 inches
Irradiation volume	≥ 7 Liters	~ 9 liters/open test assembly – eight possible OA
Test flexibility	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salt Loops	Eight high volume, instrumented in-core open test assemblies (OTA); design for up to 4 closed test loops (one installed but never used); a rabbit system was designed but not deployed.
Test advanced I&C	Test advanced sensors and instruments	OTAs and closed test loop all have capability for testing advanced sensors and instruments.
Available soon	Operational by end of FY2026	Aggressive schedule shows FFTF operational by the end of FY2027.
Easy access to experiment fabrication and PIE	Avoid shipping off of a controlled site	FMEF, MASF and IEM are all onsite. Can avoid public roads for all experiment fabrication and PIE Transportation.
Provide life cycle management for driver fuel while minimizing cost and schedule impacts	Evaluate based on cost and schedule impact with consideration for using existing DOE infrastructure with necessary modifications for fuel life-cycle management	FFTF has most infrastructure onsite for driver fuel life-cycle management. Treatment of sodium-bonded fuels would likely be done at INL, as irradiated EBR-II and FFTF fuels are now.

D.5 Sodium Cooled Fast Spectrum Test Reactor (SFTR) Alternative Description

D.5.1 Summary

A new sodium-cooled fast test reactor based on proven technologies built and operated in the past is proposed as a viable alternative for the VTR. The VTR performance requirements can be met, and the experimental user needs can be incorporated into a properly designed SFTR technology-based test reactor. The experience and lessons learned from the design, construction and operation of several sodium-cooled fast test reactors, research reactors and commercial reactors around the world can be used to minimize the technical, cost and schedule risks of this technology. INL is currently conducting pre--conceptual design studies on a new sodium-cooled fast spectrum test reactor (SFTR) that meets all the requirements of the VTR Mission Need Statement and preliminary VTR Requirements Document[17].

D.5.2 Rationale for Consideration as Potentially Viable Alternative

There have been at least 20 sodium-cooled fast reactors, both test platforms and commercial reactors, that have been built world-wide, offering >400 reactor years of operating experience, with three currently under construction. The SFTR is the most mature fast reactor technology, with a technology readiness much higher than the other fast spectrum options (LFTR and MSFTR). Because of its maturity, the SFTR would complete regulatory review and construction on a faster schedule than any of the other fast reactor options.

D.5.3 Features of SFTR

The SFTR has been under development by the United States since the 1950s with the Na-K cooled Experimental Breeder Reactor I (EBR-I). Experimental and demonstration facilities were built and operated starting in the early 1960s with the Experimental Breeder Reactor II (EBR-II) in Idaho and the Fermi-1 power plant in Michigan, both of which generated electricity. The FFTF is a 400-MWth SFTR in Washington State that was used for materials and fuels testing.

EBR-II used a metal fuel clad with stainless steel that was resistant to radiation damage and had a high-thermal conductivity. The FFTF used a mixed oxide fuel with a higher melting point, but metallic fuels were also successfully irradiated in FFTF. Recovery of the uranium in the used fuel was achieved in an electro-metallurgical process developed at Argonne National Laboratory (ANL). Fission heat from EBR-II was transferred to a steam generator via an intermediate heat exchange system. Except for EBR-II and the Prototype Fast Breeder Reactor in India, all the other SFTRs used an oxide fuel form. The VTR program has selected metal fuel for its initial concept because of its many advantages, which include higher heavy metal density than oxide fuels, ease and lower cost of fabrication, extensive fabrication and operational experience in the U.S., and support from potential advanced fast reactor vendors. South Korea is also actively pursuing metal fuels for their fast reactor concepts.

EBR-II used a pool configuration while FFTF used a multiple loop configuration. The VTR Program is developing a pool configuration SFTR design based on EBR-II and General Electric-Hitachi's GEH) Power Reactor Inherently Safe Module (PRISM) design[18].

The basic technology of EBR-II was adopted by GE-Hitachi in its design of the PRISM reactor. The 471-MWt PRISM/Mod-A design was submitted for a pre-application safety review by the NRC in 1994, during which several issues were identified as requiring further development and demonstration. The NRC staff concluded that …"no obvious impediments to licensing the PRISM design have been identified." [20]

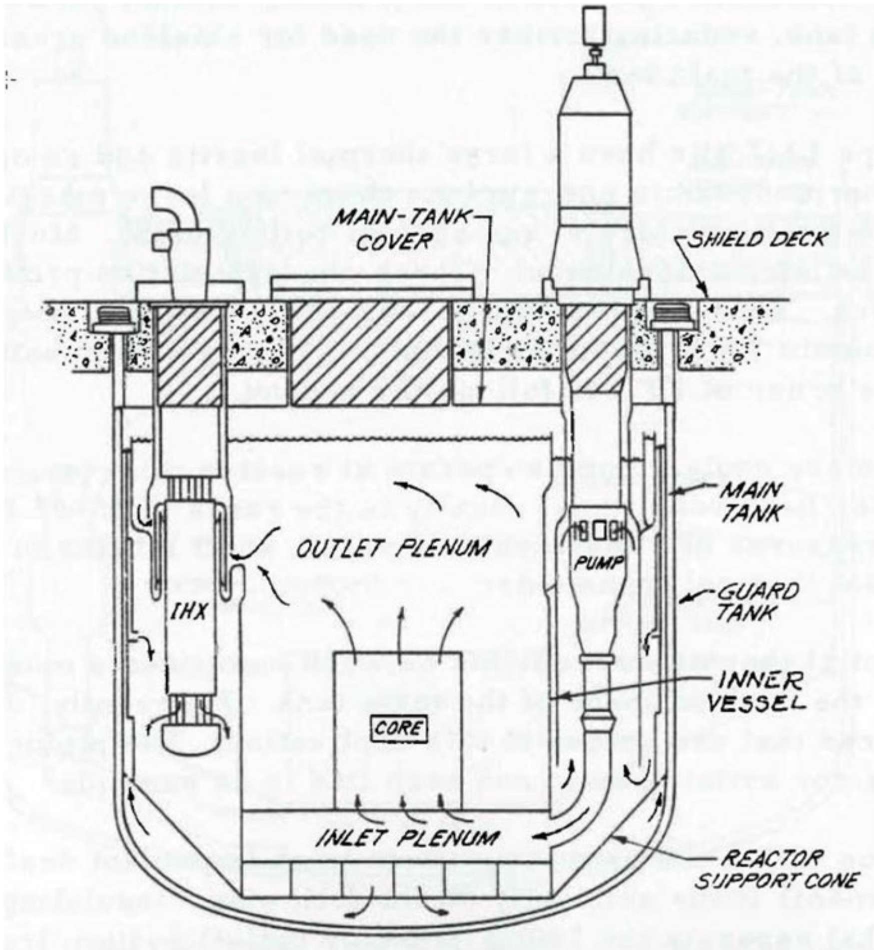

Figure D-6. Generic Pool Type SFTR Design

D.5.4 Pros and Cons of SFTR

Pros of SFTR

- Highest technical maturity of all fast reactor concepts, with considerable operational experience.
- Lowest technical and schedule risk among fast reactor options.
- FFTF and PRISM designs have had safety evaluation reports issued by the NRC.
- The SFTR can provide very high fast neutron flux as well as high-thermal flux in moderated zones to meet many of the needs of both the fast and thermal reactor developers.
- Based on past experience, SFTR can incorporate multiple test loops to test fuels and materials under different coolant conditions.
- Power density is higher than for LWRs; high heat flux.
- Passive transition to natural convective core-cooling and passive heat rejection has been demonstrated.
- Reliable control and safety-system response has been demonstrated.
- Effective systems for purity control of sodium and cleanup have been demonstrated.

- Both oxide and metallic fuels have been successfully fabricated and used in SFTRs in the United States. There is still some expertise at the national laboratories with these fuels.
- Recovery of uranium/plutonium from used metal fuel, and remote refabrication, has been demonstrated.
- Low-radiation exposures for operating and plant maintenance personnel, less than 10% of that typical for LWRs

Cons of SFTR

- If the VTR uses metallic fuel, an important gap to fill prior to licensing is the characterization of the source term from metallic fuel under normal and accident conditions.
- If a Reactor Vessel Auxiliary Cooling System (RVACS) is included in the design, that would require safety qualification.
- Sodium heat-transport systems have experienced a significant number of leaks because of design and/or operational issues, and difficulty with welds. Also, because of sodium's high-thermal conductivity, many designs did not adequately anticipate the potential for high-thermal stress on transients.
- Many problems with handling fuel in sodium systems have occurred, primarily because of the inability to visually monitor operations. Under sodium viewing systems have been under development to offset this shortcoming.
- Failure of in-sodium components without adequate means for removal and repair has resulted in costly and time-consuming recovery.
- Reactivity anomalies have occurred in several fast reactors, requiring careful attention to core restraint systems and potential for gas entrainment in sodium flowing through the core.
- Operational problems have been encountered at the sodium/cover-gas interface, resulting from deposition and freezing of sodium vapor or formation of sodium-oxide that can lead to binding of rotating machinery, control-rod drives and contamination of the sodium coolant.
- No SFRs have been built in the U.S. for over 30 years, so there will be supply chain challenges.

Pros of Sodium Coolant

- Plentiful supply.
- Low neutron moderation and absorption by the coolant.
- High coolant volumetric heat capacity and thermal conductivity.
- Low coolant density; a low pumping power requirements for cooling the reactor core.
- Large margin to coolant boiling at atmospheric pressure.
- Coolant compatibility with structural materials; minimal corrosion issues with oxygen control / coolant purification.

Cons of Sodium Coolant

- Sodium is highly reactive with air and water
  - Inert atmosphere is needed for refueling and maintenance
  - Leaks can lead to fires.

Table D-5 summarizes some of the capabilities of a hypothetical SFTR to support VTR mission needs. In general, it is assumed that if a SFTR was custom designed and built for the VTR mission, it would be designed to meet the mission requirements.

Table D-5. Comparison of SFTR Capabilities to VTR Targets

VTR Requirement	VTR Target	SFTR Capability
Peak fast flux	$\geq 4.0\times10^{15}$ n/cm^2-s	4.0×10^{15} n/cm^2-s
dpa rate	> 30 dpa/year	> 30 dpa/year
Irradiation length	0.6m – 1.0m	0.6m – 1.0m
Irradiation volume	≥ 7 Liters	≥ 7 Liters
Test flexibility	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salt Loops	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salt Loops
Test advanced I&C	Test advanced sensors and instruments	Test advanced sensors and instruments
Available soon	Operational by end of FY2026	Aggressive schedule shows SFTR operational about FY2027. Nominal schedule shows SFTR operational about FY2029.
Easy access to experiment fabrication and PIE	Avoid shipping off of a controlled site	SFTR assumed to be built at a site with adequate access and support, or the ability for these to be added. Details unknown.
Provide life cycle management for driver fuel while minimizing cost and schedule impacts	Evaluate based on cost and schedule impact with consideration for using existing DOE infrastructure with necessary modifications for fuel life-cycle management	SFTR assumed to be built at a site with adequate access and support, or the ability for these to be added. Details unknown.

D.6 Lead-Cooled Fast Test Reactor (LFTR) Alternative Description

D.6.1 Summary

A Lead-cooled-Fast Test Reactor (LFTR) would be a new custom designed fast spectrum reactor cooled by either liquid lead or lead-bismuth eutectic. Because there is significantly less knowledge base for a LFTR than a sodium fast test reactor (SFTR), much of this analysis will be based on exploring comparative benefits and challenges of a new LFTR versus a new SFTR. A LFTR design could be leveraged off any one of several conceptual designs for LFR power reactors, modified to provide a high fast flux, and to incorporate test irradiation locations in the core to accommodate both static and dynamic experiments. An LFTR design could be amenable to a high power density core and could probably achieve the desired irradiation conditions with a reactor in the 200-400 MWth range. Either pure Pb or Pb-Bi eutectic could be used for coolant. Pb-Bi eutectic offers a lower melting temperature but adds the volatile radiation hazard of Po-210 created by neutron capture in the Bismuth. The preferred fuel for highest flux would probably be U/Pu-nitride although U/Pu-oxide would be a viable option. There is little experience with nitride fuel. An ambient pressure pool-type design could facilitate experiment access, with peripheral in-vessel heat exchangers and control systems, allowing clear above-pool access to experimental channels. Pb coolants have advantages in high thermal capacity, low pressure operation, hard neutron spectrum, high thermal margin to voiding and lack of chemical reactivity. Challenges include active oxygen control to control corrosion, flow rate limits to control erosion, a new fuel type and new core materials. No heavy metal cooled reactors have been built in the United States, but a number have been tested and fielded abroad. None have been designed as irradiation test facilities. An accelerator-driven heavy metal cooled test facility (MYRRHA) is being pursued in Europe.

D.6.2 Rationale for Consideration as Potentially Viable Alternative

To meet the desired nuclear testing performance criteria, a custom designed fast spectrum reactor provides the most flexible option. Fast spectrum reactor types are commonly divided by coolant, as that defines many of the reactor characteristics. After liquid sodium, lead or lead-bismuth eutectic represents the second most commonly used coolant for fast spectrum reactors and SNS. This coolant allows a high power density which is needed for a high fast neutron flux, and operates at ambient pressure which facilitates experimental access. Because there is significantly more experience with sodium-cooled fast reactors, this analysis seeks to determine if lead-cooled designs can provide significant advantages over sodium for a test reactor and will use sodium as a comparator.

D.6.3 Features of Lead/Lead-Bismuth Coolant

By comparison to sodium, lead has higher density, lower thermal conductivity and specific heat capacity, but higher volumetric heat capacity and boiling temperature – resulting in good coolant properties. It is also much less chemically reactive than sodium as shown in Table D-6.

Table D-6. Properties of Liquid Metal Coolants

Comparison of Coolants			
Properties	**Sodium**	**PbBi Eutectic**	**PB**
Melting Temperature °C	98	125	327
Boiling Temperature °C	883	1670	1749
Density g/cm^3 (@450°C)	0.845	10.15	~10.5
Heat Capacity J/g °C (@450°C)	1.269	0.146	~0.13

The neutron spectrum is slightly different for lead and sodium, lead is an excellent fast neutron reflector and has less moderating power resulting in slightly higher fast flux for the same power density, except at energies above 1 Mev where inelastic scatter mechanisms suppress the flux slightly.

<u>Representative Lead-cooled Reactor Design</u>

The only LFTRs that have been built were designed for submarine propulsion and are clearly not suited as a flexible test reactor. In the U.S. and around the world, there are a dozen or more LFTR design concepts in various stages of development. Some are large central power reactors and others are small modular reactors, with only a few in the intermediate size that might be suitable as a versatile high flux test reactor. To provide the high flux and substantial irradiation volume/height desired for the VTR, a reactor in the few hundred megawatt thermal range is likely to be required – with a design that provides unobstructed access to the core.

One example of a current design from the Gen-IV program with desirable test reactor characteristics is shown in Figure-D-7 (the U.S. domestic Hydromine LFR-AS-200). This design, as presented to the GIF-LFR-SSC is a 450 MWth reactor with a compact high power density core. Peripheral control rods and peripheral steam generators provide access from above the core. A redesign with some fuel channels replaced with irradiation test positions would provide approximately the size and configuration desired for the VTR mission. To achieve a high fast flux, smaller diameter fuel rods could provide higher linear power density while retaining reasonable coolant flow rate – with a trade-off of shorter refueling cycle time. While nitride fuel could help provide maximum flux, oxide fuel would be more mature for implementation. If Pb is used instead of Pb-Bi, the higher melting temperature would require higher temperature for both experimental access and refueling. Another representative LFR power reactor concept is a Westinghouse design considered in the Advanced Demonstration and Test Reactor Options Study[5]. That design explored simplifications to expedite earlier implementation, such as reduced power density and oxide fuel, but these features are counter to very high flux. That WE-DLFR design could be extended to higher flux with U/Pu fuel and shorter refueling intervals, and potentially higher flow rate.

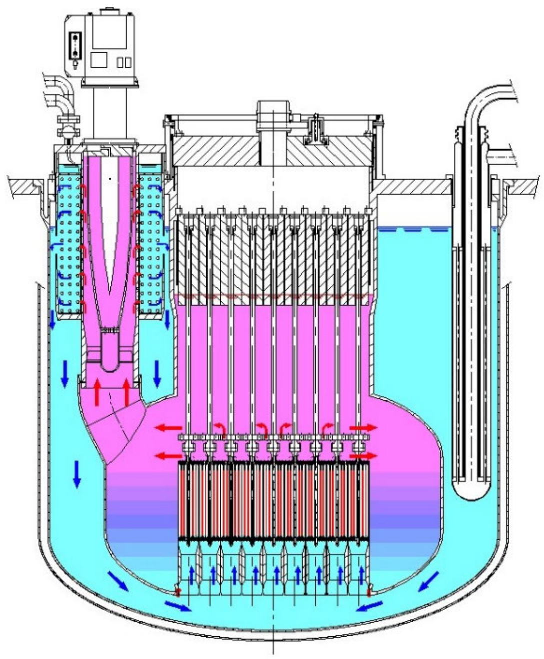

Figure-D-7. Example LFR Design Concept with Features Useful for a Test Reactor.

The pool design has clear access to the top of the core, including an option for the fuel rod tops to extend out of the coolant pool for access, which is also a natural configuration for irradiation test positions. This design proposes a compact vessel and containment and no intermediate loop with steam generators immersed directly into the lead pool – features that could reduce cost. It should be noted that the high coolant density requires fuel 'hold-down' rather than a core support structure, and experiments would be similarly buoyant and require 'hold-down'.

D.6.4 Pros/Cons of Lead or Lead-Bismuth vs Sodium for VTR Coolant

Potential advantages include:

- High density and heat capacity permit cooling a high power density core with lower coolant flow rates.
- High boiling temperature offers transient safety margins.
- Low chemical reactivity offers safety advantages and permits open access to the pool for experimental flexibility. Lack of exothermic chemical reactions with water and air.
- Potential to eliminate the cost and complexity of an intermediate loop.

- Nitride fuel would be desirable (UN, PuN or Mixed-N) and offers high density and thermal conductivity, which supports high neutron flux. Oxide fuel is a viable option, metal fuel is probably not due to solubility in lead.

Potential disadvantages include:

- Higher melting temperature always requires the reactor to be kept hotter to avoid coolant freeze, including refueling operations.
- Lead corrosion of structural materials has been an ongoing research challenge, and operational challenge for the LFRs that have been built abroad.[11]
- Coolant opacity complicates in-vessel inspection.
- High coolant density complicates seismic safety design.
- If lead-bismuth eutectic is used, production of Po-210 could be an operational safety issue.
- The preferred nitride fuel is still in the development/demonstration phase.
- Experience in building and operating lead-cooled reactors is very limited and is all in Russia, which would entail risks in cost, schedule, performance and longevity. Unless a technology demonstration prototype is built, the LFTR would be a first of a kind irradiation test reactor, with all of the risks that this could imply. If a technology prototype is built, that would extend the project schedule and increase cost significantly.

Table D-7 summarizes some of the capabilities of a hypothetical LFTR to support VTR mission needs. In general, it is assumed that if a LFTR was custom designed and built for the VTR mission, it would be designed to meet the mission requirements.

Table D-7. Comparison of LFTR Capabilities to VTR Targets

VTR Requirement	VTR Target	LFTR Capability
Peak fast flux	≥4.0×10^{15} n/cm^2-s	4.0×10^{15} n/cm^2-s
dpa rate	> 30 dpa/year	> 30 dpa/year
Irradiation length	0.6m – 1.0m	0.6m – 1.0m
Irradiation volume	≥ 7 Liters	≥ 7 Liters
Test flexibility	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salt Loops	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salt Loops
Test advanced I&C	Test advanced sensors and instruments	Test advanced sensors and instruments
Available soon	Operational by end of FY2026	Aggressive schedule shows LFTR operational about FY2032. Nominal schedule shows LFTR operational about FY2038.
Easy access to experiment fabrication and PIE	Avoid shipping off of a controlled site	LFTR assumed to be built at a site with adequate access and support, or the ability for these to be added. Details unknown.
Provide life cycle management for driver fuel while minimizing cost and schedule impacts	Evaluate based on cost and schedule impact with consideration for using existing DOE infrastructure with necessary modifications for fuel life-cycle management	LFTR assumed to be built at a site with adequate access and support, or the ability for these to be added. Details unknown.

D.7 Molten Salt Fast Test Reactor (MSFTR) Alternative Description

D.7.1 Summary

A Molten Salt-Fast Test Reactor would be a new custom designed fast spectrum reactor optimized for high fast-neutron flux and access to in-core irradiation volumes. Because there is significantly less knowledge base for a MSFTR than a SFTR, much of this analysis will be based on comparative benefits and challenges of a new MSFTR vs a new SFTR. MSRs can use either molten salt fuel or solid fuel with molten salt coolant. For a high fast flux and easy in-core access for experiments, the molten fuel pool concepts appear to have attractive features and will be considered here. (Also – a salt cooled solid fuel reactor has less differentiation from VTR alternatives using solid fuel cooled with liquid metals). The test reactor design concept could be leveraged from any one of several conceptual designs for Fast-MSR power reactors, although none appear to be natural candidates (most are large power reactor designs), and most are foreign design concepts. MSFTR designs are amenable to high-power density and might achieve the desired irradiation flux and volume with a reactor in the 200-400 MWth range.

Reactor concepts are divided between chloride-based fuel and fluoride-based fuel, and between a U/Pu fuel cycle and a Th/U233 fuel cycle. To side-step Th fuel cycle development and U233 availability, the U/Pu cycle is considered here. (Note: The thorium fuel cycle is proposed to extend fuel resources, and to take best advantage of the on-line processing of MSR fuel – and neither of these are primary mission needs for the VTR project. Thus, the more mature and available U/Pu fuel technology seems preferable for the VTR mission.) Either a fluoride or chloride salt would be possible, each with a range of physical properties dependent on composition. Each has different pros and cons, such as: chloride salts are more amenable to a harder neutron spectrum than fluoride, there is more experience with fluoride fuel, but chloride fuel could operate at somewhat lower temperature, fluoride can have higher heat capacity, but chloride can have lower viscosity, etc. We are not pre-selecting the fuel composition for this analysis and assume that a similar design and test reactor performance is possible with either. A pool-type reactor design could facilitate experiment access, with either in-vessel or external loop primary heat exchange to an external secondary loop and probably a third stage heat rejection loop. The ambient pressure pool (or pot) design allows above-pool access to experimental channels. Salt as a coolant has advantages in high thermal capacity, low pressure operation, hard neutron spectrum (avoiding Li and Be salts), high thermal margin to voiding and low chemical reactivity. Challenges include lower technical maturity, material and fuel qualification, and the implication of at least some continuous or parallel fuel processing. Depending on the salt and operating temperature selected, there could be elevated temperatures for experimental access and fuel operations. While several moderated MSR thermal spectrum reactors have been built and operated very briefly in the U.S. in the past, neither a salt fueled fast spectrum reactor nor a salt fueled irradiation testing reactor have ever been built.[7]

D.7.2 Rationale for Consideration as a Potentially Viable Alternative

To meet the desired nuclear testing performance criteria, a custom designed fast spectrum reactor provides the most flexible option. Fast spectrum reactor types are commonly divided by coolant, as that defines many of the reactor characteristics, and molten salt is one of four (Na, Pb, He, MS) that have been proposed in multiple design concepts for power reactors. The molten salt fueled reactor is unique in its use of a circulating fluid as both the fuel and the primary heat transfer medium. The reactor can be designed as a pool with little or no structure internal to the active core, and clear access from above the core. This allows a high power density which is needed for a high fast neutron flux, and operation at ambient pressure. These features facilitate experimental access, and potentially flexible experiment cross section. Because there is significantly more experience with sodium-cooled fast reactors, this analysis seeks to determine if molten salt fueled designs can provide significant advantages over sodium for a fast-spectrum high-flux test reactor – so sodium will be used as a comparator.

D.7.3 Features of Molten Salt Fuel

In comparison to sodium, molten chloride salt has a higher volumetric heat capacity, boiling temperature, and a higher density that depends on the dissolved fuel concentration – resulting in good coolant properties as shown in Table D-8. It is also much less chemically reactive than sodium, and is transparent which facilitates inspection of the reactor and experiments.

Table D-8. Properties of Molten Salt Fuels

Comparison of Coolants		
Properties	**Sodium**	**U/Pu Salt (Varies with composition)**
Melting Temperature °C	98	~ 300 – 575
Boiling Temperature °C	883	~ 1400 – 1500
Density g/cm^3 (@450°C)	0.845	~4.0 – 4.5
Heat Capacity J/g °C (@450°C)	1.269	~ 1 – 2

The neutron spectrum is slightly different for molten salt versus sodium, and can vary considerably with salt fuel composition, with U/Pu chloride spectrum being somewhat harder than fluoride.

<u>Representative Fast Molten Salt Fueled Reactor Design</u>

Only a two small experimental MSRs have been built and operated, and none with a primarily fast neutron spectrum. In the United States and around the world, there have been multiple fast-MSR design concepts that have reached various stages of development – but not built. Most are intended as large central power reactors, small modular reactors, or for an actinide transmutation mission, with a few in the intermediate size range appropriate for a versatile fast test reactor. To provide the high flux and substantial irradiation volume/height desired for the VTR, a reactor in the few hundred-megawatt thermal range is likely to be required – with a design with unobstructed access to the core. It may be possible to offer more flexible testing volume/shape due to the lack of fixed core internal structure.

An example of a more recent design from the Gen-IV program is shown in Figure-D-8. This design, as presented for a GIF-MSR workshop is a 100 MWth demonstration reactor. For the VTR mission, it would have to be redesigned with access into the active core for irradiation test positions and may need to be scaled up and optimized to provide the desired flux and test volume. Higher flux, and thus higher power density, might require increased fuel flow rate. For an irradiation testing reactor, the very high outlet temperature that is desired for efficient power generation would not be needed and could even be problematic for some experiments.

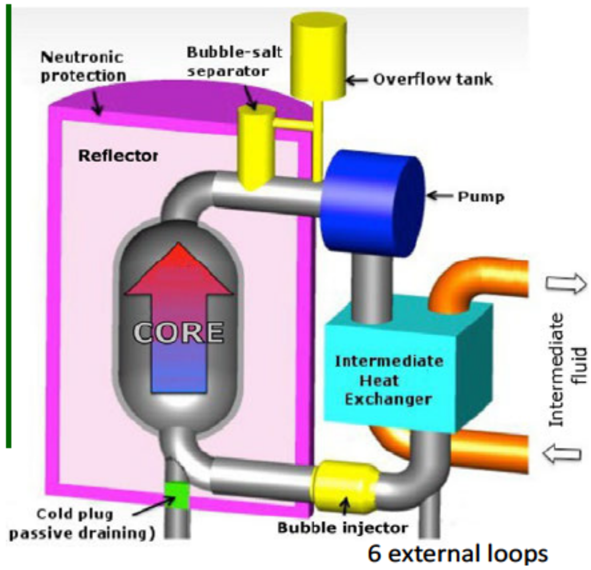

Figure-D-8. Example Fast-MSR Design Concept

An inherent feature of the fluid fuel design is the use of at least some active processing of the fuel. Gas sparging would remove volatile fission products into a gas plenum above the fuel, and typically there is some fraction of the fuel passed through a chemical processing system or filtering to remove solid and dissolved fission products. This removal of fission products results in very small reactivity changes during reactor operation, which allows for the use of peripheral control elements rather than control equipment intruding into to the active core.

D.7.4 Pros/Cons of Molten Salt Fuel vs Sodium for VTR Coolant

Potential advantages include:

- Homogenous heat generation in the coolant fluid eliminates heat transfer processes from fuel to coolant. Homogenous generation may also offer more uniform neutron flux, and some flux 'self-leveling' due to thermal expansion of the fuel.
- High heat capacity permits cooling a high power density core with modest coolant flow rates.
- Safety related advantages include:
  - High boiling temperature that offers large transient safety margins
  - Low excess reactivity and low reactivity change throughout life
  - Passive shutdown through 'melt plug' drain into cooled and criticality safe fuel storage
  - Low chemical reactivity.
- Initially transparent coolant aids inspection of the reactor and experiments.

Potential disadvantages include:

- Experience in building and operating molten salt reactors is very limited, and none have been built with fast neutron spectrum. This would entail significant risks in cost, schedule, and possibly in performance and longevity. Unless a technology demonstration prototype is built, the MSFTR would be a first of a kind reactor, with all of the risks that this could imply. If a technology prototype is built, that would extend the project schedule and increase cost significantly.

- With highly radioactive primary coolant (the fuel), most designs incorporate a three loop heat extraction system, which could increase size and cost.
- At least some fuel processing is inherent to the reactor, which adds complexity and possibly operating cost. Waste streams will be produced at the reactor, and not deferred to an external used fuel management system.
- Fuel and materials would require qualification.
- Molten salt fueled reactors tend to have low excess reactivity, and low reactivity change during operation. Because of this, the required reactivity control is limited, and the reactivity worth (either positive or negative) of experiments could become an important factor.
- Introduction of experiments into a liquid fuel raise design questions for flow control and heat removal.
- Depending on the salt chosen, a higher fuel melting temperature implies a limit on fuel handling and processing outside the core.

Table D-9 summarizes some of the capabilities of a hypothetical MSFTR to support VTR mission needs. In general, it is assumed that if a MSFTR was custom designed and built for the VTR mission, it would be designed to meet the mission requirements.

Table D-9. Comparison of MSFTR Capabilities to VTR Targets

VTR Requirement	VTR Target	MSFTR Capability
Peak fast flux	≥4.0×1015 n/cm2-s	4.0×1015 n/cm2-s
dpa rate	> 30 dpa/year	> 30 dpa/year
Irradiation length	0.6m – 1.0m	0.6m – 1.0m
Irradiation volume	≥ 7 Liters	≥ 7 Liters
Test flexibility	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salt Loops	Open core, closed loops, rabbits Na, Pb, Pb-Bi, He, Molten Salt Loops. Reactivity worth of experiments may be limited.
Test advanced I&C	Test advanced sensors and instruments	Test advanced sensors and instruments
Available soon	Operational by end of FY2026	Aggressive schedule shows MSFTR operational about FY2032. Nominal schedule shows MSFTR operational about FY2038.
Easy access to experiment fabrication and PIE	Avoid shipping off of a controlled site	MSFTR assumed to be built at a site with adequate access and support, or the ability for these to be added. Details unknown.
Provide life cycle management for driver fuel while minimizing cost and schedule impacts	Evaluate based on cost and schedule impact with consideration for using existing DOE infrastructure with necessary modifications for fuel life-cycle management	MSFTR assumed to be built at a site with adequate access and support, or the ability for these to be added. Details unknown.

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APPENDIX E LIFE CYCLE COST ESTIMATES

E.1 Basis of Estimate

Purpose of Estimate(s)

Life Cycle Cost estimates (LCCE) were developed for each viable alternative identified for the Versatile Test Reactor (VTR) Project. These rough order of magnitude (ROM) estimates are intended as a means of comparing relative costs of viable alternatives, to support the Analysis of Alternatives (AoA), and are not intended for budgeting purposes.

Estimate Assumptions

General Assumptions

- Except for alternatives that consider the use of existing facilities (ATR, HFIR, FFTF), all alternative cost estimates are considered non-site specific and reflect generic assumptions relative to labor rates, site overheads/mark-ups, availability of support facilities, etc.
- Costs for completion of NEPA activities have not been included in the alternative cost estimates and there are no assumed NEPA impacts/constraints on proposed schedules. Compared to the engineering design, construction, operations, maintenance and D&D costs, NEPA costs are fairly insignificant, and had no measurable effect on the comparisons and thus were excluded.
- Adequate funding will be provided annually to support the VTR project and alternative schedules have not been adjusted due to constrained funding.
- Annual operating costs do not include the costs of fuel material, assumed to be made available for each viable alternative.
- Fuel fabrication costs are not included as a separate cost item because the fuel characteristics and quantities cannot be known prior to design studies. Fuel supply costs and potential facilities are considered in a generic manner consistent with likely fuel needs for each alternative.
- Annual operating costs do not include the costs for management (storage/disposal) of spent nuclear fuel, test materials and other radioactive waste produced during VTR operations as these are largely undefined and not considered to be discriminating factors between alternatives at this time.
- Annual operations phase costs include an assumed cost for security personnel that has been consistently applied to each alternative, other than for HFIR (due to its being a DOE SC site).
- Facilities are assumed to be operational for 40 years.
- Major upgrades or improvement projects will be needed 3 times over the operational life of alternatives making use of currently existing facilities, and twice over the operational life of new reactors.
- Costs associated with potential life extension beyond 40 years are not included in the AoA LCCEs.

Time Value of Money Assumptions

- Base year for estimates:
  - Fiscal Year 2019

   - Prior year estimates, when used, have been escalated to this base period using historical DOE escalation rates, assumed to be an average of 4% per year.

- Escalation Rates:
   - Capital costs, to include all construction costs and other project costs – 4% per year based on current DOE guidance. (See *Independent Cost Review (ICR) and Independent Cost Estimate (ICE) Standard Operating Procedure (SOP) Revision 4*, August 27; 2018, DOE Office of Project Management.)
   - O&M costs and other operations costs – 2% per year based on current OMB guidance. (OMB Circular A-94 prescribes a nominal discount rate of 3.6% as compared to a real discount rate of 1.5%, the difference being anticipated price escalation/inflation.)
   - End of Life D&D Costs –assumes escalation at 3% per year (average of the two above rates).

- Discount Rate: 3.6% per year (OMB A-94 Nominal Rate (30 years+); 1.5% Real Rate (used for sensitivity analysis)

Alternative-Specific Assumptions/Approaches

- Alternative 1 – Status Quo
   - Assumed will be accomplished using the existing ATR and HFIR facilities.
   - The costs incurred to accomplish VTR mission at HFIR are primarily covered by DOE Office of Science (DOE SC) operation of the facility, and thus not considered for this analysis which is focused on NE expenditures. There are additional NE program covered costs for fuel fab and PIE as well, however these are not considered to be significant.
   - ATR expenditures for Advance Reactor Fuels work is approximately $12-15M per year, of which approximately 75% can be attributed to VTR mission activities.
   - Additionally, there is approximately $5M spent annually for graphite irradiation to support HTGRs. There is also $13-17M annual expenditure for the National Science Users Facilities funded by DOE NE.
   - Based on the annual expenditures described above, a conservative ROM estimate of $40M/year was used to estimate the Status Quo expenditures, assuming there may be additional costs incurred to use other facilities, ship materials, etc.
   - No D&D costs have been included for the Status Quo alternative since the facilities will be used by other programs/missions and the VTR mission will merely reflect usage to the extent facilities can be made available. As a result, it is not appropriate to include final D&D in the LCC used to assess the Status Quo approach.

- Alternative 2 – ATR with BFFL
   - Capital cost estimate is based on an estimate developed in 2007 for adding a Boosted Fast Flux Loop to the ATR.
   - Using the estimated cost details, the costs for procurement and construction were extracted and used for the AoA estimate.
   - AoA parameters were then applied to estimate the other capital project costs on a consistent basis with the other alternatives.

- In addition to the percentage calculation, the estimated engineering costs include an added cost for specific activities included in the 2007 estimate for nuclear testing and product development.
- Capital project cost also includes an allowance for possible modifications needed for existing INL facilities that support the ATR and VTR activities to position the facility for 40 years of VTR operations. Assumed approximately 25% of the current Test Train Assembly, Analytical Laboratory, Hot Fuel Examination Facility, Irradiated Materials Characterization Laboratory, Experimental Fuels Facility, and Fuels and Applied Science Building may require some degree of modification that has been estimated on a $/sf basis.
- It was assumed that the approximately 50% of ATR annual operations costs are attributed to the VTR mission for LCC analysis of the alternative. The current operating staff of the ATR, and the current ATR operating budget was used as the basis to estimate the annual operating cost of the ATR alternative for the VTR.
- D&D costs are included generically based on size of facility modifications.

- Alternative 3 – HFIR with 3/7 Pin Configuration
  - The capital cost for the HFIR modifications are based on both the escalation of a ROM estimate from 2007 and a ROM estimate for the design activities provided to the AoA Team during a site visit.
  - The capital cost estimate also includes a ROM estimate provided during the site visit to bring a dormant hot cell back into service, as well as an allowance for some potential modifications of existing ORNL facilities to support the VTR mission, estimated based using an assumed size (sf) and cost per sf.
  - The annual operating cost for using the modified HFIR for accomplishing the VTR mission reflects approximately 50% of the annual cost of HFIR operations. That estimate is based on the current annual operating budget for HFIR.
  - Because HFIR is operated by DOE SC, it is assumed the VTR mission would not be responsible for final D&D of the facility.

- Alternative 4 – FFTF
  - The starting point for the capital cost estimate was the "Siting Study for Hanford Advanced Fuels Test & Research Center" from April 2007.
  - Those estimated costs were related to appropriate AoA WBS elements and escalated to FY2019.
  - Because the current condition of the FFTF is unknown and has not been evaluated since the restart costs were estimated in 2007, an additional allowance of 100% of the estimated procurement and construction costs was included to calculate the total capital cost for Alternative 4. The resultant TPC for the FFTF modification project is approximately $1.5B (FY19$), as compared to the escalated 2007 estimate of approximately $300M (FY19$). This equates to approximately $3,000/sf which is believed to be reasonable for such a project when compared to historical DOE nuclear project costs.
  - The capital project cost estimate for this alternative also includes an allowance for potential modifications of approximately 50% of the Fuels Manufacturing and Examination Facility (FMEF) and the construction of approximately 20,000 SF of new non-nuclear facilities at Hanford to support the VTR mission.

  - The M&O Support Cost WBS element includes an added cost for certain activities included in the 2007 FFTF restart cost estimate believed needed but additional to the activities to be covered by the general parameter added for all other alternatives.
  - Time-phasing of capital project costs assumes engineering/design expenditures begin one year prior to CD-1 to allow for needed facility investigations.
  - Annual operating costs are based on an assumed 400 FTEs (consistent with FFTF experience) at an assumed $300k/FTE per year (consistent with other VTR alternatives).
  - D&D costs are included generically based on facility size.

- Alternative 5 – SFTR
  - The point estimate developed by the DOE ICR Team was used as the starting point. That estimate was broken down into the WBS elements used for the AoA based on the parameters listed under "Key Parameters" later in this appendix to facilitate the time-phasing of the estimated costs in accordance with the project schedule. The costs were adjusted upwards slightly to include potential added costs for safety basis and M&O oversight/support.
  - Time-phasing of capital project costs assumes engineering/design expenditures begin one year prior to CD-1 to allow for conceptual design completion that is assumed to be included in the total estimated engineering cost.
  - Annual operating costs are based on an assumed 400 FTE operating staff, consistent with the FFTF experience, at an assumed $300k/FTE per year, consistent with the other alternatives.
  - D&D costs are included generically based on facility size.

- Alternative 6 – LFTR
  - The LFTR is expected to have a more compact design without an intermediate loop, as compared to the SFTR. However, this potential reduction in procurement/construction costs is expected to be offset by the added costs due to new primary system material, cladding, coolant and fuel. Accordingly, the same construction cost has been assumed for the LFTR as was estimated for the SFTR alternative.
  - Because it represents new technology that has not yet matured to the same level as the SFTR, the estimated engineering/design costs for the LFTR alternative have been assumed to be 40% higher than the SFTR engineering/design cost estimate.
  - Time-phasing of capital project costs assumes engineering/design expenditures begin one year prior to CD-1 to allow for conceptual design and R&D activities that are assumed to be included in the total estimated engineering cost.
  - A higher contingency than used for the SFTR has been included to reflect the added uncertainties/risks related to technical maturity.
  - For the High Range capital cost estimate, an additional allowance has been added to cover the cost of constructing a pilot plant and operating it for two years.
  - All operational phase costs are assumed to be the same for the LFTR as estimated for the SFTR, except for the cost for major upgrades/modifications that is based on a percentage of the initial capital cost estimate.
  - D&D costs are included generically based on facility size.

- Alternative 7 – MSFTR
  - The MSFTR is expected to have similar scope and estimated cost as the SFTR, but a higher contingency has been included to reflect the added uncertainties/risks related to technical maturity.
  - Because it represents new technology that has not yet matured to the same level as the SFTR, the estimated engineering/design costs for the MSFTR alternative have been assumed to be 50% higher than the SFTR engineering/design cost estimate.
  - Time-phasing of capital project costs assumes engineering/design expenditures begin one year prior to CD-1 to allow for conceptual design and R&D activities that are assumed to be included in the total estimated engineering cost.
  - For the High Range capital cost estimate, an additional allowance has been added to cover the cost of constructing a pilot plant and operating it for two years.
  - All operational phase costs are assumed to be the same for the MSFTR as estimated for the SFTR, except for the cost for major upgrades/modifications that is based on a percentage of the initial capital cost estimate.
  - D&D costs are included generically based on facility size.

Key Parameters used for LCCEs

Key Estimated Values			
D&D of Facilities (end of life)	111,000	per sf ^0.45	per PMOA CESI nuclear facility benchmark
Operations Costs (Staffing)		Alternative Specific	
Maintenance Costs	10%	of Staffing Costs	
Supplies Costs	5%	of Staffing Costs	
Utility Charges		Alternative Specific	
Other Direct Costs (during Operations)	10%	of Staffing Costs	
Periodic Major Upgrade - retrofitted/restarted facilities	25%	of New Capital Cost every 10 years	
Periodic Major Upgrade - new reactor facilities	10%	of Initial Capital Cost twice over life	
TPC Cost per SF for New Nuclear Facilities (w/equip)	15,000	per sf	These are conservative values based on DOE historical data and SME experience
TPC Cost per SF for New Nuclear Facilities (minimal equip)	10,000	per sf	
TPC Cost per SF for New Non-Nuclear Facilities (offices, etc.)	3,000	per sf	
TPC Cost for mods of Nuclear Facilities	2,000	per sf	
TPC Cost for mods of Non-Nuclear Facilities	500	per sf	
Construction Estimate Parameters	These parameters are based on DOE/SME experience and consistent with VTR ICR engineering assessment		
Project Management and Support	15%	of all other Capital Costs	
Engineering/Design - modification projects	50%	of D&D, procurement and construction costs	
Engineering/Design - new reactor projects	35%	of D&D, procurement and construction costs	
Note: Engineering/Design includes Conceptual, Preliminary (T1) and Final (T2) Design			
T3 Engineering	20%	of procurement and other construction costs	
Start-Up / Commissioning - modification projects	30%	of procurement and construction costs (includess some amount of support facility construction)	
Start-Up / Commissioning - new reactor projects	10%	of procurement and construction costs	
M&O/DOE Oversight and Support	5%	of all other Capital Costs	
Safety Basis Related Cost	5%	of Design Cost (used in absence of specific estimates)	
MR and Contingency Allowance (applied to Capital Costs only)			
New Reactor Projects - SFR	30%		
New Reactor Projects - LFR and MSR	50%	Higher risk due to technology maturity	
Modification Projects	50%	More uncertainty re conditions and scope	
Operations Ramp-up (to support start-up/commissioning and training)			
CD-4 minus 1 year	75%	of full operating staff	
CD-4 minus 2 years	25%	of full operating staff	

E.2 Estimate Work Breakdown structure (WBS)

Table E-1 describes the WBS used to organize the LCCE for each alternative for this AoA and describes the general approach used to estimate the respective WBS elements.

Table E-1. VTR AoA Work Breakdown Structure

WBS Element		Description	Cost Estimate Approach
1.0	Capital Project (TPC)		
1.1	Project Management/Support	All activities and costs related to the management, administration and support of the capital project from inception through CD-4.	Estimated as % of all other project costs
1.2	Engineering/Design	Conceptual, Preliminary and Final Design through approval of CD-3.	Estimated as % of equipment and construction costs
1.3	Site Prep/D&D	Any site or facility investigations and site preparation activities necessary to prepare for modification of construction of the facility needed for a specific alternative.	Alternative specific estimate
1.4	Equipment Procurement	Costs related to long lead and other engineered equipment procurements through equipment delivery.	Alternative specific estimate
1.5	Construction/Installation	Costs incurred during completion of all construction, installation or modification activities. Includes bulk material purchases, craft labor, construction indirects, management supervision, and Title 3 engineering.	Alternative specific estimate
1.6	Startup / Commissioning	Costs incurred from construction turnover through CD-4. Includes systems testing, training, operational readiness reviews, etc.	Estimated as % of equipment and construction costs
1.7	Safety Basis Related Costs	Costs related to activities needed to prepare and obtain approval of safety basis documentation.	Estimated as % of engineering/design costs
1.8	M&O/DOE Oversight/Support Costs	Costs for ongoing site or operations contractor oversight and support during construction and startup of a facility. Includes costs incurred by DOE direct support contracts as well.	Estimated as % of all other project costs
1.9	MR/Contingency	Cost allowance to account for uncertainty and impacts of realized risks.	Estimated as % of all other project costs
2.0	Operations Costs		
2.1	Staffing	Costs related to all operational and support staff needed during facility operations.	Estimated based on FTE count and cost per FTE/year
2.2	Other Operations Costs		
2.2.1	Maintenance	Costs incurred supporting routine preventive and corrective maintenance during facility operations.	Estimated as % of Staffing cost
2.2.2	Supplies	Costs for supplies to be purchased or furnished during plant operations.	Estimated as % of Staffing cost
2.2.3	Utility Charges	Costs of water, electric and other utilities needed during facility operations.	Allowance or ROM estimate
2.2.4	Other Direct Costs	Costs for all other elements needed to support facility operations.	Estimated as % of Staffing cost
2.3	Security Related Costs	Costs to provide needed security during facility operations.	Estimated based on FTE count and cost per FTE/year

Table E-1. VTR AoA Work Breakdown Structure

WBS Element		Description	Cost Estimate Approach
2.4	Periodic Major Upgrades	Costs to design, construct and start-up major facility upgrade or improvement projects over the operational life of the facility.	Estimated as % of initial capital costs
3.0	End-of-Life D&D	Cost to decommission and dismantle new and/or facilities used to accomplish VTR mission.	Parametrically estimated based on facility size(s)

E.2.1 Fuel Fabrication

When addressing fuel supply and fuel fabrication costs, the VTR AoA Team concluded that: a) knowledge of the detailed fuel characteristics and quantities required varies widely across the alternatives, and cannot be known prior to design analyses b) any alternative that needs fuel will have production challenges and costs, and while these may vary by a factor of 'several' between alternatives and fuel options; c) the cost of fuel fabrication (and the ability to fabricate it) will only be a minor portion of the total, as historically fuel fabrication costs are only a minor portion of the total cost to operate reactors.

While there are no separately defined fuel costs included in the LCCEs or the WBS described above; some generic fuel fabrication capabilities are included implicitly in 'supporting infrastructure' but that does not include specific fuel fabrication details or costs. The operating phase costs for each alternative include no allowance for fuel supply or fabrication since the type and requirements are not defined/known. Thus, these have been specifically excluded from the comparative cost analysis. There are, however, potential facilities included (see below) where some fuel fabrication could theoretically be accomplished (along with PIE activities, etc.).

More specifically, here is what is included for each Alternative in the respective initial project costs:

- Alternative 2 – Advanced Test Reactor (ATR) with BFFL – the estimate that was used as a basis for the VTR AoA cost estimate did include an element for booster fuel; however, the VTR AoA cost estimate did not include this portion in keeping with the going in assumption that fuel costs were not to be included. The estimate did include an allowance of $56M for some modifications to existing INL facilities that could potentially address fuel fab capabilities.
- Alternative 3 – High Flux Isotope Reactor (HFIR) with 3/7 pin configuration – there are no fuel costs included and only $5M as a cost to bring a dormant hot cell back into service.
- Alternative 4 – Fast Flux Test Facility (FFTF) – the 2007 estimate included approximately $77M (in 2019 $'s) for "Get New Fuel-Core and stage in 400 Area" and "Bring Fuel into Containment". These costs were included in the FFTF estimate. There was also $275M for undefined support facilities that could potentially include fuel fab capabilities.
- Alternatives 5, 6 and 7 – These estimates were based on the Independent Cost Reviews (ICR) which in turn started with the INL VTR estimate. The INL VTR estimate included $120M for 2 core loads (but not lifetime fuel fab), so consequently there was some fuel and fuel fab cost included in each of the new reactor alternatives (SFTR, MSFTR and LFTR) in a consistent manner.

As the AoA effort was not a 'design study', it did not select details regarding fuel and each alternative could be quite different, and several have 'open options'. For example, the ATR with BFFL would need some added and different fuel. FFTF might use oxide or metal fuel. The VTR example used metal fuel. The LFTR could use oxide or nitride (but not metal) fuel. And finally, the MSFTR dissolves fissile material into the chosen salt. In addition, the ongoing fuel throughput requirements would require design and operating details beyond the scope of the AoA effort.

E.3 Conformance with GAO Best Practices

To the extent possible and applicable, the LCC estimates for the VTR AoA were developed in accordance with the GAO 12 steps aimed at achieving estimates that are credible, well-documented, accurate and comprehensive. These steps are shown in Table E-2, with appropriate comments on how these are applied or tailored for the LCCE used for this analysis.

Table E-2. Compliance with GAO's 12 Step Guidance

Step	Description	Associated Task	AoA Compliance//Approach
1	Define estimates purpose	1. Determine estimate's purpose, required level of detail, and overall scope. 2. Determine who will receive the estimate.	The estimate purpose is described in an Estimate Plan and in this appendix to the AoA Report. The estimates are intended to inform the DOE decision makers as well as other interested parties regarding the basis for the alternative analysis and will support alternative selection by DOE.
2	Develop estimating plan	1. Determine the cost estimating team and develop its master schedule. 2. Determine who will do the independent cost estimate; outline the cost estimating approach. 3. Develop the estimate timeline.	An Estimate Plan was prepared and submitted as part of the initial AoA planning efforts.
3	Define program characteristics	1. Identify the program's purpose and its system and performance characteristics and all system configurations. 2. Any technology implications. 3. Program acquisition schedule and acquisition strategy. 4. Its relationship to other existing systems, including predecessor or similar legacy systems. 5. Support (manpower, training, etc.) and security needs and risk items. 6. System quantities for development, test, and production. 7. Deployment and maintenance plans.	Program characteristics and alternative descriptions are documented in this AoA Report as well as the MNS.
4	Determine estimating structure	1. Define a work breakdown structure (WBS) and describe each element in a WBS dictionary (a major automated information system may have only a cost element structure). 2. Choose the best estimating method for each WBS element; Identify potential cross-checks for likely cost and schedule drivers. 3. Develop a cost estimating checklist.	A summary level WBS has been developed and used for the estimates and schedules for all alternatives to the extent elements are appropriate. This AoA Report and appendix describe the estimate methodology and approach used for each WBS element for each alternative and can be considered a checklist to insure capture of all relevant items.

Table E-2. Compliance with GAO's 12 Step Guidance

Step	Description	Associated Task	AoA Compliance//Approach
5	Identify ground rules and assumptions	1. Clearly define what the estimate includes and excludes. 2. Identify global and program-specific assumptions, such as the estimate's base year, including time-phasing and life cycle. 3. Identify program schedule information by phase and program acquisition strategy. 4. Identify any schedule or budget constraints, inflation assumptions, and travel costs. 5. Specify equipment the government is to furnish as well as the use of existing facilities or new modification or development. 6. Identify prime contractor and major subcontractors. 7. Determine technology refresh cycles, technology assumptions, and new technology to be developed. 8. Define commonality with legacy systems and assumed heritage savings. 9. Describe effects of new ways of doing business.	The assumptions are described in this AoA Report and appendix.
6	Obtain data	1. Create a data collection plan with emphasis on collecting current and relevant technical, programmatic, cost, and risk data. 2. Investigate possible data sources. 3. Collect data and normalize them for cost accounting, inflation, learning, and quantity adjustments. 4. Analyze the data for cost drivers, trends, and outliers and compare results against rules of thumb and standard factors derived from historical data. 5. Interview data sources and document all pertinent information, including an assessment of data reliability and uncertainty. 6. Store data for future estimates.	Data acquisition included research into historical cost estimates related to the modification of existing facilities. Each site was also visited and Lines of Inquiry(s) (LOIs) were used to gather appropriate data to be used for cost estimate development. This data used is described and documented in this AoA Report.
7	Develop point estimate and compare it to an independent cost estimate	1. Develop the cost model, estimating each WBS element, using the best methodology from the data collected, and including all estimating assumptions. 2. Express costs in constant year dollars. 3. Time-phase the results by spreading costs in the years they are expected to occur, based on the program schedule. 4. Sum the WBS elements to develop the overall point estimate. 5. Validate the estimate by looking for errors like double counting and omitted costs. 6. Compare estimate against the independent cost estimate and examine where and why there are differences. 7. Perform cross-checks on cost drivers to see if results are similar.	These steps have been done as appropriate and documented in the AoA Report. At this time, the AoA Alternative estimates have not yet been compared to an independent cost estimate.

Table E-2. Compliance with GAO's 12 Step Guidance

Step	Description	Associated Task	AoA Compliance//Approach
		8. Update the model as more data become available or as changes occur and compare results against previous estimates.	
8	Conduct sensitivity analysis	1. Test the sensitivity of cost elements to changes in estimating input values and key assumptions. 2. Identify effects on the overall estimate of changing the program schedule or quantities. 3. Determine which assumptions are key cost drivers and which cost elements are affected most by changes.	The cost estimated developed and used to compare VTR alternatives are not based on any key assumptions that will impact the comparisons from either an initial capital cost or LCC perspective. The one exception identified and discussed in the AoA report is the use of real as compared to nominal discount rates for the PV calculations.
9	Conduct risk and uncertainty analysis	1. Determine and discuss with technical experts the level of cost, schedule, and technical risk associated with each WBS element. 2. Analyze each risk for its severity and probability. 3. Develop minimum, most likely, and maximum ranges for each risk element. 4. Determine type of risk distributions and reason for their use. 5. Ensure that risks are not correlated. 6. Use an acceptable statistical analysis method (e.g., Monte Carlo simulation) to develop a confidence interval around the point estimate. 7. Identify the confidence level of the point estimate. 8. Identify the amount of contingency funding and add this to the point estimate to determine the risk-adjusted cost estimate. 9. Recommend that the project or program office develop a risk management plan to track and mitigate risks.	The AoA includes a qualitative risk assessment suitable for comparison of the alternatives. A quantitative risk analysis, using Monte Carlo simulation, has not been done for this AoA. Rather, cost estimates include appropriate contingency allowances, and cost estimate ranges are provided based on prescribed uncertainty ranges for Class 5 estimates, informed additionally by the results of the qualitative risk assessment.
10	Document the estimate	1. Document all steps used to develop the estimate so that a cost analyst unfamiliar with the program can recreate it quickly and produce the same result. 2. Document the purpose of the estimate, the Team that prepared it, and who approved the estimate and on what date. 3. Describe the program, its schedule, and the technical baseline used to create the estimate. 4. Present the program's time-phased life-cycle cost. 5. Discuss all ground rules and assumptions. 6. Include auditable and traceable data sources for each cost element and document for all data sources how the data were normalized. 7. Describe in detail the estimating methodology and rationale used to derive each WBS element's cost (prefer more detail over less). 8. Describe the results of the risk, uncertainty, and sensitivity analyses and whether any contingency funds were identified.	The LCCE for each alternative is fully described and documented in this AoA Report. A separate Excel file also is provided that includes all cost estimate details and calculations.

Table E-2. Compliance with GAO's 12 Step Guidance

Step	Description	Associated Task	AoA Compliance//Approach
		9. Document how the estimate compares to the funding profile. 10. Track how this estimate compares to any previous estimates.	
11	Present estimate to management for approval	1. Develop a briefing that presents the documented life-cycle cost estimate. 2. Include an explanation of the technical and programmatic baseline and any uncertainties. 3. Compare the estimate to an independent cost estimate (ICE) and explain any differences. 4. Compare the estimate (life-cycle cost estimate (LCCE)) or independent cost estimate to the budget with enough detail to easily defend it by showing how it is accurate, complete, and high in quality. 5. Focus in a logical manner on the largest cost elements and cost drivers. 6. Make the content clear and complete so that those who are unfamiliar with it can easily comprehend the competence that underlies the estimate results. 7. Make backup slides available for more probing questions. 8. Act on and document feedback from management. 9. Request acceptance of the estimate.	A briefing to NE management and others, as needed, will be scheduled after the AoA is completed. It will be clearly noted that these rough-order-of -magnitude estimates are provided to facilitate the comparison and evaluation of alternatives, and that they are not intended or suitable for budgeting purposes.
12	Update the estimate to reflect actual costs and changes	1. Update the estimate to reflect changes in technical or program assumptions or keep it current as the program passes through new phases or milestones. 2. Replace estimates with EVM EAC and independent estimate at completion (EAC) from the integrated EVM system. 3. Report progress on meeting cost and schedule estimates. 4. Perform a post mortem and document lessons learned for elements whose actual costs or schedules differ from the estimate. 5. Document all changes to the program and how they affect the cost estimate.	N/A

E.4 Alternative Summary Comparisons

Table E-3 compares the initial estimated capital investment for each alternative by WBS. These costs are in FY2019 dollars and do not include escalation allowances. There is no capital cost in the Status Quo.

Table E-3. VTR AoA Capital Cost Estimate Comparison

VTR AoA Capital Cost Estimate Summary			Alternate 2 ATR Booster	Alternate 3 HFIR	Alternate 4 FFTF	Alternate 5 SFR	Alternate 6 LFR	Alternate 7 MSR
		(Unescalated Point Estimate)	Estimated Cost (FY19 $M)	Estimated Cost (FY19 $M)	Estimated Cost (FY19 $M)	Estimated Cost (FY19 $M)	Estimated Cost (FY19 $M)	Estimated Cost (FY19 $M)
1.0	Capital Projects (Total Project Cost)		159	68	1,711	5,287	6,711	7,204
	1.1	Project Management/Support	13	6	134	505	556	597
	1.2	Engineering/Design	27	10	245	803	1,125	1,265
	1.3	Site Prep/D&D	1	0	6	10	10	10
	1.4	Equipment Procurement	1	1	33	686	686	720
	1.5	Construction/Installation	40	20	451	1,600	1,600	1,679
	1.6	Start-up / Commissioning	12	6	145	229	229	240
	1.7	Safety Basis Related Costs	6	1	12	40	56	63
	1.8	M&O/DOE Oversight/Support Costs	5	2	114	194	213	229
	1.9	MR/Contingency	53	23	570	1,220	2,237	2,401

Table E-4a presents a ten-year snapshot of the annual funding that will be needed to execute the capital projects needed for each VTR alternative. The annual costs shown are based on annual spend plan forecasts derived by spreading the point estimate costs using the average of the two schedules developed for each alternative and escalating those costs appropriately. ***Note that if an alternative is executed on the aggressive schedule for that alternative, the funding requirements will be accordingly accelerated. Likewise, since the expected cost range is significant, the high range estimates can be expected to require significantly higher annual funding levels than shown in Table E-4a.*** Table E-4b shows the operating costs that will be expended over the same ten-year time span.

Table E-4a. VTR AoA Annual Project Funding (TPC in $ millions, escalated)

	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	Later Years	TPC
Alternative 1 Status Quo	0	0	0	0	0	0	0	0	0	0	0	0
Alternative 2 ATR	0	37	19	26	31	41	36	0	0	0	0	190
Alternative 3 HFIR	2	24	22	25	4	0	0	0	0	0	0	76
Alternative 4 FFTF	0	60	213	307	306	314	348	377	315	0	0	2,240
Alternative 5 SFTR (Note 1)	220	442	697	678	883	913	970	972	778	0	0	6,579
Alternative 6 LFTR	0	79	176	262	306	459	464	562	636	1,069	6,131	10,145
Alternative 7 MSTR	0	88	196	218	248	504	525	608	722	1,133	6,763	11,004

Note 1 -- TPC includes $19M in FY 2019.

Table E-4b. VTR AoA Annual Operations Funding (in $ millions, escalated)

	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	Later Years	Total
Alternative 1 Status Quo	0	0	0	0	0	0	46	47	48	49	2,566	2,756
Alternative 2 ATR	0	0	0	0	0	34	74	100	102	104	5,793	6,206
Alternative 3 HFIR	0	0	8	24	41	42	43	44	45	46	2,310	2,603
Alternative 4 FFTF	0	0	0	0	0	0	0	56	163	196	13,662	14,077
Alternative 5 SFTR	0	0	0	0	0	0	0	56	163	196	13,282	13,698
Alternative 6 LFTR	0	0	0	0	0	0	0	0	0	0	16,930	16,930
Alternative 7 MSTR	0	0	0	0	0	0	0	0	0	0	16,798	16,798

E.5 Cost Estimate Ranges

There is uncertainty associated with several of the assumptions and key parameters used for this analysis. All estimates used in developing the LCC are Class 5 estimates; therefore, a large range is expected in the accuracy of those elements based on the data available at this time. The ranges documented in Table 5 were used to establish cost ranges for each of the five alternatives. The range for Capital Cost (TPC) and D&D is based on DOE G 413.3-21 for a Class 5 estimate, i.e., from –50% to +100%. However, because of the large degree of uncertainty associated with modifying existing facilities, combined with the lack of current cost estimates to accomplish that effort and, in the case of the FFTF, knowledge as to current facility conditions, the ranges used for the alternatives involving existing facility modifications have been assumed to be even broader. Because operational period costs are based on assumed staffing sizes and staff costs per FTE, a narrower range has been assumed for those cost estimates.

Table E-5. VTR AoA Life Cycle Cost Range Summary

WBS/LCC Element	Modified Facilities		New Reactors	
	Low Range, %	High Range, %	Low Range, %	High Range, %
Capital Cost (TPC)	-50%	150%	-30%	100%
Operation Period Cost	-30%	50%	-30%	50%
D&D of New Facilities (EOL)	-50%	100%	-50%	100%

Table E-6 presents the estimated PV of the LCC for each alternative based on the above assumed ranges. Table E-7 presents the estimated LCC cost for each alternative in "as-spent" (escalated) dollars based on the above assumed range for capital costs. The high range values for the capital cost for Alternatives 6 and 7 also include an allowance for a potential pilot plant that may be needed to confirm the viability of the reactor technology and provide a basis for the design and licensing of the test reactor.

Table E-6. VTR AoA Life Cycle Cost Range (PV in millions of $'s)

PV (millions of $'s)			
Alt 1	**Low**	**Point**	**High**
Capital Cost (TPC)	0	0	0
Operation Period Cost	724	1,035	1,552
D&D of New Facilities (EOL)	0	0	0
Total	724	1,035	1,552
Alt 2	**Low**	**Point**	**High**
Capital Cost (TPC)	78	156	390
Operation Period Cost	1,615	2,308	3,461
D&D of New Facilities (EOL)	21	41	82
Total	1,714	2,505	3,934
Alt 3	**Low**	**Point**	**High**
Capital Cost (TPC)	33	66	165
Operation Period Cost	743	1,062	1,593
D&D of New Facilities (EOL)	0	0	0
Total	776	1,128	1,758
Alt 4	**Low**	**Point**	**High**
Capital Cost (TPC)	873	1,746	4,366
Operation Period Cost	3,423	4,890	7,335
D&D of New Facilities (EOL)	34	68	136
Total	4,330	6,705	11,837
Alt 5	**Low**	**Point**	**High**
Capital Cost (TPC)	3,648	5,212	10,424
Operation Period Cost	3,319	4,741	7,112
D&D of New Facilities (EOL)	21	42	84
Total	6,988	9,995	17,620
Alt 6	**Low**	**Point**	**High**
Capital Cost (TPC)	4,719	6,742	16,165
Operation Period Cost	3,153	4,504	6,756
D&D of New Facilities (EOL)	21	42	83
Total	7,893	11,287	23,004
Alt 7	**Low**	**Point**	**High**
Capital Cost (TPC)	5,070	7,243	17,168
Operation Period Cost	3,124	4,462	6,694
D&D of New Facilities (EOL)	21	42	83
Total	8,215	11,747	23,945

Table E-7. VTR AoA Life Cycle Cost Range (As-Spent millions of $'s)

As Spent (millions of $'s)			
Alt 1	**Low**	**Point**	**High**
Capital Cost (TPC)	0	0	0
Operation Period Cost	1,929	2,756	4,134
D&D of New Facilities (EOL)	0	0	0
Total	1,929	2,756	4,134
Alt 2	**Low**	**Point**	**High**
Capital Cost (TPC)	95	190	476
Operation Period Cost	4,344	6,206	9,309
D&D of New Facilities (EOL)	129	258	515
Total	4,568	6,654	10,300
Alt 3	**Low**	**Point**	**High**
Capital Cost (TPC)	38	76	191
Operation Period Cost	1,822	2,603	3,905
D&D of New Facilities (EOL)	0	0	0
Total	1,861	2,680	4,096
Alt 4	**Low**	**Point**	**High**
Capital Cost (TPC)	1,120	2,240	5,600
Operation Period Cost	9,854	14,077	21,116
D&D of New Facilities (EOL)	228	457	914
Total	11,202	16,774	27,629
Alt 5	**Low**	**Point**	**High**
Capital Cost (TPC)	4,605	6,579	13,159
Operation Period Cost	9,589	13,698	20,547
D&D of New Facilities (EOL)	141	282	563
Total	14,335	20,559	34,269
Alt 6	**Low**	**Point**	**High**
Capital Cost (TPC)	7,102	10,145	24,184
Operation Period Cost	11,851	16,930	25,396
D&D of New Facilities (EOL)	178	357	713
Total	19,131	27,432	50,293
Alt 7	**Low**	**Point**	**High**
Capital Cost (TPC)	7,703	11,004	25,901
Operation Period Cost	11,759	16,798	25,198
D&D of New Facilities (EOL)	178	357	713
Total	19,640	28,159	51,812

E.6 Alternative Cost Estimates

This section includes cost estimate summaries and capital cost rationale for each alternative. Additional backup details and calculations can be found in a separate Microsoft Excel spreadsheet file that can be furnished upon request.

Versatile Test Reactor (VTR) Project								
Alternative 1 - Status Quo (Use only Existing Facilities/Capabilities)								
			Estimated Cost ($M)	% of TPC	Start	Finish	PV	As-Spent
1.0	Capital Projects (Total Project Cost)		0				$0	$ -
		No Capital Costs						
2.0	Operations Costs			Parameter			$1,035	$ 2,756
		Total Annual Costs	40	$M/Yr	Oct-25	Sep-65	$1,035	$ 2,756
3.0	End-of Life D&D (of new facilities)		0	$M			$0	$ -

Versatile Test Reactor (VTR) Project								
Alternative 2 - Advanced Test Reactor (ATR)								
			Estimated Cost ($M)	% of TPC	Start	Finish	PV	As-Spent
1.0	Capital Projects (Total Project Cost)		158.8				$156	$ 190
	1.1	Project Management/Support	13.1	8%	Oct-20	May-26	$13	$ 16
	1 2	Engineering/Design	27.5	17%	Oct-20	Sep-21	$27	$ 30
	1 3	Site Prep/D&D	0.8	1%	Mar-21	Sep-21	$1	$ 1
	1.4	Equipment Procurement	1.1	1%	Mar-21	Sep-23	$1	$ 1
	1 5	Construction/Installation	39.6	25%	Sep-21	Sep-25	$39	$ 48
	1.6	Start-up / Commissioning	12.2	8%	May-25	May-26	$12	$ 16
	1.7	Safety Basis Related Costs	6.4	4%	Oct-20	Nov-24	$6	$ 7
	1 8	M&O/DOE Oversight/Support Costs	5.0	3%	Oct-20	May-26	$5	$ 6
	1 9	MR/Contingency	52.9	33%	Oct-20	May-26	$52	$ 66
2.0	Operations Costs			Parameter			$2,308	$ 6,206
	2.1	Staffing	60.0	$M/Yr	May-26	May-66	$1,589	$ 4,250
	2 2	Other Operations Costs						
	2 2.1	Maintenance	6.0	$M/Yr	May-26	May-66	$154	$ 418
	2 2.2	Supplies	3.0	$M/Yr	May-26	May-66	$77	$ 209
	2 2.3	Utility Charges	0.1	$M/Yr	May-26	May-66	$3	$ 7
	2 2.4	Other Direct Costs	6.0	$M/Yr	May-26	May-66	$154	$ 418
	2 3	Security Related Costs	10.0	$M/Yr	May-26	May-66	$256	$ 697
	2.4	Periodic Major Upgrades	39.7	$M/each	3 upgrades at 10 year intervals		$75	$ 206
3.0	End-of Life D&D (of new facilities)		59.1	$M	May-68	May-71	$41	$ 258

Alternative 2 Details

INL Estimate - August 2007 ($M)	Estimate	Escalation	Contingency	Total
TEC	18.0	2.3	5.1	25.4
OPC	27.1	3.4	7.6	38.1
	45.1	5.7	12.7	63.5
		to mid March 2011	25%	

Note -- described as Class 4 but is based on project team assumptions/assessment/adjustments to earlier estimate

	Estimate Breakdown	TEC	OPC	
	PM pror to CD-1		1.0	
	PM during Operational Activities		3.2	
	Develop Safety Analysis		4.0	
	Operating Procedures (incl. MSA)		4.8	
	PM during Caplital Activities	3.6		
	Booster Fuel		8.4	
E+	Nuclear Testing		2.9	
E+	Hafnium-Aluminum Block Develop/Product.		1.3	
	Capital Design	4.5		
	Project Analyses	2.2		
1.3	System Testing	0.5		
1.5	Temp Cntl, Samling Sys, He Montoring, Insul	1.8		
1.5	Electical, I&C	2.7		
1.4	Tank Hardware	0.7		
1.5	Mod and Install of GTL in Corner Lobe	0.4		
1.5	Facility Modifications	1.0		
	Operations		0.5	
	Performance Testing		0.9	
	Other Operational Adders		0.2	These are adders for MH, G&A
	Oher Capital Adders	0.6		These are adders for MH, G&A
	Total	18.0	27.2	

Support Facilities

	Size (sf) Nuclear	non Nuclear
Test Train Assembly Facility	10,000	
Analytical Lab		83,000
HFEF	62,000	
IMCL	13,000	
EFF	5,000	
FASB		6,000
Total Space Required for Use	90,000	89,000

Assume some modifications will be required at portion of existing 25%

TPC ($M)	Nuclear	Non-Nuclear
Cost of Modifications	45.0	11.1

Total TPC for Support Faciilities at INL 56.1 for ATR Booster Alternative

Assumed breaddown		
Procurement and Construction portion of TPC	**28.1**	50% (based on Model shown with Alt. 5 Details)
Assume all "Construction for WBS and Schedule)		

	Capital Cost Inputs (see above)	Assumed Escalation Rate since 2007:	4%
		Factor Applied:	1.60
1.3	**Site Prep (assume System Testing)**	**0.8**	
1.4	**Procurement**	**1.1**	
1.5	**Construction**	**39.6**	Includes add for T3 engineering - see Key Parameters And Support Facilities Mods
	Safety Analysis	**6.4**	Use this estimate (approximately same as if Key Parameter rate is applied)
E+	**Added Engineering Costs**	**6.7**	In additon to % calculation

Versatile Test Reactor (VTR) Project								
Alternative 3 - High Flux Isotope Reactor (HFIR)								
			Estimated Cost ($M)	% of TPC	Start	Finish	PV	As-Spent
1.0	**Capital Projects (Total Project Cost)**		67.8				$69	$ 76
	1.1	Project Management/Support	5.6	8%	Aug-20	Oct-23	$6	$ 6
	1.2	Engineering/Design	10.3	15%	Aug-20	Apr-21	$10	$ 11
	1.3	Site Prep/D&D	0.0	0%	Oct-20	Apr-21	$0	$ -
	1.4	Equipment Procurement	0.8	1%	Oct-20	Jan-21	$1	$ 1
	1.5	Construction/Installation	19.8	29%	Apr-21	Jan-23	$20	$ 22
	1.6	Start-up / Commissioning	6.2	9%	Sep-22	Oct-23	$6	$ 7
	1.7	Safety Basis Related Costs	0.5	1%	Aug-20	Mar-22	$1	$ 1
	1.8	M&O/DOE Oversight/Support Costs	2.2	3%	Aug-20	Oct-23	$2	$ 2
	1.9	MR/Contingency	22.6	33%	Aug-20	Oct-23	$23	$ 26
2.0	**Operations Costs**			Parameter			$1,335	$ 2,603
	2.1	Staffing	30.0	$M/Yr	Oct-23	Sep-63	$1,040	$ 2,021
	2.2	Other Operations Costs						
	2.2.1	Maintenance	3.0	$M/Yr	Oct-23	Sep-63	$101	$ 199
	2.2.2	Supplies	1.5	$M/Yr	Oct-23	Sep-63	$51	$ 99
	2.2.3	Utility Charges		$M/Yr	Oct-23	Sep-63	$0	$ -
	2.2.4	Other Direct Costs	3.0	$M/Yr	Oct-23	Sep-63	$101	$ 199
	2.3	Security Related Costs		$M/Yr	Oct-23	Sep-63	$0	$ -
	2.4	Periodic Major Upgrades	16.9	$M/each	3 upgrades at 10 year intervals		$43	$ 85
3.0	**End-of Life D&D (of new facilities)**		0	$M	Sep-65	Sep-68	$0	$ -

Alternative 3 Details

Historical Cost Estimate			
FNTC PNNL-17140 - November 2007	$3	M	
Escalated to 2019 $'s	$4.8	M	
AoA Estimate			
Build-up of Cost based on current estimate for design	$1.50	M	
		M	
Using Key Parameter for Design, Construction/Procurement Cost =	$3.00	M	
Assume Procurement % =	25%		
Procurement	$0.75	M	
Construction	$2.25	M	
Note - the total of engineering/design and procurement/construction	$4.50	compares to escalated 2007 estimate	
Add costs for Support Facility Modifications			
Cost to bring dormant hot cell back into service (see above)	$5.00	M	
Assume all "construction/installation"			
Assume some amount of other existing facilities need modifications	20,000	SF	
Assume nuclear portion of this space	50%		
TPC of Modifications			
Nuclear Facility Modifications	$20.00	M	
Non-Nuclear Facility Modifications	$5.00	M	
	$25.00		
Assumed % of TPC for Support Facility Mods that is Construction	50%		
Inputs for AoA Estimate for Alternative 3			
Procurement	**$0.75**	M	
Construction	**$19.75**	M	

Versatile Test Reactor (VTR) Project									
Alternative 4 - Modify and Restart Fast Flux Test Facility (FFTF)									
			Estimated Cost ($M)	**% of TPC**	Start	Finish	**PV**		**As-Spent**
1.0	**Capital Projects (Total Project Cost)**		1,711.0				**$1,746**	**$**	**2,240**
	1.1	Project Management/Support	133.9	8%	Aug-21	Apr-28	**$132**	**$**	**166**
	1.2	Engineering/Design	245.0	14%	Aug-21	Apr-23	**$240**	**$**	**279**
	1.3	Site Prep/D&D	6.0	0%	Oct-22	Apr-23	**$6**	**$**	**7**
	1.4	Equipment Procurement	33.0	2%	Oct-22	Oct-25	**$32**	**$**	**40**
	1.5	Construction/Installation	451.0	26%	Apr-23	Sep-27	**$446**	**$**	**578**
	1.6	Start-up / Commissioning	145.2	8%	Mar-27	Apr-28	**$145**	**$**	**203**
	1.7	Safety Basis Related Costs	12.3	1%	Aug-22	Sep-26	**$12**	**$**	**15**
	1.8	M&O/DOE Oversight/Support Costs	114.3	7%	Aug-22	Apr-28	**$112**	**$**	**136**
	1.9	MR/Contingency	570.3	33%	Aug-22	Apr-28	**$621**	**$**	**816**
2.0	**Operations Costs**			**Parameter**			**$4,890**	**$**	**14,077**
	2.1	Staffing	120.0	$M/Yr	Apr-28	Apr-68	**$3,079**	**$**	**8,834**
	2.2	Other Operations Costs							
	2.2.1	Maintenance	12.0	$M/Yr	Apr-28	Apr-68	**$298**	**$**	**869**
	2.2.2	Supplies	6.0	$M/Yr	Apr-28	Apr-68	**$149**	**$**	**435**
	2.2.3	Utility Charges	1.0	$M/Yr	Apr-28	Apr-68	**$25**	**$**	**72**
	2.2.4	Other Direct Costs	12.0	$M/Yr	Apr-28	Apr-68	**$298**	**$**	**869**
	2.3	Security Related Costs	10.0	$M/Yr	Apr-28	Apr-68	**$248**	**$**	**724**
	2.4	Periodic Major Upgrades	427.7	$M/each	3 upgrades at 10 year intervals		**$794**	**$**	**2,273**
3.0	**End-of Life D&D (of new facilities)**		98.8	$M	Apr-70	Apr-73	**$68**	**$**	**457**

Alternative 4 Details					2007	2019		
					Escalation to 2019$'s	1.601	at Parameter (4%)	
Cost Estimate from "Siting Study For Hanford Advanced Fuels Test & Research Center" April 2007								
Type	Activity	Duration(mos)	2007 Est. ($000)	$k/mo				
O	Startup to Hire and Qualify Technical Staff	12	863	72				
P	Plug "Hole" and Requalify HTS Boundaries	12	2,150	179				
C	Remove & Refurbish 3 IVHMS	30	8,000	267				
P	Recover MASF - Begin Surveillance and Maintenan	12	1,500	125				
O	Na fill Ex-Containment Systems	6	300	50				
O	NA fill In-Containment Systems (incl NaK Loops)	12	500	42				
C	Complete Plant Upgrades (including Simulator)	48	31,200	650				
C	Restore Plant Systems (incl revseing Na-drain Mod	24	17,500	729				
E	Revise FSAR & Get Reg Approval (ncl NEPA and DBE	36	9,000	250				
S	Perform Hot Function Testing	6	492	82				
C	Na & Tag Gas Analysis Labs	24	7,000	292				
C	Upgrade 400 Area Security	36	31,000	861				
O	Get New Fuel -Core Comp and stage in 400 Area	42	37,200	886				
O	Bring Fuel into Containment	6	500	83				
O	Load Core and Pull Rods	12	Exist Force					
S	Perform Integrated Leak Rate Test	24	984	41				
S	Perform Operational Readiness Review ORRs		1,845					
S	Perform SnubberTesting in Primary Cells	12	1,400	117				
	Total Cost for Resolving Recovery/Restart Issues		151,434					
	Technical Staff to operate FFTF		234,400					
S	Electricity, Inert Gas, Roads, Commodities, Spares		40,000					
	Grand Total		425,834					
Summary of Above Cost Estimate by Major WBS Elements								
			2019 k$'s					
E	Engineering		14,409					
P	Site Prep		5,844					
C	Construction (incl Procurement)		151,618					
S	Start-up & Commissioning		71,600	Assumes the Ops Staff is covered in Operations Estimate				
O	Other Project Costs		63,021					
	Total Project Cost		306,492					
Adjustments								
	Do not use Engineering Estimate -- apply Key Parameter instead							
	Add Allowance to Construction to account for Facility Degradation since earlier estimate							
			100%					
	Assume Procurement element small portion of Construction		10%					
	Use Key Parameter rather than above estimate for Start-up & Commissioning							
	Add OPC from above to the M&O Oversight WBS calculated using Key Parameter							
	Assume modifications needed to FMEF to support FFTF operations as VTR							
		175,000	sf					
	Assume portion to be modified	50%						
	Estimated cost of FMEF Mods	175	M					
	Assume new support facilities will be needed	20,000	SF non-nuclear					
	Estimated Cost of added new faciltities	60	M					
	Total TPC for Support Facilities	**235**	**M**					
	Percentage of TPC is construction(per model)	50%						
	Include Allowance for PIDAS upgrade/mods							
	Procurement	3	Assumed 50% of new VTR (Alt 5)					
	Construction	6						
Capital Cost Inputs (see above)								
1.3	**Site Prep**	**6.0**						
1.4	**Procurement**	**33.0**						
1.5	**Construction**	**451.0**	Includes add for T3 and also support facilities					
1.8	**Added M&O Support Costs**	**63.0**	In additon to % calculation					

Versatile Test Reactor (VTR) Project								
Alternative 5 - Sodium-cooled fast test reactor (SFR)								
			Estimated Cost ($M)	**% of TPC**	Start	Finish	**PV**	**As-Spent**
1.0	**Capital Projects (Total Project Cost)**		5,286.8				**$5,212**	**$ 6,579**
	1.1	Project Management/Support	505.2	10%	Aug-19	Apr-28	**$497**	**$ 610**
	1.2	Engineering/Design	803.5	15%	Aug-19	Aug-22	**$782**	**$ 874**
	1.3	Site Prep/D&D	9.5	0%	Mar-22	Aug-22	**$9**	**$ 11**
	1.4	Equipment Procurement	686.3	13%	Mar-22	May-25	**$675**	**$ 826**
	1.5	Construction/Installation	1,599 8	30%	Aug-22	Apr-27	**$1,580**	**$ 2,020**
	1.6	Start-up / Commissioning	228.6	4%	Oct-26	Apr-28	**$228**	**$ 318**
	1.7	Safety Basis Related Costs	40.2	1%	Aug-20	May-26	**$39**	**$ 48**
	1.8	M&O/DOE Oversight/Support Costs	193.7	4%	Aug-20	Apr-28	**$192**	**$ 251**
	1.9	MR/Contingency	1,220.0	23%	Aug-20	Apr-28	**$1,211**	**$ 1,622**
2.0	**Operations Costs**			**Parameter**			**$4,741**	**$ 13,698**
	2.1	Staffing	120.0	$M/Yr	Apr-28	Apr-68	**$3,079**	**$ 8,834**
	2.2	Other Operations Costs						
	2.2.1	Maintenance	12.0	$M/Yr	Apr-28	Apr-68	**$298**	**$ 869**
	2.2.2	Supplies	6 0	$M/Yr	Apr-28	Apr-68	**$149**	**$ 435**
	2.2.3	Utility Charges	1.0	$M/Yr	Apr-28	Apr-68	**$25**	**$ 72**
	2.2.4	Other Direct Costs	12.0	$M/Yr	Apr-28	Apr-68	**$298**	**$ 869**
	2.3	Security Related Costs	10.0	$M/Yr	Apr-28	Apr-68	**$248**	**$ 724**
	2.4	Periodic Major Upgrades	528.7	$M/each	2 upgrades over life		**$645**	**$ 1,894**
3.0	**End-of Life D&D (of new facilities)**		60.9	$M	Apr-70	Apr-73	**$42**	**$ 282**

Alternative 5 Details		($M)		
	Point Estimate proposed by ICR Team	4,920	(FY19$)	
	Cost Breakdown by WBS (using model based on Key Parameter %'st)			
1.1	Project Management/Support	494		
1.2	Engineering/Design	794		
1.3	Site Prep/D&D	**10**		
1.4	Equipment Procurement	**681**		
1.5	Construction/Installation	**1,589**		
1.6	Start-up / Commissioning	227		
1.7	Safety Basis Related Costs	40		
1.8	M&O/DOE Oversight/Support Costs	192		
1.9	MR/Contingency	1,208		
		5,233		
From VTR Overview Documentation presented to AoA Team			($B)	
		Low	High	
	VTR Cost Range	3.4	4.7	
	ICR Range	*3.7*	*5.1*	
	Mid-Point	3.8		
	Infrastructure	0.5	1.0	
	Design	0.75	1.0	
	Construction	2.0	2.5	
		3.3	4.5	
PIDAS				
	Estimated length of VTR PIDAS fence:	3300	lf	
	Basis: 1.5 times the existing ZPPR/FMF PIDAS outer fence or (1.5) x 2x500 + 2x600, estimated from INL iMap image			
	Estimated Cost of PIDAS ($M)		*Based on analysis of DOE experience = $5,00/lf*	
	Procurement	$ 5.4	33%	
	Construction	$ 11.1	67%	
Support Facilities				
	None assumed - Generic Site	$ -		
Totals to Transfer to "Alt. 5 - Summary"				
	Site Work	**$ 9.5**		
	Procurement	**$ 686.3**		
	Construction	**$ 1,599.8**		

Versatile Test Reactor (VTR) Project									
Alternative 6 - Lead-Cooled Fast Test Reactor									
			Estimated Cost ($M)	**% of TPC**	Start	Finish	**PV**		**As-Spent**
1.0	**Capital Projects (Total Project Cost)**		6,711.4				**$6,742**	**$**	**10,145**
	1.1	Project Management/Support	555.8	8%	Mar-21	Nov-34	**$554**	**$**	**775**
	1.2	Engineering/Design	1,124.9	17%	Mar-21	Feb-29	**$1,111**	**$**	**1,423**
	1.3	Site Prep/D&D	9.5	0%	Aug-28	Feb-29	**$10**	**$**	**14**
	1.4	Equipment Procurement	686.3	10%	Aug-28	Dec-31	**$691**	**$**	**1,047**
	1.5	Construction/Installation	1,599.8	24%	Feb-29	Dec-33	**$1,617**	**$**	**2,559**
	1.6	Start-up / Commissioning	228.6	3%	Jun-33	Nov-34	**$234**	**$**	**409**
	1.7	Safety Basis Related Costs	56.2	1%	Mar-22	Dec-32	**$56**	**$**	**76**
	1.8	M&O/DOE Oversight/Support Costs	213.1	3%	Mar-22	Nov-34	**$214**	**$**	**315**
	1.9	MR/Contingency	2,237.1	33%	Mar-22	Nov-34	**$2,257**	**$**	**3,529**
2.0	**Operations Costs**			**Parameter**			**$4,504**	**$**	**16,930**
	2.1	Staffing	120.0	$M/Yr	Nov-34	Nov-74	**$2,846**	**$**	**10,496**
	2.2	Other Operations Costs							
	2.2.1	Maintenance	12.0	$M/Yr	Nov-34	Nov-74	**$275**	**$**	**1,033**
	2.2 2	Supplies	6.0	$M/Yr	Nov-34	Nov-74	**$138**	**$**	**517**
	2.2 3	Utility Charges	1.0	$M/Yr	Nov-34	Nov-74	**$23**	**$**	**86**
	2.2.4	Other Direct Costs	12.0	$M/Yr	Nov-34	Nov-74	**$275**	**$**	**1,033**
	2.3	Security Related Costs	10.0	$M/Yr	Nov-34	Nov-74	**$229**	**$**	**861**
	2.4	Periodic Major Upgrades	671.1	$M/each	2 upgrades over life		**$718**	**$**	**2,904**
3.0	**End-of Life D&D (of new facilities)**		60.9	$M	Nov-76	Nov-79	**$42**	**$**	**357**

Alternative 6 Details

The LFR is expected to have a more compact design without intermediate loop
with associated reduced procurement & construction costs
This is offset by added cost due to new primary system material, cladding, coolant and fuel

Net effect of above is there are no differences to Alt. 5 Estimated Cost, except for added engineering cost

Alt. 6 Cost Inputs				
Engineering	40%	Higher to accommodate above "new" issues and R&D efforts		
Site Prep	9.5	same as Alt. 5		
Procurement	686.3	same as Alt. 6		
Construction	1599.8	same as Alt. 7		

Assume Engineering Add above covers Conceptual Design as well as added R&D efforts that would be included in TPC

For High Range Estimate, include added cost to design, construct and operate a Pilot Plant

TPC For Pilot Plant	$ 3,000	M		
Asume 2 years of operations for total of	200	M	As-Spent	PV
Total Add for High Range Capital Cost	**$ 3,200**		3,893	2,815
	Assume centroid out 5 years		1.217	1.137

Versatile Test Reactor (VTR) Project								
Alternative 7 - Molten Salt Fast Test Reactor (MSR)								
			Estimated Cost ($M)	**% of TPC**	Start	Finish	**PV**	**As-Spent**
1.0	**Capital Projects (Total Project Cost)**		7,203.6				**$7,243**	**$ 11,004**
	1.1	Project Management/Support	596.6	8%	Jun-21	Feb-35	**$595**	**$ 834**
	1.2	Engineering/Design	1,264 8	18%	Jun-21	May-29	**$1,251**	**$ 1,633**
	1.3	Site Prep/D&D	9.5	0%	Nov-28	May-29	**$10**	**$ 14**
	1.4	Equipment Procurement	720.4	10%	Nov-28	Mar-32	**$727**	**$ 1,132**
	1.5	Construction/Installation	1,679 2	23%	May-29	Mar-34	**$1,701**	**$ 2,741**
	1.6	Start-up / Commissioning	240 0	3%	Sep-33	Feb-35	**$246**	**$ 437**
	1.7	Safety Basis Related Costs	63 2	1%	Jun-22	Mar-33	**$63**	**$ 86**
	1.8	M&O/DOE Oversight/Support Costs	228.7	3%	Jun-22	Feb-35	**$229**	**$ 339**
	1.9	MR/Contingency	2,401 2	33%	Jun-22	Feb-35	**$2,422**	**$ 3,788**
2.0	**Operations Costs**			**Parameter**			**$4,462**	**$ 16,798**
	2.1	Staffing	120 0	$M/Yr	Feb-35	Feb-75	**$2,784**	**$ 10,193**
	2.2	Other Operations Costs						
	2.2.1	Maintenance	12 0	$M/Yr	Feb-35	Feb-75	**$269**	**$ 1,003**
	2.2.2	Supplies	6 0	$M/Yr	Feb-35	Feb-75	**$135**	**$ 501**
	2.2.3	Utility Charges	1 0	$M/Yr	Feb-35	Feb-75	**$22**	**$ 84**
	2.2.4	Other Direct Costs	12 0	$M/Yr	Feb-35	Feb-75	**$269**	**$ 1,003**
	2.3	Security Related Costs	10 0	$M/Yr	Feb-35	Feb-75	**$224**	**$ 836**
	2.4	Periodic Major Upgrades	720.4	$M/each	2 upgrades over life		**$758**	**$ 3,179**
3.0	**End-of Life D&D (of new facilities)**		60 9	$M	Feb-77	Feb-80	**$42**	**$ 357**

Alternative 7 Details

The MSR is expected to have a similar scope and estimated cost as the SFR, but higher contingency applied due to technical maturity

Also, added costs related to online fuel process system and waste stream 5% higher than Alternative 5

Alt. 7 Cost Inputs					
Engineering	50%	Higher to accommodate above "new" issues and R&D efforts			
Site Prep	**9.5**	same as Alt. 5			
Procurement					
Reactor	714.9	5% higher			
PIDAS	5.4	same as Alt. 5			
	720.4				
Construction					
Reactor	1668.2	5% higher			
PIDAS	11.1	same as Alt. 5			
Support Facilities	0.0	same as Alt. 5			
	1679.2				

Assume Engineering Add above covers Conceptual Design as well as added R&D efforts that would be included in TPC

For High Range Estimate, include added cost to design, construct and operate a Pilot Plant

TPC For Pilot Plant	$ 3,000	M		
Asume 2 years of operations for total of	200	M	As-Spent	PV
Total Add for High Range Capital Cost	**$ 3,200**		3,893	2,815
	Assume centroid out 5 years		1.217	1.137

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APPENDIX F SCHEDULE ESTIMATES AND BASIS

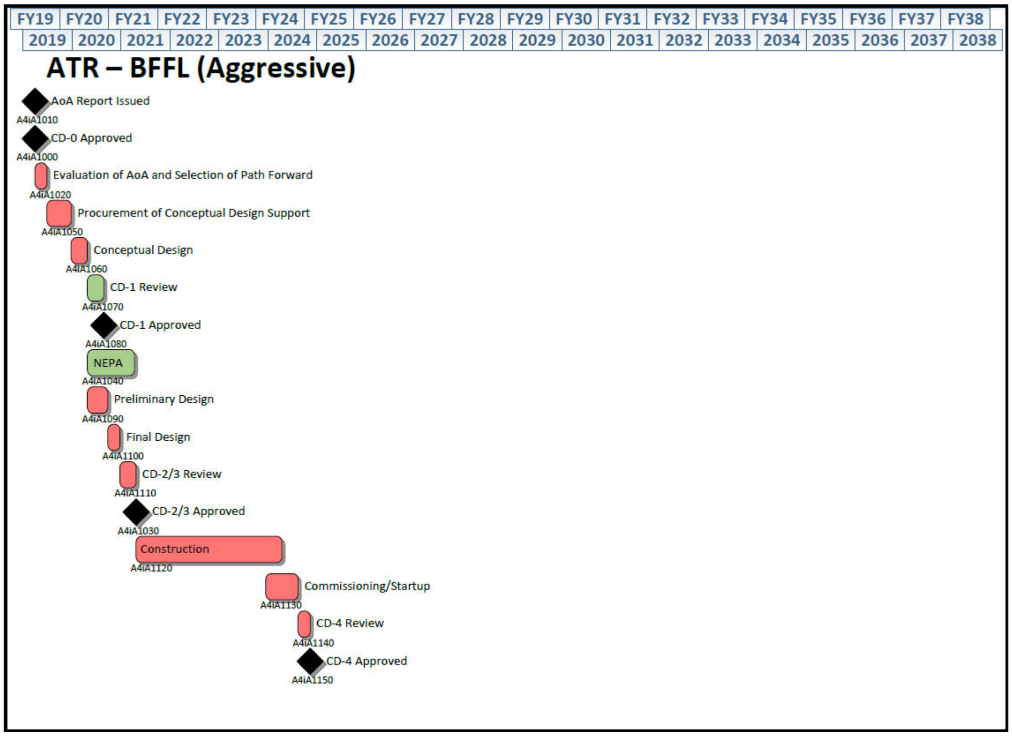

Figure F-1. Alternative 2 – ATR BFFL Aggressive Schedule

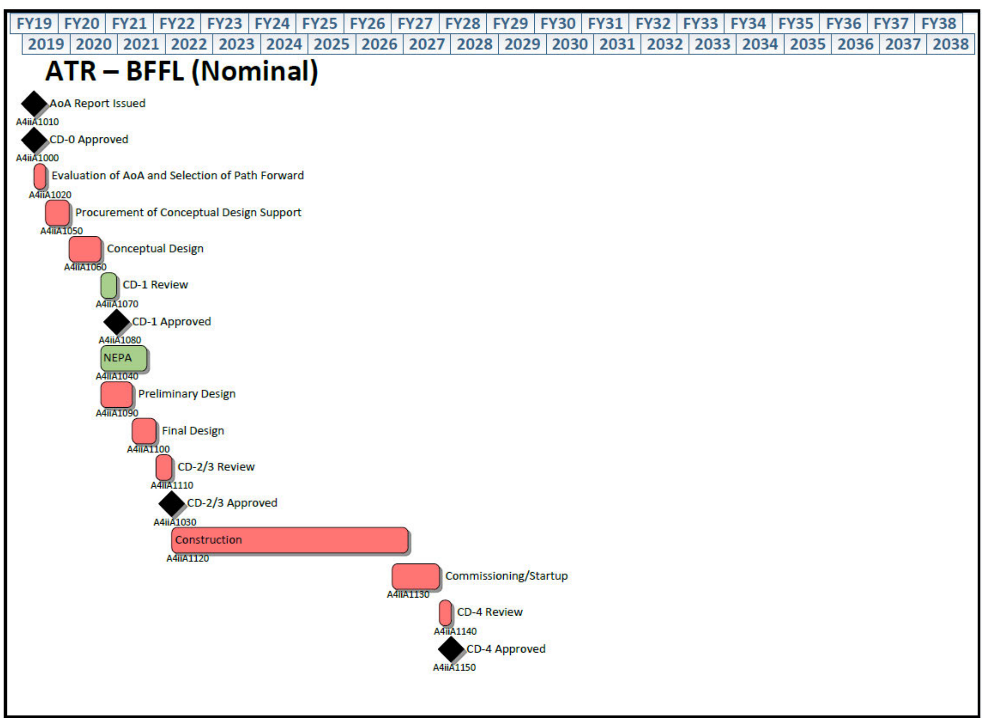

Figure F-2. Alternative 2 – ATR BFFL Nominal Schedule

Table F-1. Alternative 2 – ATR BFFL Schedule Basis

		Nominal		Aggressive	
Activity ID	**Description**	**Duration (m)**	**Basis / Assumptions**	**Duration (m)**	**Basis / Assumptions**
A4A1020	Evaluation of AoA and Selection of Path Forward	3	Assumed 3 months.	3	Same as nominal.
A4A1040	NEPA	12	Assume that the ATR BFFL only requires an EA, not an EIS. Assume 12 months and that this activity is not on critical path.	12	Same as nominal.
A4A1050	Procurements of Conceptual Design Support	6	Assumed that BEA will be contracted to design the upgrades. Assumed 6 months.	6	Same as nominal.
A4A1060	Conceptual Design	8	The "Boosted Fast Flux Loop Final Report" (September 2009) said that the overall duration was 7 years. Assumed that the total design effort is 22 months.	4	Assumed Conceptual Design can be accelerated 4 months. This assumption is made to conform to a minimum design cycle of 12 months.
A4A1070	CD-1 Review	4	Assumed 2 months faster than SFTR due to due to relatively reduced project complexity. Assumed that this activity is not on critical path.	4	Same as nominal.
A4A1090	Preliminary Design	8	See note under "Conceptual Design".	5	Assumed Preliminary Design can be accelerated 3 months. This assumption is made to conform to a minimum design cycle of 12 months.
A4A1100	Final Design	6	See note under "Conceptual Design".	3	Assumed Final Design can be accelerated 3 months. This assumption is made to conform to a minimum design cycle of 12 months.
A4A1110	CD-2/3 Review	4	Assumed 2 months faster than SFTR due to relatively reduced project complexity.	4	Same as nominal.
A4A1120	Construction	60	The "Boosted Fast Flux Loop Final Report" (September 2009) said that the overall duration was 7 years. 5 years assumed to be construction.	36	Assume Construction can be accelerated 2 years.
A4A1130	Commissioning/ Startup	12	Assumed 12 months.	8	Assumed Commissioning/Startup can be accelerated 4 months.
A4A1140	CD-4 Review	3	Assumed 3 months.	3	Same as nominal.

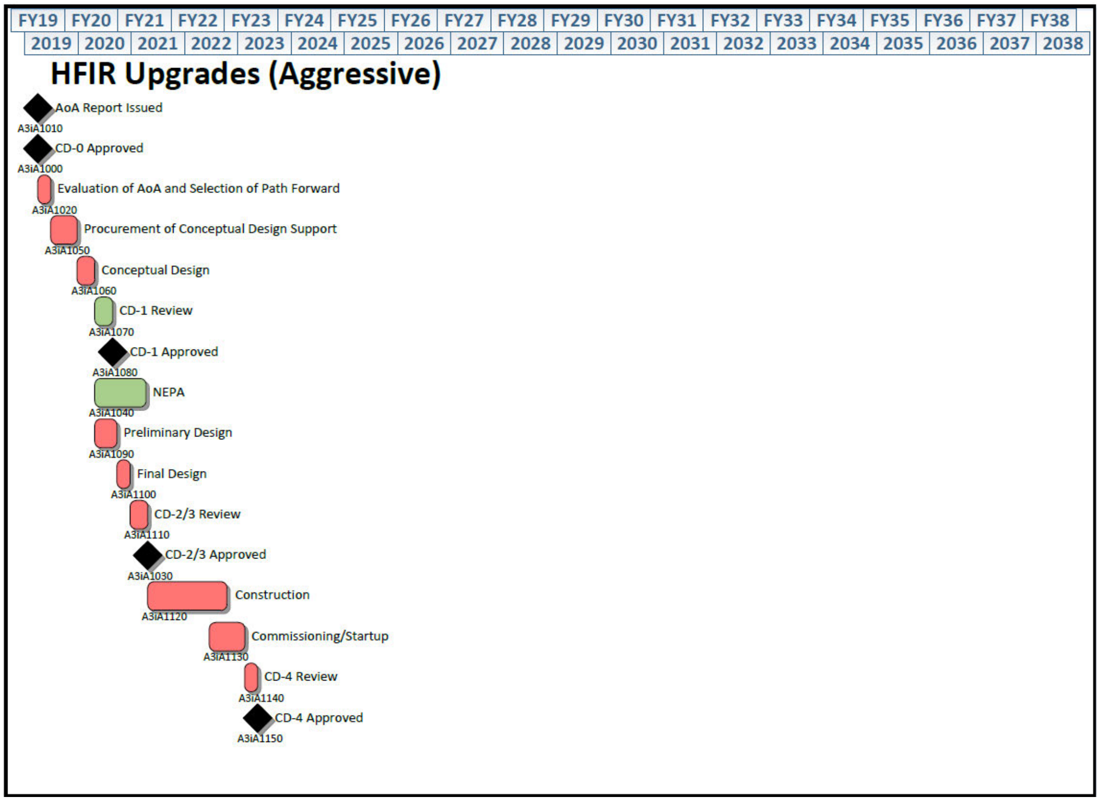

Figure F-3. Alternative 3 – HFIR Upgrades Aggressive Schedule

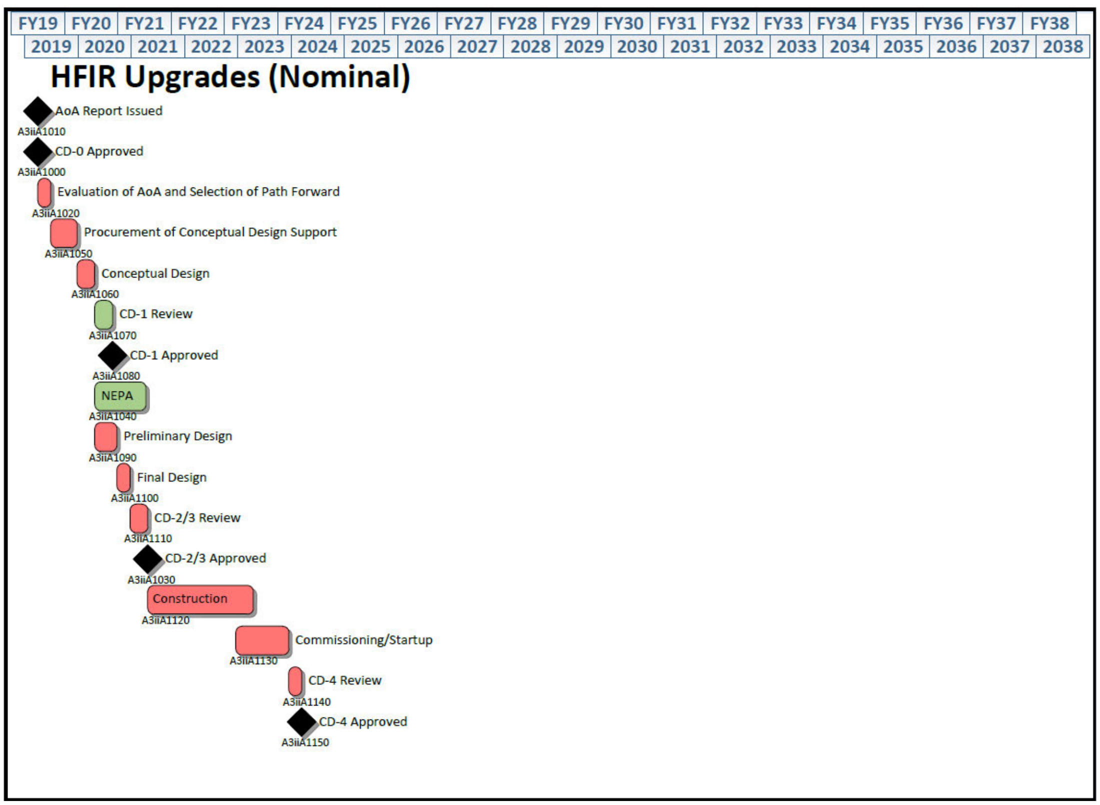

Figure F-4. Alternative 3 – HFIR Upgrades Nominal Schedule

Table F-2. Alternative 3 – HFIR Upgrades Schedule Basis

		Nominal		Aggressive	
Activity ID	**Description**	**Duration (m)**	**Basis / Assumptions**	**Duration (m)**	**Basis / Assumptions**
A3A1020	Evaluation of AoA and Selection of Path Forward	3	Assumed 3 months.	3	Same as nominal.
A3A1040	NEPA	12	Assume that the HFIR Upgrades only require an EA, not an EIS. Assume 12 months and that this activity is not on critical path.	12	Same as nominal.
A3A1050	Procurements of Conceptual Design Support	6	Assumed 6 months.	6	Same as nominal.
A3A1060	Conceptual Design	4	Conceptual, Preliminary, and Final design are given assumed portions of a 12 month minimum design cycle.	4	Same as nominal.
A3A1070	CD-1 Review	4	Assumed 2 months faster than SFTR due to due to relatively reduced project complexity. Assumed that this activity is not on critical path.	4	Same as nominal.
A3A1090	Preliminary Design	5	Conceptual, Preliminary, and Final design are given assumed portions of a 12 month minimum design cycle.	5	Same as nominal.
A3A1100	Final Design	3	Conceptual, Preliminary, and Final design are given assumed portions of a 12 month minimum design cycle.	3	Same as nominal.
A3A1110	CD-2/3 Review	4	Assumed 2 months faster than SFTR due to due to relatively reduced project complexity.	4	Same as nominal.
A3A1120	Construction	24	2007 Presentation from ORNL estimate of 18-24 months.	18	2007 Presentation from ORNL estimate of 18-24 months.
A3A1130	Commissioning/ Startup	12	Assumed 12 months	8	Assumed Commissioning/Startup can be accelerated 4 months.
A3A1140	CD-4 Review	3	Assumed 3 months.	3	Same as nominal.

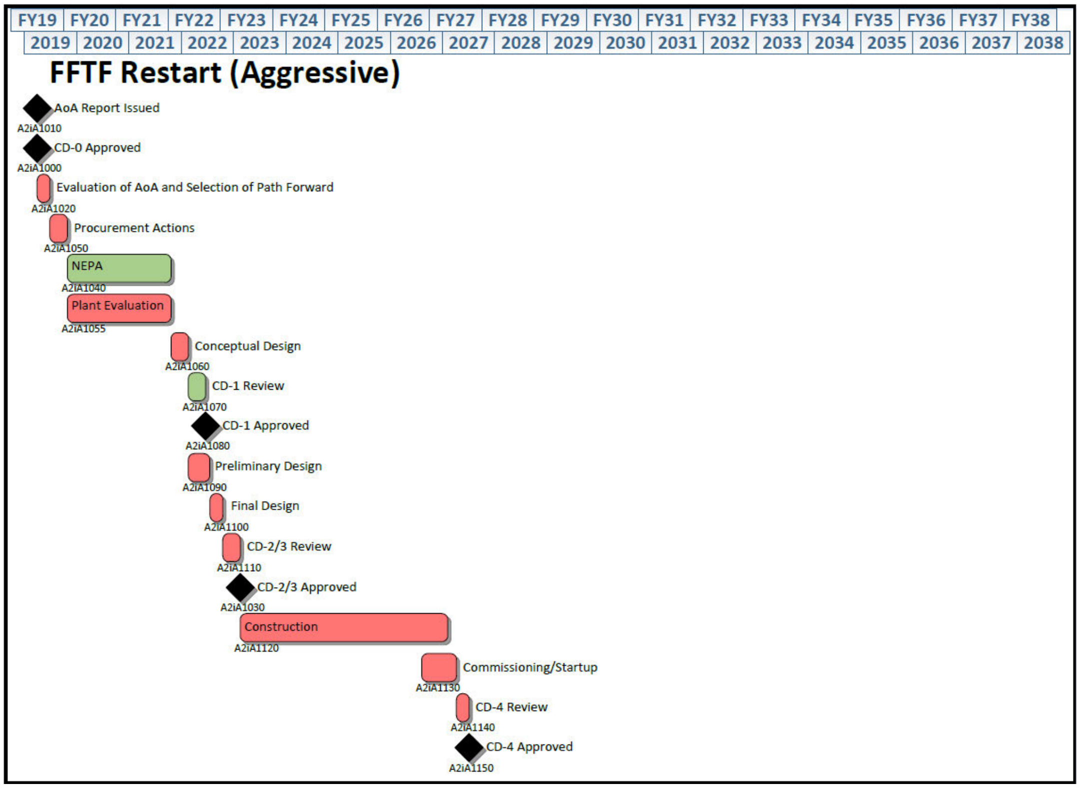

Figure F-5. Alternative 4 – FFTF Restart Aggressive Schedule

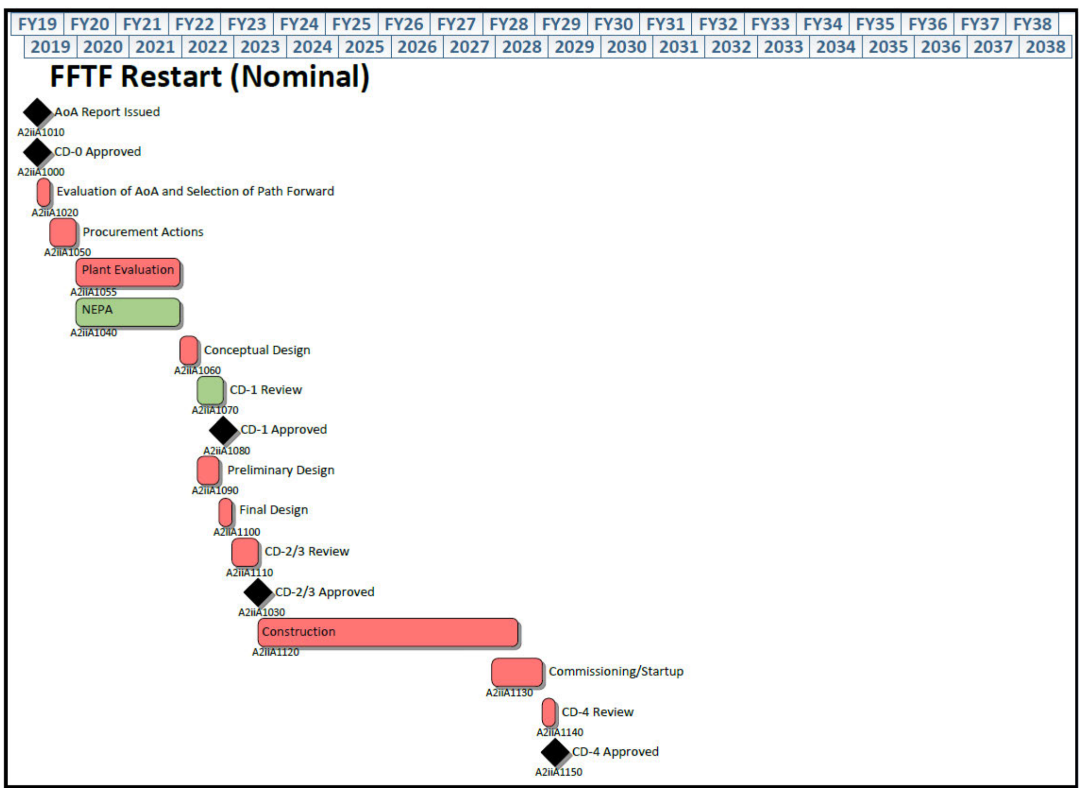

Figure F-6. Alternative 4 – FFTF Restart Nominal Schedule

Table F-3. Alternative 4 – FFTF Restart Schedule Basis

		Nominal		Aggressive	
Activity ID	**Description**	**Duration (m)**	**Basis / Assumptions**	**Duration (m)**	**Basis / Assumptions**
A2A1020	Evaluation of AoA and Selection of Path Forward	3	Assumed 3 months.	3	Same as nominal.
A2A1040	NEPA	24	Assumed 24 months.	24	Same as nominal.
A2A1050	Procurement Actions	6	Assumed 6 months.	4	Assumed Procurement Actions can be accelerated 2 months.
A2A1055	Plant Evaluation	24	Assumed that two additional years are required for plant evaluation due to the relatively large number of unknowns regarding the plant's current condition.	24	Same as nominal.
A2A1060	Conceptual Design	4	Conceptual Design duration is proportional to SFTR Conceptual Design duration. Proportion is based on the "Engineering/ Design" proportion between SFTR and FFTF costs in the associated cost estimate.	4	Same as nominal.
A2A1070	CD-1 Review	6	Assumed 6 months	4	Assumed CD-1 Review can be accelerated by 2 months if review process is prioritized.
A2A1090	Preliminary Design	5	Preliminary Design duration is proportional to SFTR Preliminary Design duration. Proportion is based on the "Engineering/Design" proportion between SFTR and FFTF costs in the associated cost estimate.	5	Same as nominal.
A2A1100	Final Design	3	Final Design duration is proportional to SFTR Final Design duration. Proportion is based on the "Engineering/Design" proportion between SFTR and FFTF costs in the associated cost estimate.	3	Same as nominal.
A2A1110	CD-2/3 Review	6	Assumed 6 months. Assumed to lag behind completion of NEPA by 1 month.	4	Assumed CD-2/3 Review can be accelerated by 2 months if review process is prioritized.
A2A1120	Construction	60	Assumed construction can potentially take an additional 12 months.	48	4 Years based on the 04/29/07 Schedule from the "FFTF-GNEP-Report-FINAL-091027-2017".
A2A1130	Commissioning/ Startup	12	Assumed 12 months.	8	Assumed Commissioning/Startup can be accelerated 4 months.
A2A1140	CD-4 Review	3	Assumed 3 months.	3	Same as nominal.

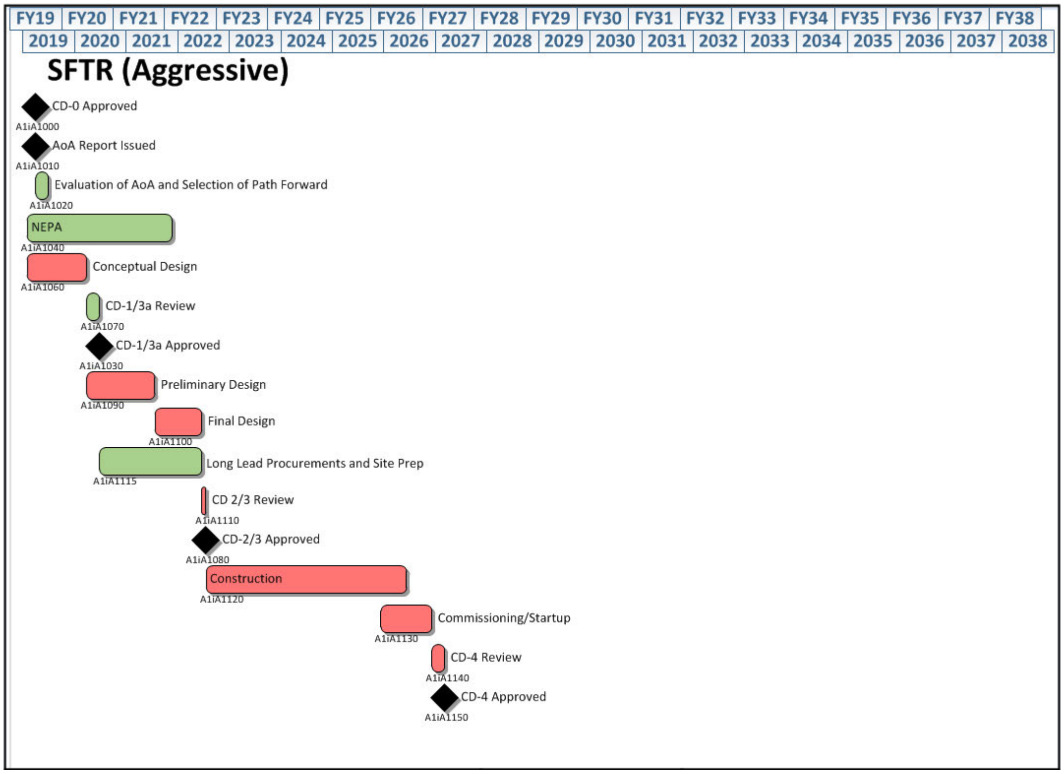

Figure F-7. Alternative 5 – SFTR Aggressive Schedule

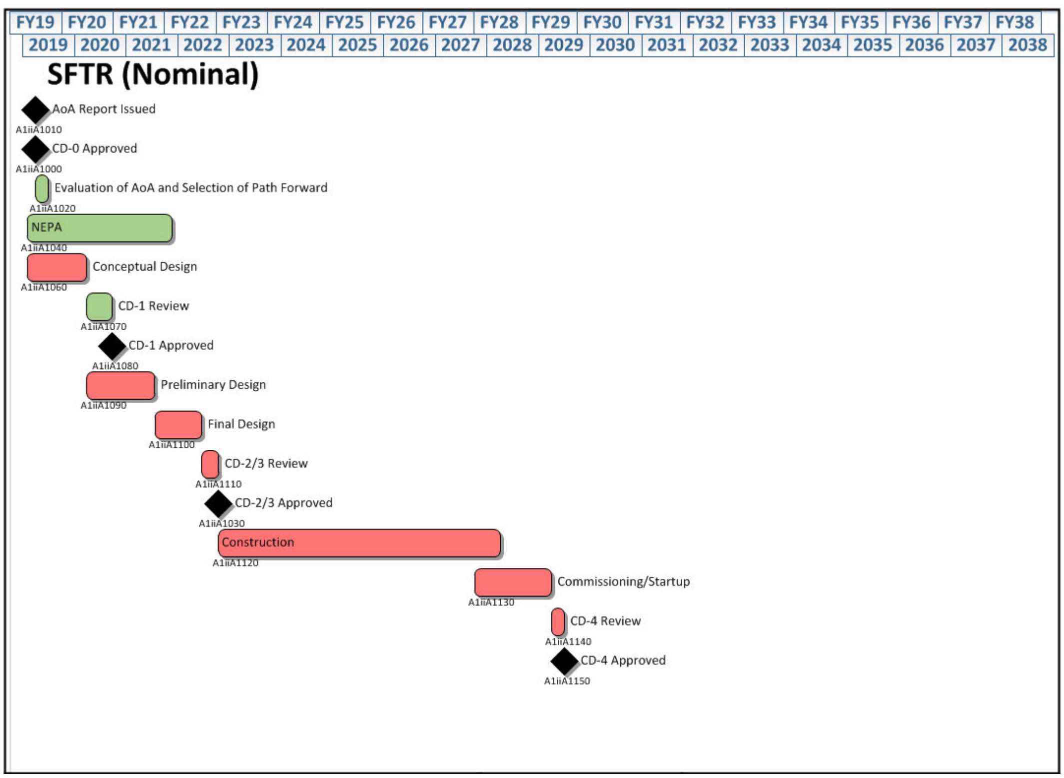

Figure F-8. Alternative 5 – SFTR Nominal Schedule

Table F-4. Alternative 5 – SFTR Schedule Basis

		Nominal		Aggressive	
Activity ID	**Description**	**Duration(m)**	**Basis / Assumptions**	**Duration (m)**	**Basis / Assumptions**
A1A1020	Evaluation of AoA and Selection of Path Forward	3	Assumed 3 months.	3	Same as nominal.
A1A1040	NEPA	32	Same as aggressive.	32	Based on "DRAFT Versatile Test Reactor Schedule" received Feb 21st, 2019.
A1A1060	Conceptual Design	12	Same as aggressive.	12	Current schedule duration of scope already contracted with GE Hitachi.
A1A1070	CD-1 Review	6	Assumed that CD-1 review is extended by 3 months.	3	CD 1/3a Review. Based on review steps in "DRAFT Versatile Test Reactor Schedule" received Feb 21st, 2019.
A1A1090	Preliminary Design	16	Same as aggressive.	16	Cumulative duration between CD1/3a approval and CD 2/3 review based on Activity ID 347 in "DRAFT Versatile Test Reactor Schedule" received Feb 21st, 2019. Critical path activities between these milestones are assumed to be durations that sum to this cumulative duration.
A1A1100	Final Design	11	Same as aggressive.	11	See "Preliminary Design", as Final design is critical path between CD-1/3a approval and CD-2/3 review.
A1A1110	CD-2/3 Review	4	Assumed that CD-2/3 review is extended by 3 months.	1	Based on Activity ID 350 in "DRAFT Versatile Test Reactor Schedule" received Feb 21st, 2019.
A1A1115	Long Lead Procurements and Site Prep	N/A	N/A	24	Based on the period of Activity ID 347 in "DRAFT Versatile Test Reactor Schedule" received Feb 21st, 2019 taking place between CD 1/3a Review and CD 2/3 Review.
A1A1120	Construction	66	Assumed construction will be extended 13 months due to a lack of a long lead procurement process and an additional 6 months due to a less aggressive construction schedule.	47	Based on Activity ID 353 in "DRAFT Versatile Test Reactor Schedule" received Feb 21st, 2019.
A1A1130	Commissioning/ Startup	18	Assumed 18 months.	12	Assumed Commissioning/Startup can be accelerated 6 months.
A1A1140	CD-4 Review	3	Assumed 3 months.	3	Same as nominal.

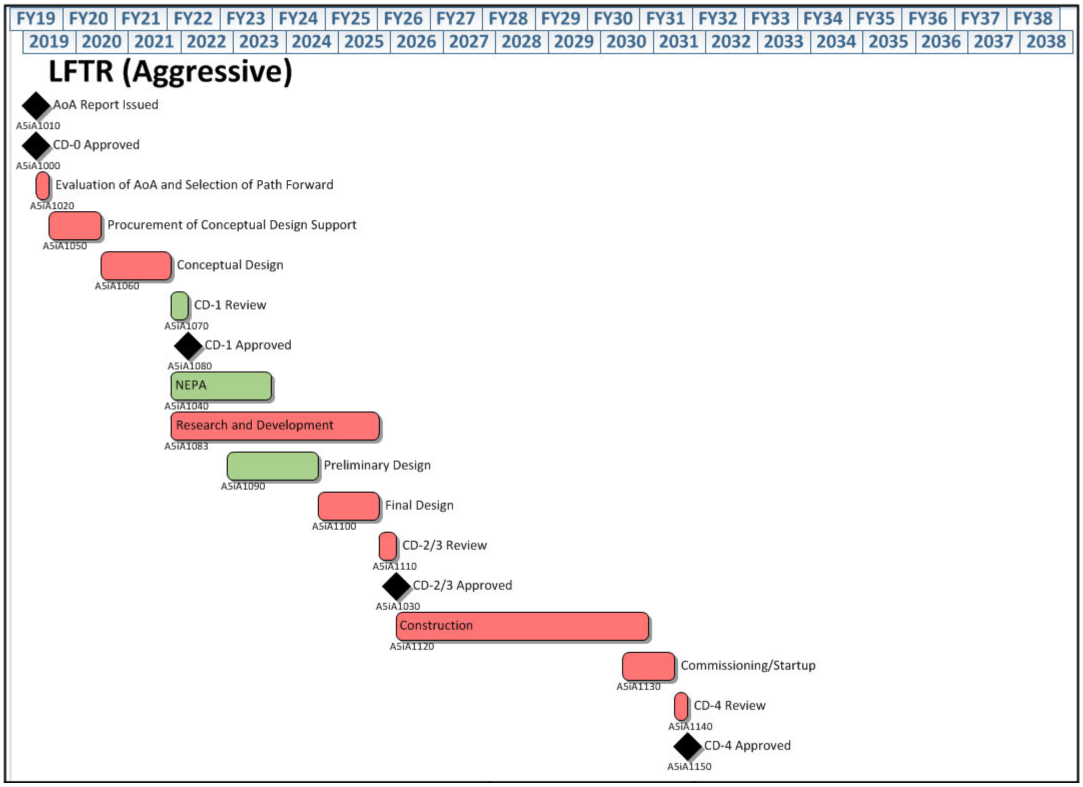

Figure F-9. Alternative 6 – LFTR Aggressive Schedule

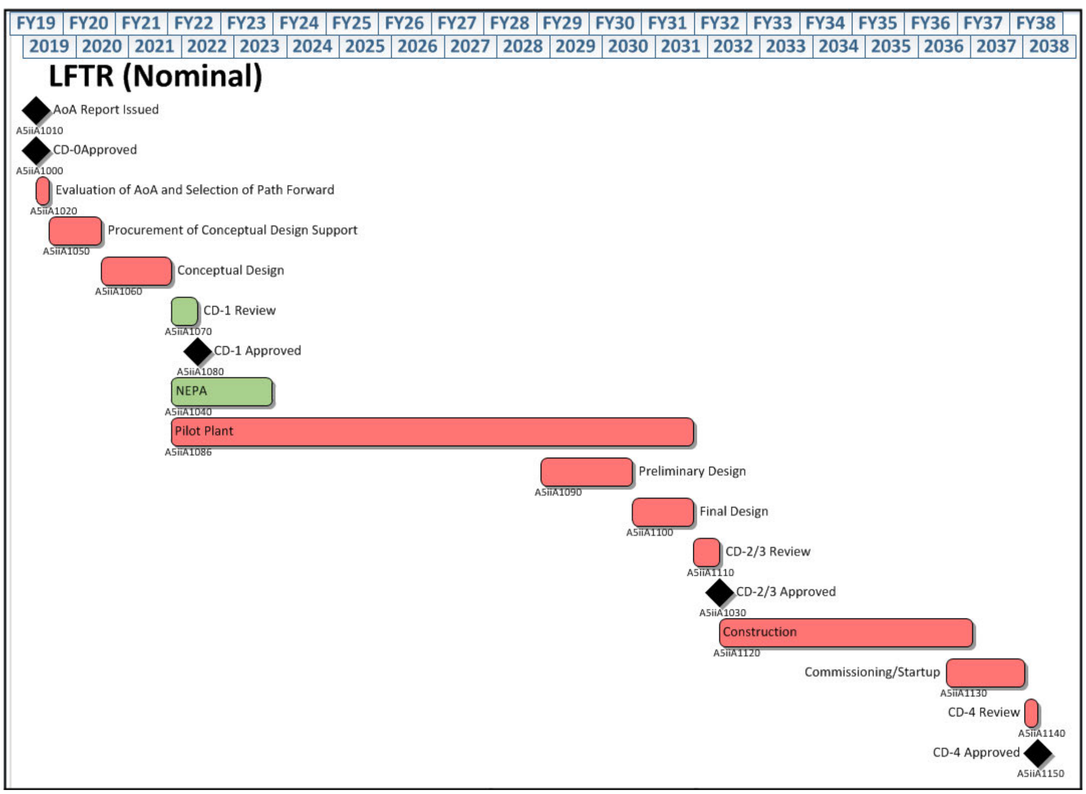

Figure F-10. Alternative 6 – LFTR Nominal Schedule

Table F-5. Alternative 6 – LFTR Schedule Basis

		Nominal		Aggressive	
Activity ID	**Description**	**Duration (m)**	**Basis / Assumptions**	**Duration (m)**	**Basis / Assumptions**
A5A1020	Evaluation of AoA and Selection of Path Forward	3	Assumed 3 months.	3	Same as nominal.
A5A1040	NEPA	24	Assumed 24 months.	24	Same as nominal.
A5A1050	Procurements of Conceptual Design Support	12	Assumed 12 months.	12	Same as nominal.
A5A1060	Conceptual Design	16	Conceptual Design duration is proportional to SFTR Conceptual Design duration. Proportion is based on the "Engineering/Design" proportion between SFTR and LFTR costs in the associated cost estimate.	16	Same as nominal.
A5A1070	CD-1 Review	6	Assumed 6 months	4	Assumed CD-1 Review can be accelerated by 2 months if review process is prioritized.
A5A1083	Research and Development	N/A	Assumes that the pilot plant phase would account for all Research and Development activities.	48	Assumed 48 months.
A5A1086	Pilot Plant	120	Assumed 120 months (10 years) based on engineering judgment for the effort required to design, startup, and operate a pilot plant for several years.	N/A	Assumes that on an aggressive schedule, there would be a way to design the reactor such that a Pilot Plant would not be required.
A5A1090	Preliminary Design	21	Preliminary Design duration is proportional to SFTR Preliminary Design duration. Proportion is based on the "Engineering/Design" proportion between SFTR and LFTR costs in the associated cost estimate.	21	Same as nominal.
A5A1100	Final Design	14	Final Design duration is proportional to SFTR Final Design duration. Proportion is based on the "Engineering/Design" proportion between SFTR and LFTR costs in the associated cost estimate.	14	Same as nominal.
A5A1110	CD-2/3 Review	6	Assumed 6 months.	4	Assumed CD-2/3 Review can be accelerated 2 months.
A5A1120	Construction	60	Assumed 60 months.	60	Same as nominal.
A5A1130	Commissioning/ Startup	18	Assumed 18 months.	12	Assumed Commissioning/Startup can be accelerated 6 months.
A5A1140	CD-4 Review	3	Assumed 3 months.	3	Same as nominal.

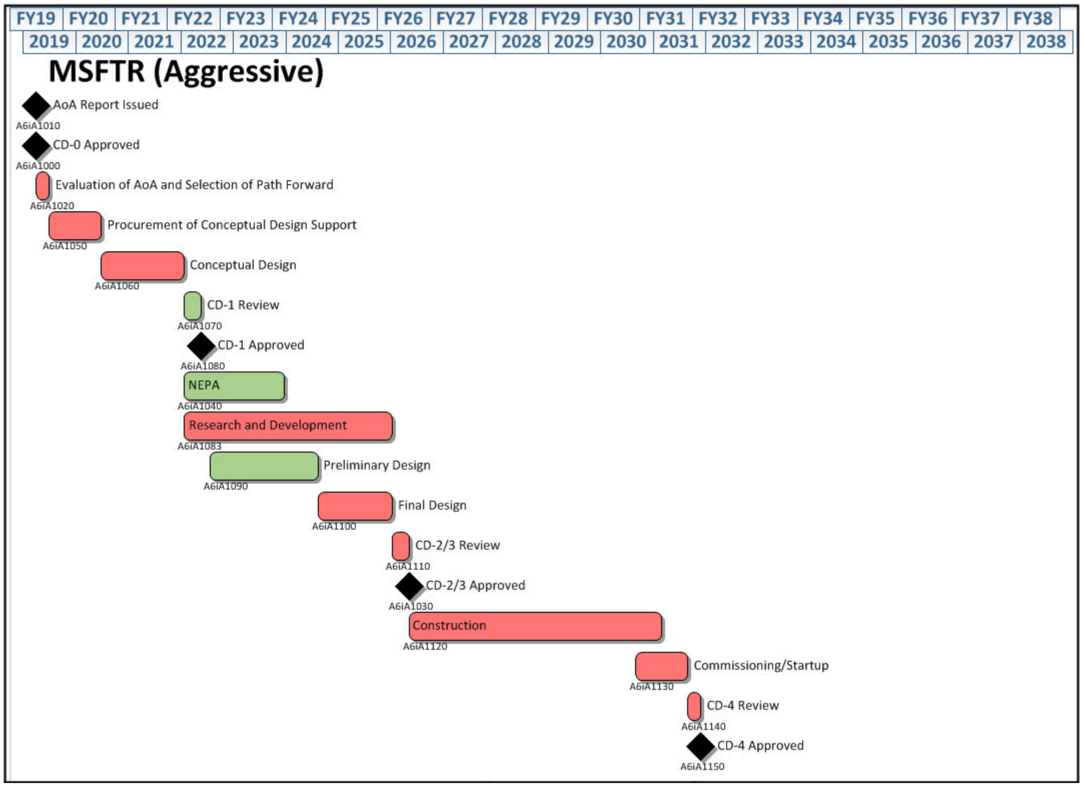

Figure F-11. Alternative 7 – MSFTR Aggressive Schedule

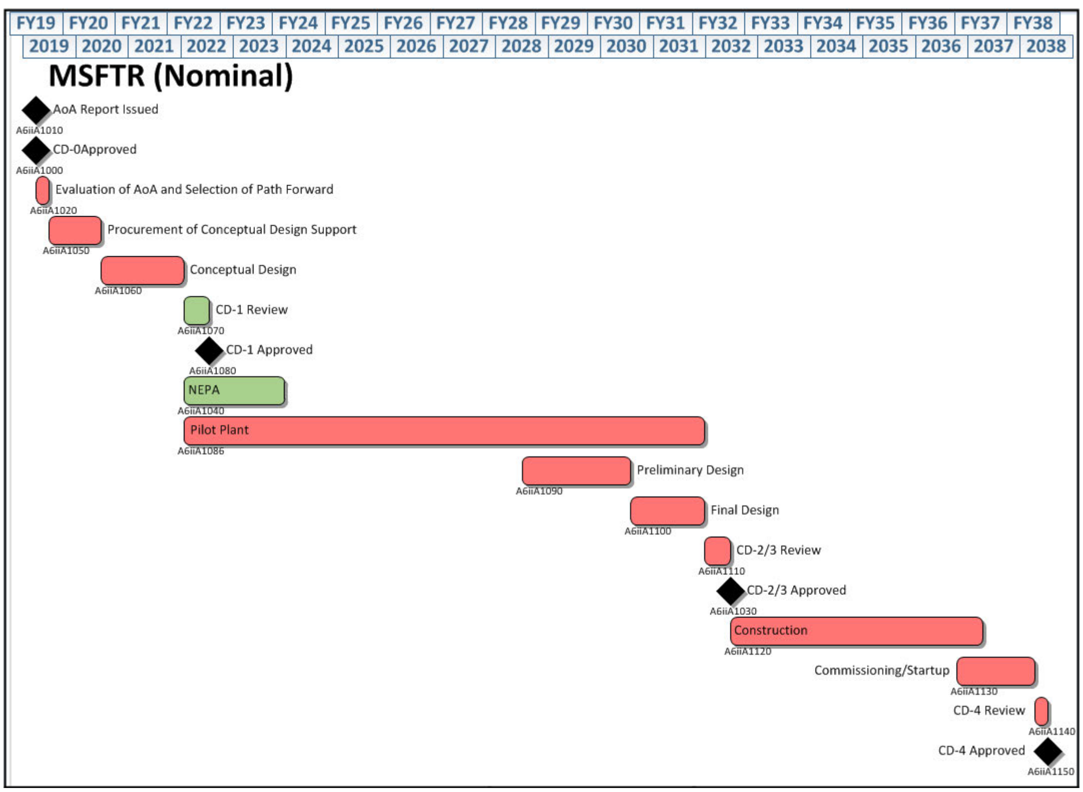

Figure F-12. Alternative 7 – MSFTR Nominal Schedule

Table F-6. Alternative 7 – MSFTR Schedule Basis

		Nominal		Aggressive	
Activity ID	**Description**	**Duration (m)**	**Basis / Assumptions**	**Duration (m)**	**Basis / Assumptions**
A6A1020	Evaluation of AoA and Selection of Path Forward	3	Assumed 3 months.	3	Same as nominal.
A6A1040	NEPA	24	Assumed 24 months.	24	Same as nominal.
A6A1050	Procurements of Conceptual Design Support	12	Assumed 12 months.	12	Same as nominal.
A6A1060	Conceptual Design	19	Conceptual Design duration is proportional to SFTR Conceptual Design duration. Proportion is based on the "Engineering/Design" proportion between SFTR and MFTR costs in the associated cost estimate.	19	Same as nominal.
A6A1070	CD-1 Review	6	Assumed 6 months	4	Assumed CD-1 Review can be accelerated by 2 months if review process is prioritized.
A6A1083	Research and Development	N/A	Assumes that the pilot plant phase would account for all Research and Development activities.	48	Assumed 48 months.
A6A1086	Pilot Plant	120	Assumed 120 months (10 years) based on engineering judgment for the effort required to design, startup, and operate a pilot plant for several years.	N/A	Assumes that on an aggressive schedule, there would be a way to design the reactor such that a Pilot Plant would not be required.
A6A1090	Preliminary Design	25	Preliminary Design duration is proportional to SFTR Preliminary Design duration. Proportion is based on the "Engineering/Design" proportion between SFTR and MFTR costs in the associated cost estimate.	25	Same as nominal.
A6A1100	Final Design	17	Final Design duration is proportional to SFTR Final Design duration. Proportion is based on the "Engineering/Design" proportion between SFTR and MFTR costs in the associated cost estimate.	17	Same as nominal.
A6A1110	CD-2/3 Review	6	Assumed 6 months.	4	Assumed CD-2/3 Review can be accelerated 2 months.
A6A1120	Construction	60	Assumed 60 months.	60	Same as nominal.
A6A1130	Commissioning/ Startup	18	Assumed 18 months.	12	Assumed Commissioning/Startup can be accelerated 6 months.
A6A1140	CD-4 Review	3	Assumed 3 months.	3	Same as nominal.

APPENDIX G DETAILS OF RISK ANALYSIS

Table G-1. Detail Risk Descriptions

Risk No.	Brief Title	Detailed Description
T-1	Inability to establish sufficient operating workforce of cleared, trained personnel having relevant experience with the technology delays design and operations.	This risk addresses the availability of individuals with the appropriate technological expertise that can be cleared and trained in a timely manner to support overall project design and operations.
T-2	Available funding delays the project start/completion.	This risk addresses actions that delay funding, such as congressional budget actions, changes to DOE/NE priorities, and OMB reviews that consequently adversely impact project completion. (Higher total or annual cost and longer schedule incur more risk.
T-3	Design Basis Threat changes impact facility design, construction, and operations.	This risk addresses unplanned revisions to DOE safeguards and security requirements, as reflected in the Design Basis Threat, that impact facility design, construction, and operations.
T-4	Environmental/NEPA reviews delay project implementation.	This risk addresses unplanned assessments that delay construction and adversely impact planned project performance (i.e., cost and schedule).
T-5	Project accidents during construction delay project completion.	This risk addresses the propensity of certain construction activities to be associated with greater worker exposure to accidents. It focuses on the relative probability and expected consequences of worker accidents based on the type of construction activity (i.e., worker accident impacts with new construction versus re-purposing/re-modelling/renovating existing construction).
T-6	Community or other stakeholders' concerns, lawsuits, and/or other legal proceedings delay project start.	This risk addresses concerns of the surrounding populace, including residents and stakeholders, about their proximity to a test reactor that may result in legal actions, such as suits, and/or litigation consequently delaying project start/completion.
T-7	Labor disputes lead to work slowdowns or stoppages delaying construction and operations.	This risk addresses known, or potential labor-related issues or labor disputes based on emerging issues leading to work slowdowns or stoppages delaying operations.
T-8	Construction materials or equipment availability delays project or adds costs.	The difference between new construction and remodeling construction materials and equipment availability, and the associated methods and means, adds costs and delays project completion. This risk addresses the relative idiosyncrasies associated with procurement of materials and equipment associated with new construction versus modifications to existing facilities delaying project completion.
T-9	Program requirements change impacting cost and schedule.	This risk addresses unforeseen changes to nuclear material, reactor requirements, or other program changes causing delays to project completion. It focuses on changes to reactor capability or performance requirements and type and mix of nuclear material that delays project completion.
T-10	Facility degradation results in premature mission failure.	This risk addresses the degradation of existing facilities that consequently may not adequately support mission needs for the 40-year life requirement.
T-11	Changes to safety requirements require project re-design.	This risk addresses unplanned or unforeseen changes to safety requirements that result in project re-design, impacting cost and schedule.
T-12	External event impacts VTR Project construction or operations.	This risk addresses on-site, off-project events impacting VTR Project construction or operations.
T-13	Nuclear material quantity changes facility mission, thereby impacting cost and schedule.	This risk addresses the possibility that the addition of certain nuclear material might adversely impact the mission or the installation, causing delays, and therefore costs.
T-14	Additional space requirements for certain material delay project design and execution.	This risk addresses the possibility that the addition of certain nuclear material requires unforeseen changes in the design or execution of the project, causing delays, and therefore costs.

Table G-1. Detail Risk Descriptions

Risk No.	Brief Title	Detailed Description
T-15	IAEA requirements impact design and delays project start with additional impacts on operations.	This risk addresses the possibility that the addition of IAEA safeguards might require unforeseen changes in the design or execution of the project, causing delays, and therefore costs.
T-16	Project design issues during work (construction/modifications/repairs) result in more work than planned causing cost increases and schedule delays.	This risk addresses the possibility that additional design work is needed during the construction process (compared to planned work). This applies to all new construction and to alternatives that involve modifications to existing facilities (e.g., upgrades that would require significant design).
T-17	Facility design has greater potential for containment failure.	This risk addresses the possibility for containment system failure. It focuses on the relative propensity for containment system failure among existing, modified or new construction.
T-18	Ability to develop technology within planned schedule.	This risk addresses the possibility of technology development requiring longer than anticipated, consequently impacting cost and schedule.
T-19	Weather events cause delays that impact construction.	This risk addresses the specific difference in usual and unusual weather conditions that would impact the number of days outdoor construction can or cannot be performed. It focuses on weather events, considering geographic or regional environmental conditions, that could cause delays impacting outdoor construction activities.
T-20	Inability to acquire sufficient workforce delays construction.	This risk addresses construction delays attributable to availability of specific craft workers. It focuses on the inability to acquire sufficient workforce due to the availability of specific craft workers.
T-21	Ongoing site operations delay project completion.	This risk addresses ongoing normal site operations interfering with project progress, consequently delaying project completion. It focuses on the impact of performing normal on-site operations amidst construction activities.
T-22	Security requirements delay project completion.	This risk addresses the impact that adherence to certain security requirements delay project construction based on location or other relevant factors. It focuses on specific requirements that may impact construction for reasons specific to the site location or other reasons.
T-23	Unforeseen site or existing facility conditions delay or add to construction work.	This risk addresses unforeseen site or existing facility-specific conditions, such as below-ground contamination, hazards, utilities, artifacts of historical significance, and unknown conditions (e.g., status of control system) delaying project completion.
T-24	Uncertainty in site planning delays project implementation.	This risk addresses the possibility of political or programmatic decisions surfacing that impact project implementation. It focuses on unknown planned use for specific areas at DOE sites.
T-25	Longevity of agreements impact continued operations.	The risk addresses facility use subject to longevity of agreements that may be changed or withdrawn in the future, thereby impacting continued operations. It focuses on the availability of a facility for uninterrupted occupancy over time that may be withdrawn.
T-26	Existing facilities require more work than planned to meet applicable codes and standards impacting cost and schedule.	This risk addresses the possibility that certain facilities (i.e., existing versus new) require more work than planned to meet applicable codes and standards. This risk focuses on the potential for additional unforeseen work on alternatives that involve modifications to existing facilities.
T-27	Inability to establish staff for performing post-irradiation examination (PIE) of fuels, materials and detectors.	This risk addresses the availability of individuals with fuels, materials, and detectors analysis [(post-irradiation examination (PIE)] expertise to support project operations.
T-28	Onsite operations interfere with VTR operations.	This risk addresses the possibility that on-gong sitewide operations impact the schedule to start operations.

Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative						
		Status Quo	**ATR**	**HFIR**	**FFTF**	**SFTR**	**LFTR**	**MSFTR**
T-1	Inability to establish sufficient operating workforce of cleared, trained personnel having relevant experience with the technology delays design and operations.	1	1	1	1	1	3	3
	Rationale	Unlikely and minimal impact; no staffing concerns.	Unlikely and minimal impact; no staffing concerns.	Unlikely and minimal impact; no staffing concerns.	Unlikely and minimal impact; no staffing concerns.	Unlikely and minimal impact; no staffing concerns.	Moderate risk and marginal impact due to delays and difficulties acquiring staff and training on new technology.	Moderate risk and marginal impact due to delays and difficulties acquiring staff and training on new technology.
	Mitigation Handling Strategy						Mitigate. Perform training and implement early hiring practices to develop pipeline of competent personnel and seek to acquire staff from closest comparable projects that are near completion.	Mitigate. Perform training and implement early hiring practices to develop pipeline of competent personnel and seek to acquire staff from closest comparable projects that are near completion.
T-2	Available funding delays the project start/completion.	1	1	1	3	5	5	5
	Rationale	Unlikely due to national security need, lower cost and shorter schedule.	Unlikely due to national security need, lower cost and shorter schedule.	Unlikely due to national security need, lower cost and shorter schedule.	Moderate likelihood and impact due to amount to be funded and work to be completed. The anticipated work and associated cost exceeds other existing facilities, but is less than any new build.	Higher threat due to level of annual funding required to support project schedule. Total and annual cost of new build exceeds existing facility alternatives.	Higher threat due to level of annual funding required to support project schedule. Total and annual cost of new build exceeds existing facility alternatives.	Higher threat due to level of annual funding required to support project schedule. Total and annual cost of new build exceeds existing facility alternatives.
	Handling Strategy				Mitigate. Obtain funding for facility assessment to demonstrate its cost-effectiveness.	Mitigate. Break up project into smaller subprojects that are more likely to receive approval and funding. Ensure project remains on schedule to receive continued congressional support.	Mitigate. Break up project into smaller subprojects that are more likely to receive approval and funding. Evaluate options to extend schedule in order to implement political activities to obtain needed high annual funding.	Mitigate. Break up project into smaller subprojects that are more likely to receive approval and funding. Evaluate options to extend schedule in order to implement political activities to obtain needed high annual funding.

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Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative						
		Status Quo	ATR	HFIR	FFTF	SFTR	LFTR	MSFTR
T-3	Design Basis Threat changes impact facility design, construction, and operations.	1	1	1	1	1	1	1
	Rationale	Unlikely and minimal impact due to anticipated grace period for implementation.	Unlikely and minimal impact due to anticipated grace period for implementation.	Unlikely and minimal impact due to anticipated grace period for implementation.	Unlikely and minimal impact due to anticipated grace period for implementation.	Unlikely and minimal impact due to anticipated grace period for implementation.	Unlikely and minimal impact due to anticipated grace period for implementation.	Unlikely and minimal impact due to anticipated grace period for implementation.
	Mitigation Handling Strategy		Mitigate. Staggered or delayed implementation.	Mitigate. Staggered or delayed implementation.	Mitigate. Staggered or delayed implementation.	Mitigate. Staggered or delayed implementation.	Mitigate. Staggered or delayed implementation.	Mitigate. Staggered or delayed implementation.
T-4	Environmental/NEPA reviews delay project implementation.	1	1	1	5	3	3	3
	Rationale	Not credible; no new construction.	Unlikely and minimal due to national security need; minimal impact due known site environment.	Unlikely and minimal impact due to national security need and known site environment.	High likelihood but marginal impact due to unknown facility condition, and existing Record of Decision (ROD).	Moderate likelihood and marginal impact due to difficulties achieving/demonstrating NEPA compliance with new technology.	Moderate likelihood and marginal impact due to difficulties achieving/demonstrating NEPA compliance with new technology.	Moderate likelihood and marginal impact due to difficulties achieving/demonstrating NEPA compliance with new technology.
	Mitigation Handling Strategy				Mitigate. Perform preliminary condition assessment and resolve response to ROD.	Mitigate. Implement advance scoping activities and work closely with stakeholders.	Mitigate. Implement advance scoping activities and work closely with stakeholders.	Mitigate. Implement advance scoping activities and work closely with stakeholders.

Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative						
		Status Quo	**ATR**	**HFIR**	**FFTF**	**SFTR**	**LFTR**	**MSFTR**
T-5	Project accidents during construction delay project completion.	1	1	1	3	3	3	3
	Rationale	Unlikely and minimal impact; no extraordinary unplanned events anticipated.	Unlikely and minimal impact; no extraordinary unplanned events anticipated.	Unlikely and minimal impact; no extraordinary unplanned events anticipated.	Moderate likelihood and marginal impact due to aging facility with many unknow conditions resulting in greater propensity for accidents.	Moderate likelihood and marginal impact due to greater opportunity for accidents to occur during longer construction period.	Moderate likelihood and marginal impact due to greater opportunity for accidents to occur during longer construction period.	Moderate likelihood and marginal impact due to greater opportunity for accidents to occur during longer construction period.
	Mitigation Handling Strategy		Mitigate. Frequent safety awareness meetings.	Mitigate. Frequent safety awareness meetings.	Mitigate. Frequent safety awareness meetings.	Mitigate. Frequent safety awareness meetings.	Mitigate. Frequent safety awareness meetings.	Mitigate. Frequent safety awareness meetings.
T-6	Community or other stakeholders' concerns, lawsuits, and/or other legal proceedings delay project start.	1	1	1	3	3	3	3
	Rationale	Not credible; no new construction.	Unlikely and minimal impact; no evidence of stakeholder concerns.	Unlikely and minimal impact; no evidence of stakeholder concerns.	Moderate likelihood and marginal impact due to concerns of Native American tribes and other stakeholders.	Moderate likelihood and marginal impact due to concerns with stakeholder concerns regarding new technology.	Moderate likelihood and marginal impact due to concerns with stakeholder concerns regarding new technology.	Moderate likelihood and marginal impact due to concerns with stakeholder concerns regarding new technology.
	Mitigation Handling Strategy				Mitigate. Frequent meetings to resolve stakeholder concerns.	Mitigate. Frequent meetings to resolve stakeholder concerns.	Mitigate. Frequent meetings to resolve stakeholder concerns.	Mitigate. Frequent meetings to resolve stakeholder concerns.

Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative						
		Status Quo	ATR	HFIR	FFTF	SFTR	LFTR	MSFTR
T-7	Labor disputes lead to work slowdowns or stoppages delaying construction and operations.	1	1	1	1	3	3	3
	Rationale	Unlikely and minimal impact.	Unlikely and minimal or no impact; no current or anticipated issues.	Unlikely and minimal impact.	Unlikely and minimal or no impact; no current or anticipated issues.	Moderate likelihood and marginal impact due longer construction schedule.	Moderate likelihood and marginal impact due longer construction schedule.	Moderate likelihood and marginal impact due longer construction schedule.
	Mitigation Handling Strategy					Mitigate. Frequent meetings with labor representatives.	Mitigate. Frequent meetings with labor representatives.	Mitigate. Frequent meetings with labor representatives.
T-8	Construction materials or equipment availability delays project or adds costs.	1	1	1	3	3	3	3
	Rationale	Not credible; no new construction.	Unlikely and minimal impact; no demand for very unusual equipment and/or materials.	Unlikely and minimal impact; no demand for very unusual equipment and/or materials.	Moderate likelihood and marginal impact due to availability of construction material and complexity associated with testing components for operational readiness.	Moderate likelihood and marginal impact due to availability of construction material and complexity associated with testing components for operational readiness.	Moderate likelihood and marginal impact due to availability of materials and general construction associated with new technology.	Moderate likelihood and marginal impact due to availability of materials and general construction associated with new technology.
	Mitigation Handling Strategy			Unlikely and minimal impact; not unusual equipment and materials	Mitigate. Obtain approval for long lead procurements early.	Mitigate. Obtain approval for long lead procurements early.	Mitigate. Obtain approval for long lead procurements early.	Mitigate. Obtain approval for long lead procurements early.

Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative						
		Status Quo	**ATR**	**HFIR**	**FFTF**	**SFTR**	**LFTR**	**MSFTR**
T-9	Program requirements change impacting cost and schedule.	**1**	**1**	**1**	**1**	**3**	**3**	**3**
	Rationale	Unlikely and minimal impact; existing technology can accommodate some changes.	Unlikely and minimal impact; existing technology can accommodate some changes.	Unlikely and minimal impact; existing technology can accommodate some changes.	Unlikely and minimal impact; existing technology can accommodate some changes.	Moderate likelihood and marginal impact due longer construction schedule.	Moderate likelihood and marginal impact due longer construction schedule.	Moderate likelihood and marginal impact due longer construction schedule.
	Mitigation Handling Strategy					Mitigate. Pre-identify potential changes and create a design with flexibility	Mitigate. Pre-identify potential changes and create a design with flexibility.	Mitigate. Pre-identify potential changes and create a design with flexibility.
T-10	Facility degradation results in premature mission failure.	**1**	**1**	**1**	**5**	**3**	**5**	**5**
	Rationale	Unlikely and minimal or no impact; life extension being implemented.	Unlikely and minimal or no impact; life extension being implemented.	Unlikely and minimal or no impact; life extension being implemented.	High likelihood and significant impact; renovation and retrofit/upgrades to older degraded facility with unknown condition.	Moderate likelihood and marginal impact due to uncertain longevity of new technology.	High likelihood and significant impact due to extending the currently experimental lead coolant materials technology to a higher than previously considered flow rate (to enable high neutron flux), and for the ~40 year longevity desired.	High likelihood and significant impact due to extending the currently unproven salt-fuel materials technology to high fast-flux use, potentially higher flow rate and for the ~40 year longevity desired.
	Mitigation Handling Strategy				Mitigate. Perform preliminary condition assessment.	Mitigate. Extensive testing at lower TRLs.	Mitigate. Extensive testing at lower TRLs and design for periodic major system replacement if needed during lifetime.	Mitigate. Extensive testing at lower TRLs and design for periodic major system replacement if needed during lifetime.

Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative						
		Status Quo	**ATR**	**HFIR**	**FFTF**	**SFTR**	**LFTR**	**MSFTR**
T-11	Changes to safety requirements require project re-design.	1	1	1	3	3	3	3
	Rationale	Not credible; no new construction	Unlikely and minimal impact as major design changes not anticipated.	Unlikely and minimal impact as major design changes not anticipated.	Moderate likelihood and marginal impacts to older facility requiring retrofits to achieve compliance.	Moderate likelihood and marginal impacts due to longer construction schedule for new technology.	Moderate likelihood and marginal impacts due to longer construction schedule for new technology.	Moderate likelihood and marginal impacts due to longer construction schedule for new technology.
	Mitigation Handling Strategy				Mitigate. Perform preliminary condition assessment and develop work-arounds.	Mitigate. Identify possible issues and develop candidate resolutions.	Mitigate. Identify possible issues and develop candidate resolutions.	Mitigate. Identify possible issues and develop candidate resolutions.
T-12	External event impacts VTR Project construction or operations.	1	1	1	1	1	1	1
	Rationale	Unlikely and minimal impact. Off-site unplanned events are seldom significant to warrant major impacts.	Unlikely and minimal impact. Off-site unplanned events are seldom significant to warrant major impacts.	Unlikely and minimal impact. Off-site unplanned events are seldom significant to warrant major impacts.	Unlikely and minimal impact. Off-site unplanned events are seldom significant to warrant major impacts.	Unlikely and minimal impact. Off-site unplanned events are seldom significant to warrant major impacts.	Unlikely and minimal impact. Off-site unplanned events are seldom significant to warrant major impacts.	Unlikely and minimal impact. Off-site unplanned events are seldom significant to warrant major impacts.
	Mitigation Handling Strategy							
T-13	Nuclear material quantity changes facility mission, thereby impacting cost and schedule.	1	1	1	1	1	1	1
	Rationale	Unlikely and minimal impact; nothing anticipated.	Unlikely and minimal impact; nothing anticipated.	Unlikely and minimal impact; nothing anticipated.	Unlikely and minimal impact; nothing anticipated.	Unlikely and minimal impact; nothing anticipated.	Unlikely and minimal impact; nothing anticipated.	Unlikely and minimal impact; nothing anticipated.
	Mitigation Handling Strategy							

Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative						
		Status Quo	ATR	HFIR	FFTF	SFTR	LFTR	MSFTR
T-14	Additional space requirements for certain material delay project design and execution.	1	1	1	1	1	1	1
	Rationale	Unlikely and minimal impact; additional space needs are easily accommodated.	Unlikely and minimal impact; additional space needs are easily accommodated.	Unlikely and minimal impact; additional space needs are easily accommodated.	Unlikely and minimal impact; additional space needs are easily accommodated.	Unlikely and minimal impact; additional space needs are easily accommodated.	Unlikely and minimal impact; additional space needs are easily accommodated.	Unlikely and minimal impact; additional space needs are easily accommodated.
	Mitigation Handling Strategy							
T-15	IAEA requirements impact design and delays project start with additional impacts on operations.	1	1	1	1	1	1	1
	Rationale	Not credible; no new construction.	Unlikely and minimal impact; IAEA issues can be readily addressed.	Unlikely and minimal impact; IAEA issues can be readily addressed.	Unlikely and minimal impact; IAEA issues can be readily addressed.	Unlikely and minimal impact; IAEA issues can be readily addressed.	Unlikely and minimal impact; IAEA issues can be readily addressed.	Unlikely and minimal impact; IAEA issues can be readily addressed.
	Mitigation Handling Strategy							
T-16	Project design issues during work (construction/modifications/repairs) result in more work than planned causing cost increases and schedule delays.	1	1	1	5	3	3	3
	Rationale	Not credible; no new construction.	Unlikely and minimal impact as such changes generally occur and schedule contains sufficient contingency.	Unlikely and minimal impact as such changes generally occur and schedule contains sufficient contingency.	High likelihood and marginal impact due to unknown condition of aging facility.	Moderate likelihood and marginal impact due to new technology and long schedule.	Moderate likelihood and marginal impact due to new technology and long construction schedule.	Moderate likelihood and marginal impact due to new technology and long construction schedule.
	Mitigation Handling Strategy				Mitigate. Perform preliminary condition assessment.	Mitigate. Pre-identify possible scenarios and develop remedy.	Mitigate. Pre-identify possible scenarios and develop remedy.	Mitigate. Pre-identify possible scenarios and develop remedy.

Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative: Status Quo	ATR	HFIR	FFTF	SFTR	LFTR	MSFTR
T-17	Facility design has greater potential for containment failure.	1	1	1	3	1	1	1
	Rationale	Not credible; has confinement system.	Not credible; has confinement system.	Not credible; has confinement system.	Moderate likelihood and marginal impact due to facility age and unknown condition.	Unlikely and minimal impact due to new technology design features.	Unlikely and minimal impact due to new technology design features.	Unlikely and minimal impact due to new technology design features.
	Mitigation Handling Strategy				Mitigate. Perform condition assessment and identify failure scenarios and develop contingency plans.			
T-18	Ability to develop technology within planned schedule.	1	1	1	3	3	5	5
	Rationale	Unlikely and minimal impact; proven technology.	Unlikely and minimal impact; proven technology.	Unlikely and minimal impact; proven technology.	Moderate likelihood and marginal impact due to facility age and unknown condition.	Moderate likelihood and marginal impact due to new technology.	Likely and significant impact. Difficulties achieving appropriate TRL with new technology.	High likelihood and significant impact. Difficulties achieving appropriate TRL with new technology.
	Mitigation Handling Strategy				Mitigate. Pre-identify possible schedule weaknesses and develop contingency plans/solutions.	Mitigate. Pre-identify possible schedule weaknesses and monitor TRL progress to develop contingency plans/solutions.	Mitigate. Extensive testing at lower TRLs. Potentially build and operate a technology/demonstration facility prior to VTR construction.	Mitigate. Extensive testing at lower TRLs. Potentially build and operate a technology/demonstration facility prior to VTR construction.
T-19	Weather events cause delays that impact construction.	1	1	1	1			
	Rationale	Not credible; no new construction.	Unlikely and minimal impact.	Unlikely and minimal impact; mild climate.	Unlikely and minimal impact; experienced working in climate.	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**
	Mitigation Handling Strategy		Mitigate. Erect tenting/outdoor enclosure or revise schedule to accommodate construction.		Mitigate. Erect tenting/outdoor enclosure or revise schedule to accommodate construction.			

Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative						
		Status Quo	**ATR**	**HFIR**	**FFTF**	**SFTR**	**LFTR**	**MSFTR**
T-20	Inability to acquire sufficient workforce delays construction.	**1**	**3**	**1**	**1**			
	Rationale	Not credible; no new construction.	Craft staffing shortages due to current experience and concurrent construction activities.	Unlikely and minimal impact.	Unlikely and minimal impact.	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**
	Mitigation Handling Strategy		Mitigate. Wage premiums and other labor incentives (e.g., travel stipend).					
T-21	Ongoing site operations delay project completion.	**1**	**1**	**3**	**1**			
	Rationale	Not credible; no new construction and operations in progress.	Unlikely and minimal impact due to expansive land area and no concurrent activities identified to cause interference.	Moderate likelihood and marginal impact due congested site land area/foot print.	Unlikely and minimal or no impact dues to facility location on expansive site.	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**
	Mitigation Handling Strategy			Mitigate. Planned traffic patterns, flexible work schedules, and laydown areas that do not impede traffic flow.				

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Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative						
		Status Quo	ATR	HFIR	FFTF	SFTR	LFTR	MSFTR
T-22	Security requirements delay project completion.	1	1	1	1			
	Rationale	Unlikely and minimal or no impact due to site experience addressing changing requirements.	Unlikely and minimal or no impact due to site experience addressing changing requirements.	Unlikely and minimal or no impact due to site experience addressing changing requirements.	Unlikely and minimal or no impact due to site experience addressing changing requirements.	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**
	Mitigation Handling Strategy							
T-23	Unforeseen site or existing facility conditions delay or add to construction work.	1	1	1	3			
	Rationale	Not credible; no new construction.	Unlikely and minimal impact; land previously undisturbed.	Unlikely and minimal impact; site previously explored.	Moderate likelihood and marginal impact due to facility age and unknown condition.	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**
	Mitigation Handling Strategy				Mitigate; perform facility assessment.			
T-24	Uncertainty in site planning delays project implementation.	1	1	3	1			
	Rationale	Not credible; no new construction.	Unlikely and minimal or no impact; site preliminarily identified.	Moderate and marginal impact, as site ownership is DOE-SC.	Unlikely and minimal or no impact; using current facility.	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**
	Mitigation Handling Strategy			Mitigate. Early planning and agreement of shared usage schedule.				

Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative						
		Status Quo	**ATR**	**HFIR**	**FFTF**	**SFTR**	**LFTR**	**MSFTR**
T-25	Longevity of agreements impact continued operations.	5	3	5	1			
	Rationale	Moderate likelihood and significant impact. HFIR currently experiencing operational problems and "owned" by Office of Science.	Moderate likelihood and marginal impact due to competing demands with for use.	Moderate likelihood and significant impact. Facility currently experiencing operational problems.	Unlikely and minimal or no impact as facility is available and currently is cold and dark.	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**
	Mitigation Handling Strategy	Mitigate. Implement improved preventive and corrective maintenance; establish a reliability-centered maintenance program.	Mitigate. Establish long term mission objectives with DOE concurrence.	Mitigate. Implement improved preventive and corrective maintenance and establish a reliability-centered maintenance program.				
T-26	Existing facilities require more work than planned to meet applicable codes and standards impacting cost and schedule.	1	1	1	3			
	Rationale	Not credible; no new construction.	Unlikely and minimal impact as anticipated changes can be addressed.	Unlikely and minimal impact as anticipated changes can be addressed.	Moderate likelihood and marginal impact due to abandoned and aging facility.	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**
	Mitigation Handling Strategy				Mitigate. Perform preliminary condition assessment.			

Table G-2. Risk Score, Rationale, and Mitigation Handling Strategy for Moderate and High Threats Only

Risk	Brief Description	Alternative						
		Status Quo	ATR	HFIR	FFTF	SFTR	LFTR	MSFTR
T-27	Inability to establish staff for performing post-irradiation examination (PIE) of fuels, materials and detectors.	1	1	3	1			
	Rationale	Unlikely and minimal or no impact due to existing skilled labor pool.	Unlikely and minimal or no impact due to existing skilled labor pool.	Moderate likelihood and marginal impact due to competition for skilled personnel from neighboring DOE-NNSA facilities.	Unlikely and minimal impact due to existing skilled labor pool.	Site is Yet to Be Determined.	Site is Yet to Be Determined.	Site is Yet to Be Determined.
	Mitigation Handling Strategy			Mitigate. Provide incentives (e.g., wage and travel stipend).				
T-28	Onsite operations interfere with VTR operations.	5	3	5	1			
	Rationale	Likely and significant impact due small site footprint and numerous on-going activities.	Moderate likelihood and marginal impact due to competing users.	Likely and significant impact due small site footprint and numerous on-going activities, competing users and controlled by DOE-SC.	Unlikely and minimal impact; identify preferred site with limited interferences.	Site is Yet to Be Determined.	Site is Yet to Be Determined.	Site is Yet to Be Determined.
	Mitigation Handling Strategy	Mitigate. Flexible schedule, early establishment of priorities, and adequate contingency.	Mitigate. Schedule priorities.	Mitigate. Flexible schedule, early establishment of priorities, and adequate contingency.				

Table G-3. Risk Score and Rationale for Opportunities

Opportunity	Brief Description	Alternative						
		Status Quo	**ATR**	**HFIR**	**FFTF**	**SFTR**	**LFTR**	**MSFTR**
O-1	Operational efficiencies from new construction/upgrades yield better throughput.	**5**	**5**	**5**	**1**	**1**	**1**	**1**
	Rationale	**Not credible; no new construction.**	**No new construction; upgrades to increase fast flux will not improve operational efficiencies.**	**No new construction; upgrades to increase fast flux will not improve operational efficiencies.**	**New technology upgrades are expected to improve efficiencies.**	**New technology is expected to yield efficiencies.**	**New technology is expected to yield efficiencies.**	**New technology is expected to yield efficiencies.**
O-2	Improved political environment reduces schedule.	**5**	**5**	**5**	**3**	**1**	**1**	**1**
	Rationale	**Not credible; no new construction.**	**Small project; political support variations not likely to impact schedule.**	**Small project; political support variations not likely to impact schedule.**	**Stakeholder acceptance will resolve funding delays.**	**Benefits to potential users (e.g., commercial reactor vendors, reactor developers, and universities); congressional approval to maintain international superiority will prevent funding delays.**	**Benefits to potential users (e.g., commercial reactor vendors, reactor developers, and universities); congressional approval to maintain international superiority will prevent funding delays.**	**Benefits to potential users (e.g., commercial reactor vendors, reactor developers, and universities); congressional approval to maintain international superiority will prevent funding delays.**
O-3	Existing facilities have more capability (i.e., space) than initially expected.	**5**	**3**	**3**	**3**	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**	**Site is Yet to Be Determined.**
	Rationale	**Not credible; no new construction.**	**Moderate likelihood and marginal impact to existing facility**	**Moderate likelihood and marginal impact to existing facility**	**Moderate likelihood and marginal impact to existing facilities.**			

Table G-3. Risk Score and Rationale for Opportunities

Opportunity	Brief Description	Alternative						
		Status Quo	**ATR**	**HFIR**	**FFTF**	**SFTR**	**LFTR**	**MSFTR**
O-4	Improved construction logistics yields schedule savings.	5	5	5	5	3	3	3
	Rationale	Not credible; no new construction.	Not credible; no new construction.	Not credible; no new construction.	Not credible; no new construction.	This opportunity will be site dependent; site-specific factors affecting construction schedules would include local environmental conditions, weather, workforce availability, and existing support facilities and modifications thereto.	This opportunity will be site dependent; site-specific factors affecting construction schedules would include local environmental conditions, weather, workforce availability, and existing support facilities and modifications thereto.	This opportunity will be site dependent; site-specific factors affecting construction schedules would include local environmental conditions, weather, workforce availability, and existing support facilities and modifications thereto.
O-5	Domestic or foreign industrial partnering support yields cost savings.	5	3	3	3	1	1	1
	Rationale	Not credible; no new construction.	Small project; partnerships would have minimal impact on costs or schedules.	Small project; partnerships would have minimal impact on costs or schedules.	Successful partnerships could result in some cost and schedule savings, although an old facility will not be as attractive to potential partners as a new reactor.	New reactor could be very attractive to potential domestic and foreign industrial partners.	New reactor could be very attractive to potential domestic and foreign industrial partners.	New reactor could be very attractive to potential domestic and foreign industrial partners.

Table G-3. Risk Score and Rationale for Opportunities

Oppor-tunity	Brief Description	Alternative						
		Status Quo	ATR	HFIR	FFTF	SFTR	LFTR	MSFTR
O-6	Leveraging safety documentation prepared for existing facility yields cost and/or schedule savings.	5	3	3	3	Site is Yet to Be Determined.	Site is Yet to Be Determined.	Site is Yet to Be Determined.
	Rationale	Not credible; no new construction.	Moderate and marginal impact due to existing facility.	Moderate and marginal impact due to existing facility.	Moderate and marginal impact due to existing facility.			

Table G-4. Composite Risk Scores for Alternatives

Alternative Risk	Brief Description	Alternatives						
		1	2	3	4	5	6	7
		Status Quo	ATR	HFIR	FFTF	SFTR	LFTR	MSFTR
Threats								
T-1	Inability to establish sufficient operating workforce of cleared, trained personnel having relevant experience with the technology delays design and operations.	1	1	1	1	1	3	3
T-2	Available funding delays the project start/completion.	1	1	1	3	5	5	5
T-3	Design Basis Threat changes impact facility design, construction, and operations.	1	1	1	1	1	1	1
T-4	Environmental/NEPA reviews delay project implementation.	1	1	1	5	3	3	3
T-5	Project accidents during construction delay project completion.	1	1	1	3	3	3	3
T-6	Community or other stakeholders' concerns, lawsuits, and/or other legal proceedings delay project start.	1	1	1	3	3	3	3
T-7	Labor disputes lead to work slowdowns or stoppages delaying construction and operations.	1	1	1	1	3	3	3
T-8	Construction materials or equipment availability delays project or adds costs.	1	1	1	3	3	3	3
T-9	Program requirements change impacting cost and schedule.	1	1	1	1	3	3	3
T-10	Facility degradation results in premature mission failure.	1	1	1	5	3	5	5
T-11	Changes to safety requirements require project re-design.	1	1	1	3	3	3	3
T-12	External event impacts VTR Project construction or operations.	1	1	1	1	1	1	1
T-13	Nuclear material changes facility mission impacting cost and schedule.	1	1	1	1	1	1	1
T-14	Additional space requirements for certain material delay project design and execution.	1	1	1	1	1	1	1
T-15	IAEA requirements impact design and delays project start with additional impacts on operations.	1	1	1	1	1	1	1
T-16	Project design issues during work (construction/modifications/repairs) result in more work than planned causing cost increases and schedule delays.	1	1	1	5	3	3	3
T-17	Facility design has greater potential for containment failure.	1	1	1	3	1	1	1
T-18	Ability to develop technology within planned schedule.	1	1	1	3	3	5	5
	Total (T-1 through T-18)	**18**	**18**	**18**	**44**	**42**	**48**	**48**

Table G-4. Composite Risk Scores for Alternatives

Site Risk	Brief Description	Alternatives						
		1	2	3	4	5	6	7
		Status Quo	ATR	HFIR	FFTF	SFTR	LFTR	MSFTR
		Threats						
T-19	Weather events cause delays that impact construction.	1	1	1	1	Site TBD	Site TBD	Site TBD
T-20	Inability to acquire sufficient workforce delays construction.	1	3	1	1	Site TBD	Site TBD	Site TBD
T-21	Ongoing site operations delay project completion.	1	1	3	1	Site TBD	Site TBD	Site TBD
T-22	Security requirements delay project completion.	1	1	1	1	Site TBD	Site TBD	Site TBD
T-23	Unforeseen site or existing facility conditions delay or add to construction work.	1	1	1	3	Site TBD	Site TBD	Site TBD
T-24	Uncertainty in site planning delays project implementation.	1	1	3	1	Site TBD	Site TBD	Site TBD
T-25	Longevity of agreements impact continued operations.	5	3	5	1	Site TBD	Site TBD	Site TBD
T-26	Existing facilities require more work than planned to meet applicable codes and standards impacting cost and schedule.	1	1	1	3	Site TBD	Site TBD	Site TBD
T-27	Inability to establish staff for performing post-irradiation examination (PIE) of fuels, materials and detectors.	1	1	3	1	Site TBD	Site TBD	Site TBD
T-28	Onsite operations interfere with VTR operations.	5	3	5	1	Site TBD	Site TBD	Site TBD
	Total (T-19 through T-28 for applicable alternatives only)	18	16	24	14			
Oppor-tunities								
O-1	Operational efficiencies from new construction/upgrades yield better throughput.	5	5	5	1	1	1	1
O-2	Improved political environment reduces schedule.	5	5	5	3	1	1	1
O-3	Existing facilities have more capability (i.e., space) than initially expected.	5	3	3	3	Site TBD	Site TBD	Site TBD
O-4	Improved construction logistics yields schedule savings.	5	5	5	5	3	3	3
O-5	Domestic or foreign industrial partnering support yields cost savings.	5	3	3	3	1	1	1
O-6	Leveraging safety documentation prepared for existing facility yields cost and/or schedule savings.	5	3	3	3	Site TBD	Site TBD	Site TBD
	Total of Opportunities (common to all alternatives)	20	18	18	12	6	6	6
	Total of Opportunities (specific to a site)	10	6	6	6			

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APPENDIX H VTR SCORING BASIS

H.1 Alternatives Scoring

The six 'viable alternatives' described in Section 5.2, plus the 'Status Quo', were evaluated by the AoA Team against the 20 criteria described in Section 6.1. This provides a raw 'evaluation score' that is then weighted by the 'normalized relative weight' described in Section 6.2 to provide the 'alternative score'. Tables H-1 (a-t) present the 140 raw and weighted scores and a brief summary of the rationale from AoA Team scoring discussions. As input was received during the conduct and review of this analysis, any potential changes were considered by the team for accuracy, consistency and lack of bias. The final scoring is presented in Tables H.

Table H-1(a). Scoring of the Alternatives

Criterion #1: Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo contains very limited fast neutron irradiation flux, meeting very little of the prospective user needs.	0	0
2	ATR	With the fast flux booster, ATR provides improved but limited capability for fast neutron irradiations, meeting only a portion of the prospective user needs.	0.3	2.0
3	HFIR	Even with potential flux increase, HFIR provides limited capability for fast neutron irradiations, meeting only a small portion of the prospective user needs.	0.1	0.7
4	Modify and Restart FFTF	If successfully restarted and modernized, the FFTF could provide sufficient fast neutron irradiation flux to fully meet the prospective user needs.	1.0	6.6
5	SFTR	A new SFTR built for the VTR mission is assumed to be designed to provide sufficient fast neutron irradiation flux to fully meet the prospective user needs.	1.0	6.6
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission is assumed to be designed to provide sufficient fast neutron irradiation flux to fully meet the prospective user needs.	1.0	6.6
7	MSFTR	A MSFTR built for the VTR mission is assumed to be designed to provide sufficient fast neutron irradiation flux to fully meet the prospective user needs.	1.0	6.6

Table H-1(b). Scoring of the Alternatives

Criterion #2: Provides high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo provides limited capability for high dose rate testing, meeting only a small portion of the mission need.	0.1	0.7
2	ATR	With the fast flux booster, ATR could provide somewhat improved capability for fast neutron high dose rate testing, meeting a portion of the mission need.	0.3	2.0
3	HFIR	With the flux enhancement, HFIR could provide somewhat improved capability for fast neutron high dose rate testing, meeting a portion of the mission need.	0.3	2.0
4	Modify and Restart FFTF	If restarted, FFTF could provide sufficient high dose rate testing to fully meet the mission need.	1.0	6.6
5	SFTR	A new SFTR built for the VTR mission is assumed to be designed to provide sufficient high dose rate testing to fully meet the mission need.	1.0	6.6
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission is assumed to be designed to provide sufficient high dose rate testing to fully meet the mission need.	1.0	6.6
7	MSFTR	A MSFTR built for the VTR mission is assumed to be designed to provide sufficient high dose rate testing to fully meet the mission need.	1.0	6.6

Table H-1(c). Scoring of the Alternatives

Criterion #3: Provides an irradiation length that is typical of fast reactor designs				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo can meet the irradiation length requirement in ATR.	1.0	6.6
2	ATR	ATR can meet the irradiation length requirement	1.0	6.6
3	HFIR	HFIR can nearly meet the irradiation length requirement in ATR.	0.5	3.3
4	Modify and Restart FFTF	A restarted FFTF would meet the irradiation length requirement.	1.0	6.6
5	SFTR	A new SFTR built for the VTR mission would meet the irradiation length requirement.	1.0	6.6
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission would meet the irradiation length requirement.	1.0	6.6
7	MSFTR	A MSFTR built for the VTR mission would meet the irradiation length requirement.	1.0	6.6

Table H-1(d). Scoring of the Alternatives

Criterion #4: Provides a large irradiation volume within the core region				
#	Alternative	Description	Raw Score	Weighted Score
1	Base Case (Status Quo)	The Status Quo provides limited fast neutron irradiation volume, meeting only a small portion of the mission need.	0.1	0.7
2	ATR	Even with the fast flux booster, ATR provides limited fast neutron irradiation volume, meeting only a small portion of the mission need.	0.1	0.7
3	HFIR	Even with potential flux increase, HFIR provides limited fast neutron irradiation volume, meeting only a small portion of the mission need.	0.1	0.7
4	Modify and Restart FFTF	If successfully restarted and modernized, the FFTF could provide sufficient fast neutron irradiation volume to fully meet the mission need.	1.0	6.6
5	SFTR	A new SFTR built for the VTR mission is assumed to be designed to provide sufficient fast neutron irradiation volume to fully meet the mission need.	1.0	6.6
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission is assumed to be designed to provide sufficient fast neutron irradiation volume to fully meet the mission need.	1.0	6.6
7	MSFTR	A MSFTR built for the VTR mission is assumed to be designed to provide sufficient fast neutron irradiation volume to fully meet the mission need.	1.0	6.6

Table H-1(e). Scoring of the Alternatives

Criterion #5: Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo provides limited flexibility for fast neutron testing, meeting only a small portion of the mission need.	0.1	0.7
2	ATR	With a dedicated fast flux booster, ATR could provide improved flexibility for fast neutron testing, but still meeting only a portion of the mission need.	0.3	2.0
3	HFIR	With upgrades, HFIR could provide improved flexibility for fast neutron testing, but still meeting only a portion of the mission need.	0.3	2.0
4	Modify and Restart FFTF	If successfully restarted and modernized, the FFTF could provide flexible testing configurations and closed loop environments and could fully meet the mission need.	1.0	6.6
5	SFTR	A Na-cooled-FTR designed for the VTR mission could provide flexible testing configurations and closed loop environments and could fully meet the mission need.	1.0	6.6
6	LFTR	A Pb/Pb-Bi-cooled-FTR designed for the VTR mission could provide flexible testing configurations and closed loop environments and could fully meet the mission need.	1.0	6.6
7	MSFTR	A MSFTR designed for the VTR mission could provide flexible testing configurations and closed loop environments and could fully meet the mission need.	1.0	6.6

Table H-1(f). Scoring of the Alternatives

Criterion #6: In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo provides some ability to test sensors and instrumentation, meeting a portion of the mission need.	0.5	2.0
2	ATR	ATR could provide some ability to test sensors and instrumentation, meeting a portion of the mission need.	0.5	2.0
3	HFIR	HFIR could provide some ability to test sensors and instrumentation, meeting a portion of the mission need.	0.5	2.0
4	Modify and Restart FFTF	A restarted FFTF could provide extensive ability to test sensors and instrumentation, fully meeting the mission need.	1.0	3.9
5	SFTR	A SFTR designed for the VTR mission could provide extensive ability to test sensors and instrumentation, fully meeting the mission need.	1.0	3.9
6	LFTR	A Pb/Pb-Bi-cooled-FTR designed for the VTR mission could provide extensive ability to test sensors and instrumentation, fully meeting the mission need.	1.0	3.9
7	MSFTR	A MSFTR designed for the VTR mission could provide extensive ability to test sensors and instrumentation, fully meeting the mission need.	1.0	3.9

Table H-1(g). Scoring of the Alternatives

Criterion #7: High technical confidence with the facility can be available for testing as soon as possible				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	Although the Status Quo is currently available, it only meets a small portion of the mission need.	0.1	0.7
2	ATR	ATR with flux booster could provide significant testing ability in a moderate timeframe, meeting a portion of the mission need.	0.3	2.0
3	HFIR	Although HFIR upgrades could be available in a timely manner, it would still only provide a small portion of the testing ability for the mission need.	0.1	0.7
4	Modify and Restart FFTF	Restart of FFTF has substantial schedule uncertainty due to the unknown condition of the facility, partially meeting the mission need.	0.3	2.0
5	SFTR	A SFTR designed for the VTR mission could be available on a lengthy but comparatively certain schedule, partially meeting the mission need.	0.3	2.0
6	LFTR	A Pb/Pb-Bi-cooled-FTR designed for the VTR mission could be available on a lengthy and highly uncertain schedule, meeting a small portion of the mission need. (Schedule uncertainty includes the possible need for a technology demonstration facility.)	0.1	0.7
7	MSFTR	A MSFTR designed for the VTR mission could be available on a lengthy and highly uncertain schedule, meeting a small portion of the mission need. (Schedule uncertainty includes the possible need for a technology demonstration facility.)	0.1	0.7

Table H-1(h). Scoring of the Alternatives

Criterion #8: Expedites experiment life cycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo provides limited capacity distributed at various sites with variable support, meeting a portion of the criterion.	0.5	3.3
2	ATR	The ATR site at INL has access to extensive NE dedicated support facilities, fully meeting the criterion.	1.0	6.6
3	HFIR	The HFIR site at ORNL has access to significant support facilities shared with other missions, meeting a portion of the criterion.	0.5	3.3
4	Modify and Restart FFTF	The FFTF site on the Hanford reservation has access to significant support facilities. Some are shared with other missions, and one (FMEF) could be dedicated but has never been activated, meeting a portion of the criterion.	0.5	3.3
5	SFTR	A SFTR built for the VTR mission is assumed to be sited where there is access to extensive support facilities, fully meeting the criterion.	1.0	6.6
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission is assumed to be sited where there is access to extensive support facilities, fully meeting the criterion.	1.0	6.6
7	MSFTR	A MSFTR built for the VTR mission is assumed to be sited where there is access to extensive support facilities, fully meeting the criterion.	1.0	6.6

Table H-1(i). Scoring of the Alternatives

Criterion #9: Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo has existing management of driver fuel and test samples, meeting the criterion.	1.0	1.3
2	ATR	The ATR has existing management of driver fuel and test samples, meeting the criterion.	1.0	1.3
3	HFIR	The HFIR has existing management of driver fuel and test samples, meeting the criterion.	1.0	1.3
4	Modify and Restart FFTF	Restart of the FFTF requires reconstitution of the driver fuel and test fuel supply chains and irradiated fuel and sample management. The site has some capability, but activation and equipping FMEF would be required to provide extensive capability. This is not currently planned, only partially meeting the criterion.	0.3	0.4
5	SFTR	A SFTR designed for the VTR mission would be sited with extensive fuel and waste management support facilities, meeting the criterion.	1.0	1.3
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission would be sited with fuel and waste management support facilities. However, the unknown fuel selection leaves significant uncertainties, only partially meeting the criterion.	0.3	0.4
7	MSFTR	A MSFTR built for the VTR mission would include integral fuel supply and at least some waste management support facilities due to the inherent requirements for the use of molten salt fuel. However, unknown fuel and processing details leave significant uncertainties, not fully meeting the criterion.	0.5	0.7

Table H-1(j). Scoring of the Alternatives

Criterion #10: Provides capabilities that support experimental high-temperature testing				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo provides some capacity for high-temperature testing, meeting a portion of the criterion.	0.3	2.0
2	ATR	The ATR with dedicated flux booster could provide some capacity for high-temperature testing, meeting a portion of the criterion.	0.3	2.0
3	HFIR	The HFIR with upgrades could provide some capacity for high-temperature testing, meeting a portion of the criterion.	0.3	2.0
4	Modify and Restart FFTF	The FFTF could provide extensive capacity for high-temperature testing, fully meeting the criterion.	1.0	6.6
5	SFTR	A SFTR designed for the VTR mission could provide extensive capacity for high-temperature testing, fully meeting the criterion.	1.0	6.6
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission could provide extensive capacity for high-temperature testing, fully meeting the criterion.	1.0	6.6
7	MSFTR	A MSFTR built for the VTR mission could provide extensive capacity for high-temperature testing, fully meeting the criterion.	1.0	6.6

Table H-1(k). Scoring of the Alternatives

Criterion #11: Provides capabilities for irradiation with neutrons of a lower energy spectrum				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo provides extensive capacity for testing with lower energy neutrons, fully meeting the criterion.	1.0	2.6
2	ATR	The ATR provides extensive capacity for testing with lower energy neutrons, fully meeting the criterion.	1.0	2.6
3	HFIR	The HFIR provides extensive capacity for testing with lower energy neutrons, fully meeting the criterion.	1.0	2.6
4	Modify and Restart FFTF	A restarted FFTF could provide extensive capacity for testing with lower energy neutrons, fully meeting the criterion.	1.0	2.6
5	SFTR	A SFTR designed for the VTR mission could provide extensive capacity for testing with lower energy neutrons, fully meeting the criterion.	1.0	2.6
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission could provide extensive capacity for testing with lower energy neutrons, fully meeting the criterion.	1.0	2.6
7	MSFTR	A MSFTR built for the VTR mission could provide extensive capacity for testing with lower energy neutrons, fully meeting the criterion.	1.0	2.6

Table H-1(l). Scoring of the Alternatives

Criterion #12: Lower Capital Investment (Total Project Cost)				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo requires no capital investment, scoring high on this criterion.	1.0	3.9
2	ATR	The ATR flux booster requires comparatively moderate capital investment, scoring moderate on this criterion.	0.5	2.0
3	HFIR	The HFIR upgrades requires comparatively moderate capital investment, scoring moderate on this criterion.	0.5	2.0
4	Modify and Restart FFTF	FFTF restart, and modernization requires significant capital investment, scoring lower on this criterion.	0.3	1.2
5	SFTR	A SFTR designed for the VTR mission requires large capital investment, scoring low on this criterion.	0.1	0.4
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission requires large capital investment, and might require a preceding technology demonstration facility, scoring low on this criterion.	0.1	0.4
7	MSFTR	A MSFTR built for the VTR mission requires large capital investment, and might require a preceding technology demonstration facility, scoring low on this criterion.	0.1	0.4

Table H-1(m). Scoring of the Alternatives

Criterion #13: Lower Annual Operating and Maintenance Costs during operations				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo has low operating costs due to very limited testing, scoring high on this criterion.	1.0	2.6
2	ATR	The ATR operating costs are shared with other missions, but would increase with the BFFL, scoring moderate on this criterion.	0.5	1.3
3	HFIR	The HFIR operating costs are shared with other missions, scoring high on this criterion since they are comparable to the Status Quo case.	1.0	2.6
4	Modify and Restart FFTF	FFTF restart and operation requires significant operating costs, scoring lower on this criterion.	0.3	0.8
5	SFTR	A SFTR operation requires significant operating costs, scoring lower on this criterion.	0.3	0.8
6	LFTR	A Pb/Pb-Bi-cooled-FTR operation requires significant operating costs, scoring lower on this criterion.	0.3	0.8
7	MSFTR	A MSFTR operation requires significant operating costs, scoring lower on this criterion.	0.3	0.8

Table H-1(n). Scoring of the Alternatives

Criterion #14: Lower present value of lifecycle costs				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo requires low cost and no capital investment, scoring high on this criterion.	1.0	3.9
2	ATR	The ATR flux booster requires comparatively moderate near-term investment and ongoing operational costs, scoring moderate on this criterion.	0.5	2.0
3	HFIR	The HFIR upgrade requires little near-term investment and ongoing operational costs, scoring high on this criterion since they are comparable to the Status Quo case.	1.0	3.9
4	Modify and Restart FFTF	FFTF restart, and modernization requires significant capital and substantial operation costs, scoring lower on this criterion.	0.3	1.2
5	SFTR	A SFTR requires both substantial capital and operating costs, scoring low on this criterion.	0.1	0.4
6	LFTR	A Pb/Pb-Bi-cooled-FTR requires both substantial capital and operating costs, scoring low on this criterion.	0.1	0.4
7	MSFTR	A MSFTR requires both substantial capital and operating costs, scoring low on this criterion.	0.1	0.4

Table H-1(o). Scoring of the Alternatives

Criterion #15: Shortest schedule to initiate operations				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo is currently implemented, scoring high on this criterion.	1.0	3.9
2	ATR	The ATR flux booster requires comparatively moderate implementation time, scoring moderate on this criterion.	0.5	2.0
3	HFIR	The HFIR upgrade requires comparatively shorter implementation time, scoring high on this criterion.	1.0	3.9
4	Modify and Restart FFTF	FFTF restart, and modernization requires significant (and uncertain) time, scoring lower on this criterion.	0.3	1.2
5	SFTR	A SFTR requires significant construction time, scoring lower on this criterion.	0.3	1.2
6	LFTR	A Pb/Pb-Bi-cooled-FTR requires substantial (and uncertain) construction time, and may require a technology demonstration step, scoring low on this criterion.	0.1	0.4
7	MSFTR	A MSFTR requires substantial (and uncertain) construction time, and may require a technology demonstration step, scoring low on this criterion.	0.1	0.4

Table H-1(p). Scoring of the Alternatives

Criterion #16: Ease of meeting security requirements				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo is currently implemented, with required security, scoring high on this criterion.	1.0	1.3
2	ATR	The ATR is currently operating with required security for navy testing. The flux booster is unlikely to change the requirements, scoring high on this criterion.	1.0	1.3
3	HFIR	The HFIR is currently operating with required security. The upgrades are unlikely to change the requirements, scoring high on this criterion.	1.0	1.3
4	Modify and Restart FFTF	FFTF operated in the past with required security, and restart will review any security update requirements, scoring high on this criterion.	1.0	1.3
5	SFTR	A SFTR would be built to meet security requirements - which are not expected to be limiting, scoring high on this criterion.	1.0	1.3
6	LFTR	A Pb/Pb-Bi-cooled-FTR would be built to meet security requirements - which are not expected to be limiting, scoring high on this criterion.	1.0	1.3
7	MSFTR	A MSFTR would be built to meet security requirements - which are not expected to be limiting, scoring high on this criterion.	1.0	1.3

Table H-1(q). Scoring of the Alternatives

Criterion #17: Greater ease and confidence of compliance with codes, standards, regulations				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo is currently implemented, meeting all requirements, scoring high on this criterion.	1.0	6.6
2	ATR	The ATR is currently operating meeting all requirements. The flux booster is unlikely to present any significant challenges, scoring high on this criterion.	1.0	6.6
3	HFIR	The HFIR is currently operating meeting all requirements. The upgrades are unlikely to present any significant challenges, scoring high on this criterion.	1.0	6.6
4	Modify and Restart FFTF	FFTF operated in the past meeting all requirements. However, restart will require extensive review and uncertain updates for an aged existing facility, scoring lower on this criterion. There is a Record of Decision for closure that would require reversal.	0.3	2.0
5	SFTR	A SFTR would be designed to meet requirements – which has been done in the past, scoring high on this criterion.	1.0	6.6
6	LFTR	A Pb/Pb-Bi-cooled-FTR would be designed to meet requirements. However, there is no experience with LFTR regulation so these requirements (regulations, codes, standards and practices) must be created, scoring low on this criterion.	0.1	0.7
7	MSFTR	A MSFTR would be designed to meet requirements. However, there is no experience with MSFTR regulation so these requirements (regulations, codes, standards and practices) must be created, scoring low on this criterion.	0.1	0.7

Table H-1(r). Scoring of the Alternatives

Criterion #18: Higher confidence in stakeholder acceptance				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo provides very little testing capability, so technology stakeholders would have no benefit. There are no clear stakeholders with benefit from the Status Quo.	0.0	0.0
2	ATR	While a boosted ATR could provide improved test capability, however, the incremental change is insufficient to meet technology stakeholder needs, and some may see it as an impediment to development of more substantial capabilities.	0.1	0.4
3	HFIR	An upgraded HFIR could provide somewhat improved test capability, however, the incremental change is insufficient to meet technology stakeholder needs, and some may see it as an impediment to development of more substantial capabilities.	0.1	0.4
4	Modify and Restart FFTF	Restart of the FFTF has an active mix of stakeholder support and opposition from the technology, local and regional communities. Through a series of prior efforts for restart, there has been stakeholder polarization that is likely to continue.	0.3	1.2
5	SFTR	A SFTR built for the VTR mission would meet technology stakeholder requirements, has strong local support, and has little apparent opposition from other interested parties.	1.0	3.9
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission is likely to be more costly and with a longer schedule than more mature technology. There is little apparent stakeholder support for using the VTR as a technology innovation experiment.	0.1	0.4
7	MSFTR	A MSFTR built for the VTR mission is likely to be more costly and with a longer schedule than more mature technology. There is little apparent stakeholder support for using the VTR as a technology innovation experiment.	0.1	0.4

Table H-1(s). Scoring of the Alternatives

Criterion #19: Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo provides no ability for U.S. technology leadership, and signals lack of national support for reactor technology.	0.0	0.0
2	ATR	A boosted ATR could provide somewhat improved test capability, but would lag behind other nations and would not be sufficient to regain and sustain technology leadership.	0.1	0.7
3	HFIR	An upgraded HFIR could provide somewhat improved test capability, but would lag behind other nations and would not be sufficient to regain and sustain technology leadership.	0.1	0.7
4	Modify and Restart FFTF	Restart of the FFTF could provide greatly improved test capability, but operation of an aged facility may not fully regain and sustain technology leadership against nations building newer test facilities.	0.5	3.3
5	SFTR	A SFTR built for the VTR mission would meet the testing requirements, and a new world-class research facility would facilitate leadership in advanced nuclear technology and demonstrate national commitment.	1.0	6.6
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission would meet the testing requirements, and a new world-class research facility would facilitate leadership in advanced nuclear technology and demonstrate national commitment – and would bring a new nuclear technology to maturity.	1.0	6.6
7	MSFTR	A MSFTR built for the VTR mission would meet the testing requirements, and a new world-class research facility would facilitate leadership in advanced nuclear technology and demonstrate national commitment – and would bring a new nuclear technology to maturity.	1.0	6.6

Table H-1(t). Scoring of the Alternatives

Criterion #20: Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)				
#	**Alternative**	**Description**	**Raw Score**	**Weighted Score**
1	Base Case (Status Quo)	The Status Quo provides very little ability to meet user needs and relies on reactors with other missions.	0.0	0.0
2	ATR	The ATR with a dedicated booster could provide some of the user needs, but would still have potential conflicts with navy use.	0.3	2.0
3	HFIR	An upgraded HFIR could provide some of the user needs, but would have significant ongoing potential conflicts with other users.	0.1	0.7
4	Modify and Restart FFTF	Restart of the FFTF could provide greatly improved test capability but in a dedicated facility with possible conflict with other missions such as site remediation.	0.5	3.3
5	SFTR	A SFTR built for the VTR mission could provide greatly improved test capability in a dedicated facility with minimum conflict with other missions.	1.0	6.6
6	LFTR	A Pb/Pb-Bi-cooled-FTR built for the VTR mission could provide greatly improved test capability in a dedicated facility with minimum conflict with other missions.	1.0	6.6
7	MSFTR	A MSFTR built for the VTR mission could provide greatly improved test capability in a dedicated facility with minimum conflict with other missions.	1.0	6.6

Tables H-2 through H-9 provide the Evaluation Criteria scoring of the sensitivity analysis scenarios.

Table H-2. Evaluation Criteria Sensitivity Analysis
Summary of Alternative Scoring

			Scenario 1	Scenario 2	Scenario 3	Scenario 4	Ranking of Alternatives				
		Base Case	Cost/Schedule High Importance	All High Importance	Tech Performance Lower than C/S	Linear Scaling	Base Case	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	Alternative 1 Status Quo	43	49	54	58	45	6	5	5	5	6
2	Alternative 2 ATR	48	48	53	51	48	5	6	6	7	5
3	Alternative 3 HFIR	43	47	53	55	41	7	7	7	6	7
4	Alternative 4 FFTF	67	63	65	59	68	4	4	4	2	4
5	Alternative 5 SFTR	84	77	81	73	79	1	1	1	1	1
6	Alternative 6 LFTR	71	65	66	58	69	3	3	3	4	3
7	Alternative 7 MSFTR	71	66	67	58	69	2	2	2	3	2

Table H-3. VTR AoA Evaluation of Alternatives – Base Case with Evaluation Score

	Requirement	Importance	Weight	Relative Weight	Normalized Weight	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users.	1	5.00	0.25	6.58	0.00	0.30	0.10	1.00	1.00	1.00	1.00
2	Provides high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	1	5.00	0.25	6.58	0.10	0.30	0.30	1.00	1.00	1.00	1.00
3	Provides an irradiation length that is typical of fast reactor designs	1	5.00	0.25	6.58	1.00	1.00	0.50	1.00	1.00	1.00	1.00
4	Provides a large irradiation volume within the core region	1	5.00	0.25	6.58	0.10	0.10	0.10	1.00	1.00	1.00	1.00
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	1	5.00	0.25	6.58	0.10	0.30	0.30	1.00	1.00	1.00	1.00
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	2	3.00	0.15	3.95	0.50	0.50	0.50	1.00	1.00	1.00	1.00
7	High technical confidence the facility can be available for testing as soon as possible	1	5.00	0.25	6.58	0.10	0.30	0.10	0.30	0.30	0.10	0.10
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	1	5.00	0.25	6.58	0.50	1.00	0.50	0.50	1.00	1.00	1.00
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	4	1.00	0.05	1.32	1.00	1.00	1.00	0.30	1.00	0.30	0.50
10	Provides capabilities that support experimental high-temperature testing	1	5.00	0.25	6.58	0.30	0.30	0.30	1.00	1.00	1.00	1.00
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	3	2.00	0.10	2.63	1.00	1.00	1.00	1.00	1.00	1.00	1.00
12	Lower Capital Investment (Total Project Cost)	2	3.00	0.15	3.95	1.00	0.50	0.50	0.30	0.10	0.10	0.10
13	Lower Annual Operating and Maintenance Costs during operations	3	2.00	0.10	2.63	1.00	0.50	1.00	0.30	0.30	0.30	0.30
14	Lower present value of life cycle costs	2	3.00	0.15	3.95	1.00	0.50	1.00	0.30	0.10	0.10	0.10
15	Shortest schedule to initiate operations	2	3.00	0.15	3.95	1.00	0.50	1.00	0.30	0.30	0.10	0.10
16	Ease of meeting security requirements	4	1.00	0.05	1.32	1.00	1.00	1.00	1.00	1.00	1.00	1.00
17	Greater ease and confidence of compliance with codes, standards, regulations	1	5.00	0.25	6.58	1.00	1.00	1.00	0.30	1.00	0.10	0.10
18	Higher confidence in stakeholder acceptance	2	3.00	0.15	3.95	0.00	0.10	0.10	0.30	1.00	0.10	0.10
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	1	5.00	0.25	6.58	0.00	0.10	0.10	0.50	1.00	1.00	1.00
20	Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)	1	5.00	0.25	6.58	0.00	0.30	0.10	0.50	1.00	1.00	1.00
	Total Calculated Score (using weighted criteria)			3.800	100.00							

Table H-4. VTR AoA Evaluation of Alternatives – Base Case with Alternative Scoring

	Requirement	Importance	Weight	Relative Weight	Normalized Weight	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users.	1	5.00	0.25	6.58	0.00	1.97	0.66	6.58	6.58	6.58	6.58
2	Provides high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	1	5.00	0.25	6.58	0.66	1.97	1.97	6.58	6.58	6.58	6.58
3	Provides an irradiation length that is typical of fast reactor designs	1	5.00	0.25	6.58	6.58	6.58	3.29	6.58	6.58	6.58	6.58
4	Provides a large irradiation volume within the core region	1	5.00	0.25	6.58	0.66	0.66	0.66	6.58	6.58	6.58	6.58
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	1	5.00	0.25	6.58	0.66	1.97	1.97	6.58	6.58	6.58	6.58
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	2	3.00	0.15	3.95	1.97	1.97	1.97	3.95	3.95	3.95	3.95
7	High technical confidence the facility can be available for testing as soon as possible	1	5.00	0.25	6.58	0.66	1.97	0.66	1.97	1.97	0.66	0.66
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	1	5.00	0.25	6.58	3.29	6.58	3.29	3.29	6.58	6.58	6.58
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	4	1.00	0.05	1.32	1.32	1.32	1.32	0.39	1.32	0.39	0.66
10	Provides capabilities that support experimental high-temperature testing	1	5.00	0.25	6.58	1.97	1.97	1.97	6.58	6.58	6.58	6.58
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	3	2.00	0.10	2.63	2.63	2.63	2.63	2.63	2.63	2.63	2.63
12	Lower Capital Investment (Total Project Cost)	2	3.00	0.15	3.95	3.95	1.97	1.97	1.18	0.39	0.39	0.39
13	Lower Annual Operating and Maintenance Costs during operations	3	2.00	0.10	2.63	2.63	1.32	2.63	0.79	0.79	0.79	0.79
14	Lower present value of life cycle costs	2	3.00	0.15	3.95	3.95	1.97	3.95	1.18	0.39	0.39	0.39
15	Shortest schedule to initiate operations	2	3.00	0.15	3.95	3.95	1.97	3.95	1.18	1.18	0.39	0.39
16	Ease of meeting security requirements	4	1.00	0.05	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32
17	Greater ease and confidence of compliance with codes, standards, regulations	1	5.00	0.25	6.58	6.58	6.58	6.58	1.97	6.58	0.66	0.66
18	Higher confidence in stakeholder acceptance	2	3.00	0.15	3.95	0.00	0.39	0.39	1.18	3.95	0.39	0.39
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	1	5.00	0.25	6.58	0.00	0.66	0.66	3.29	6.58	6.58	6.58
20	Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)	1	5.00	0.25	6.58	**0.00**	**1.97**	**0.66**	**3.29**	**6.58**	**6.58**	**6.58**
	Total Calculated Score (using weighted criteria)			3.800	100.00	**42.76**	**47.76**	**42.50**	**67.11**	**83.68**	**71.18**	**71.45**

Table H-5. VTR AoA Evaluation of Alternatives – Scenario 1 – Cost and Schedule Criteria Rated Highest Importance – Evaluation Score

	Requirement	Importance	Weight	Relative Weight	Normalized Weight	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users.	1	5.00	0.25	5.88	0.00	0.30	0.10	1.00	1.00	1.00	1.00
2	Provides high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	1	5.00	0.25	5.88	0.10	0.30	0.30	1.00	1.00	1.00	1.00
3	Provides an irradiation length that is typical of fast reactor designs	1	5.00	0.25	5.88	1.00	1.00	0.50	1.00	1.00	1.00	1.00
4	Provides a large irradiation volume within the core region	1	5.00	0.25	5.88	0.10	0.10	0.10	1.00	1.00	1.00	1.00
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	1	5.00	0.25	5.88	0.10	0.30	0.30	1.00	1.00	1.00	1.00
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	2	3.00	0.15	3.53	0.50	0.50	0.50	1.00	1.00	1.00	1.00
7	High technical confidence the facility can be available for testing as soon as possible	1	5.00	0.25	5.88	0.10	0.30	0.10	0.30	0.30	0.10	0.10
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	1	5.00	0.25	5.88	0.50	1.00	0.50	0.50	1.00	1.00	1.00
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	4	1.00	0.05	1.18	1.00	1.00	1.00	0.30	1.00	0.30	0.50
10	Provides capabilities that support experimental high-temperature testing	1	5.00	0.25	5.88	0.30	0.30	0.30	1.00	1.00	1.00	1.00
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	3	2.00	0.10	2.35	1.00	1.00	1.00	1.00	1.00	1.00	1.00
12	Lower Capital Investment (Total Project Cost)	1	5.00	0.25	5.88	1.00	0.50	0.50	0.30	0.10	0.10	0.10
13	Lower Annual Operating and Maintenance Costs during operations	1	5.00	0.25	5.88	1.00	0.50	1.00	0.30	0.30	0.30	0.30
14	Lower present value of life cycle costs	1	5.00	0.25	5.88	1.00	0.50	1.00	0.30	0.10	0.10	0.10
15	Shortest schedule to initiate operations	1	5.00	0.25	5.88	1.00	0.50	1.00	0.30	0.30	0.10	0.10
16	Ease of meeting security requirements	4	1.00	0.05	1.18	1.00	1.00	1.00	1.00	1.00	1.00	1.00
17	Greater ease and confidence of compliance with codes, standards, regulations	1	5.00	0.25	5.88	1.00	1.00	1.00	0.30	1.00	0.10	0.10
18	Higher confidence in stakeholder acceptance	2	3.00	0.15	3.53	0.00	0.10	0.10	0.30	1.00	0.10	0.10
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	1	5.00	0.25	5.88	0.00	0.10	0.10	0.50	1.00	1.00	1.00
20	Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)	1	5.00	0.25	5.88	0.00	0.30	0.10	0.50	1.00	1.00	1.00
	Total Calculated Score (using weighted criteria)			4.250	100.00							

Table H-6. VTR AoA Evaluation of Alternatives – Scenario 1 – Cost and Schedule Criteria Rated Highest Importance – Alternative Score

	Requirement	Importance	Weight	Relative Weight	Normalized Weight	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users.	1	5.00	0.25	5.88	0.00	1.76	0.59	5.88	5.88	5.88	5.88
2	Provides high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	1	5.00	0.25	5.88	0.59	1.76	1.76	5.88	5.88	5.88	5.88
3	Provides an irradiation length that is typical of fast reactor designs	1	5.00	0.25	5.88	5.88	5.88	2.94	5.88	5.88	5.88	5.88
4	Provides a large irradiation volume within the core region	1	5.00	0.25	5.88	0.59	0.59	0.59	5.88	5.88	5.88	5.88
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	1	5.00	0.25	5.88	0.59	1.76	1.76	5.88	5.88	5.88	5.88
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	2	3.00	0.15	3.53	1.76	1.76	1.76	3.53	3.53	3.53	3.53
7	High technical confidence the facility can be available for testing as soon as possible	1	5.00	0.25	5.88	0.59	1.76	0.59	1.76	1.76	0.59	0.59
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	1	5.00	0.25	5.88	2.94	5.88	2.94	2.94	5.88	5.88	5.88
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	4	1.00	0.05	1.18	1.18	1.18	1.18	0.35	1.18	0.35	0.59
10	Provides capabilities that support experimental high-temperature testing	1	5.00	0.25	5.88	1.76	1.76	1.76	5.88	5.88	5.88	5.88
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	3	2.00	0.10	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35
12	Lower Capital Investment (Total Project Cost)	1	5.00	0.25	5.88	5.88	2.94	2.94	1.76	0.59	0.59	0.59
13	Lower Annual Operating and Maintenance Costs during operations	1	5.00	0.25	5.88	5.88	2.94	5.88	1.76	1.76	1.76	1.76
14	Lower present value of life cycle costs	1	5.00	0.25	5.88	5.88	2.94	5.88	1.76	0.59	0.59	0.59
15	Shortest schedule to initiate operations	1	5.00	0.25	5.88	5.88	2.94	5.88	1.76	1.76	0.59	0.59
16	Ease of meeting security requirements	4	1.00	0.05	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
17	Greater ease and confidence of compliance with codes, standards, regulations	1	5.00	0.25	5.88	5.88	5.88	5.88	1.76	5.88	0.59	0.59
18	Higher confidence in stakeholder acceptance	2	3.00	0.15	3.53	0.00	0.35	0.35	1.06	3.53	0.35	0.35
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	1	5.00	0.25	5.88	0.00	0.59	0.59	2.94	5.88	5.88	5.88
20	Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)	1	5.00	0.25	5.88	**0.00**	**1.76**	**0.59**	**2.94**	**5.88**	**5.88**	**5.88**
	Total Calculated Score (using weighted criteria)			4.250	100.00	**48.82**	**48.00**	**47.41**	**63.18**	**77.06**	**65.41**	**65.65**

Table H-7. VTR AoA Evaluation of Alternatives – Scenario 2 – All Criteria Rated as Highest Importance – Evaluation Score

	Requirement	Importance	Weight	Relative Weight	Normalized Weight	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users.	1	5.00	0.25	5.00	0.00	0.30	0.10	1.00	1.00	1.00	1.00
2	Provides high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	1	5.00	0.25	5.00	0.10	0.30	0.30	1.00	1.00	1.00	1.00
3	Provides an irradiation length that is typical of fast reactor designs	1	5.00	0.25	5.00	1.00	1.00	0.50	1.00	1.00	1.00	1.00
4	Provides a large irradiation volume within the core region	1	5.00	0.25	5.00	0.10	0.10	0.10	1.00	1.00	1.00	1.00
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	1	5.00	0.25	5.00	0.10	0.30	0.30	1.00	1.00	1.00	1.00
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	1	5.00	0.25	5.00	0.50	0.50	0.50	1.00	1.00	1.00	1.00
7	High technical confidence the facility can be available for testing as soon as possible	1	5.00	0.25	5.00	0.10	0.30	0.10	0.30	0.30	0.10	0.10
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	1	5.00	0.25	5.00	0.50	1.00	0.50	0.50	1.00	1.00	1.00
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	1	5.00	0.25	5.00	1.00	1.00	1.00	0.30	1.00	0.30	0.50
10	Provides capabilities that support experimental high-temperature testing	1	5.00	0.25	5.00	0.30	0.30	0.30	1.00	1.00	1.00	1.00
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	1	5.00	0.25	5.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
12	Lower Capital Investment (Total Project Cost)	1	5.00	0.25	5.00	1.00	0.50	0.50	0.30	0.10	0.10	0.10
13	Lower Annual Operating and Maintenance Costs during operations	1	5.00	0.25	5.00	1.00	0.50	1.00	0.30	0.30	0.30	0.30
14	Lower present value of life cycle costs	1	5.00	0.25	5.00	1.00	0.50	1.00	0.30	0.10	0.10	0.10
15	Shortest schedule to initiate operations	1	5.00	0.25	5.00	1.00	0.50	1.00	0.30	0.30	0.10	0.10
16	Ease of meeting security requirements	1	5.00	0.25	5.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
17	Greater ease and confidence of compliance with codes, standards, regulations	1	5.00	0.25	5.00	1.00	1.00	1.00	0.30	1.00	0.10	0.10
18	Higher confidence in stakeholder acceptance	1	5.00	0.25	5.00	0.00	0.10	0.10	0.30	1.00	0.10	0.10
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	1	5.00	0.25	5.00	0.00	0.10	0.10	0.50	1.00	1.00	1.00
20	Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)	1	5.00	0.25	5.00	0.00	0.30	0.10	0.50	1.00	1.00	1.00
	Total Calculated Score (using weighted criteria)			5.000	100.00							

Table H-8. VTR AoA Evaluation of Alternatives – Scenario 2 – All Criteria Rates as Highest Importance – Alternative Score

	Requirement	Importance	Weight	Relative Weight	Normalized Weight	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users.	1	5.00	0.25	5.00	0.00	1.50	0.50	5.00	5.00	5.00	5.00
2	Provides high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	1	5.00	0.25	5.00	0.50	1.50	1.50	5.00	5.00	5.00	5.00
3	Provides an irradiation length that is typical of fast reactor designs	1	5.00	0.25	5.00	5.00	5.00	2.50	5.00	5.00	5.00	5.00
4	Provides a large irradiation volume within the core region	1	5.00	0.25	5.00	0.50	0.50	0.50	5.00	5.00	5.00	5.00
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	1	5.00	0.25	5.00	0.50	1.50	1.50	5.00	5.00	5.00	5.00
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	1	5.00	0.25	5.00	2.50	2.50	2.50	5.00	5.00	5.00	5.00
7	High technical confidence the facility can be available for testing as soon as possible	1	5.00	0.25	5.00	0.50	1.50	0.50	1.50	1.50	0.50	0.50
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	1	5.00	0.25	5.00	2.50	5.00	2.50	2.50	5.00	5.00	5.00
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	1	5.00	0.25	5.00	5.00	5.00	5.00	1.50	5.00	1.50	2.50
10	Provides capabilities that support experimental high-temperature testing	1	5.00	0.25	5.00	1.50	1.50	1.50	5.00	5.00	5.00	5.00
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	1	5.00	0.25	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
12	Lower Capital Investment (Total Project Cost)	1	5.00	0.25	5.00	5.00	2.50	2.50	1.50	0.50	0.50	0.50
13	Lower Annual Operating and Maintenance Costs during operations	1	5.00	0.25	5.00	5.00	2.50	5.00	1.50	1.50	1.50	1.50
14	Lower present value of life cycle costs	1	5.00	0.25	5.00	5.00	2.50	5.00	1.50	0.50	0.50	0.50
15	Shortest schedule to initiate operations	1	5.00	0.25	5.00	5.00	2.50	5.00	1.50	1.50	0.50	0.50
16	Ease of meeting security requirements	1	5.00	0.25	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
17	Greater ease and confidence of compliance with codes, standards, regulations	1	5.00	0.25	5.00	5.00	5.00	5.00	1.50	5.00	0.50	0.50
18	Higher confidence in stakeholder acceptance	1	5.00	0.25	5.00	0.00	0.50	0.50	1.50	5.00	0.50	0.50
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	1	5.00	0.25	5.00	0.00	0.50	0.50	2.50	5.00	5.00	5.00
20	Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)	1	5.00	0.25	5.00	**0.00**	**1.50**	**0.50**	**2.50**	**5.00**	**5.00**	**5.00**
	Total Calculated Score (using weighted criteria)			5.000	100.00	**53.50**	**53.00**	**52.50**	**64.50**	**80.50**	**66.00**	**67.00**

Table H-9. VTR AoA Evaluation of Alternatives – Scenario 3 – Technical Criteria Downgraded to Very Important – Evaluation Score

	Requirement	Importance	Weight	Relative Weight	Normalized Weight	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users.	2	3.00	0.15	4.55	0.00	0.30	0.10	1.00	1.00	1.00	1.00
2	Provides high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	2	3.00	0.15	4.55	0.10	0.30	0.30	1.00	1.00	1.00	1.00
3	Provides an irradiation length that is typical of fast reactor designs	2	3.00	0.15	4.55	1.00	1.00	0.50	1.00	1.00	1.00	1.00
4	Provides a large irradiation volume within the core region	2	3.00	0.15	4.55	0.10	0.10	0.10	1.00	1.00	1.00	1.00
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	2	3.00	0.15	4.55	0.10	0.30	0.30	1.00	1.00	1.00	1.00
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	2	3.00	0.15	4.55	0.50	0.50	0.50	1.00	1.00	1.00	1.00
7	High technical confidence the facility can be available for testing as soon as possible	2	3.00	0.15	4.55	0.10	0.30	0.10	0.30	0.30	0.10	0.10
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	2	3.00	0.15	4.55	0.50	1.00	0.50	0.50	1.00	1.00	1.00
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	4	1.00	0.05	1.52	1.00	1.00	1.00	0.30	1.00	0.30	0.50
10	Provides capabilities that support experimental high-temperature testing	2	3.00	0.15	4.55	0.30	0.30	0.30	1.00	1.00	1.00	1.00
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	2	3.00	0.15	4.55	1.00	1.00	1.00	1.00	1.00	1.00	1.00
12	Lower Capital Investment (Total Project Cost)	1	5.00	0.25	7.58	1.00	0.50	0.50	0.30	0.10	0.10	0.10
13	Lower Annual Operating and Maintenance Costs during operations	1	5.00	0.25	7.58	1.00	0.50	1.00	0.30	0.30	0.30	0.30
14	Lower present value of life cycle costs	1	5.00	0.25	7.58	1.00	0.50	1.00	0.30	0.10	0.10	0.10
15	Shortest schedule to initiate operations	1	5.00	0.25	7.58	1.00	0.50	1.00	0.30	0.30	0.10	0.10
16	Ease of meeting security requirements	4	1.00	0.05	1.52	1.00	1.00	1.00	1.00	1.00	1.00	1.00
17	Greater ease and confidence of compliance with codes, standards, regulations	1	5.00	0.25	7.58	1.00	1.00	1.00	0.30	1.00	0.10	0.10
18	Higher confidence in stakeholder acceptance	2	3.00	0.15	4.55	0.00	0.10	0.10	0.30	1.00	0.10	0.10
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	2	3.00	0.15	4.55	0.00	0.10	0.10	0.50	1.00	1.00	1.00
20	Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)	2	3.00	0.15	4.55	0.00	0.30	0.10	0.50	1.00	1.00	1.00
	Total Calculated Score (using weighted criteria)			3.300	100.00							

Table H-10. VTR AoA Evaluation of Alternatives – Scenario 3 – Technical Criteria Downgraded to Very Important – Alternative Score

	Requirement	Importance	Weight	Relative Weight	Normalized Weight	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users.	2	3.00	0.15	4.55	0.00	1.36	0.45	4.55	4.55	4.55	4.55
2	Provides high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	2	3.00	0.15	4.55	0.45	1.36	1.36	4.55	4.55	4.55	4.55
3	Provides an irradiation length that is typical of fast reactor designs	2	3.00	0.15	4.55	4.55	4.55	2.27	4.55	4.55	4.55	4.55
4	Provides a large irradiation volume within the core region	2	3.00	0.15	4.55	0.45	0.45	0.45	4.55	4.55	4.55	4.55
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	2	3.00	0.15	4.55	0.45	1.36	1.36	4.55	4.55	4.55	4.55
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	2	3.00	0.15	4.55	2.27	2.27	2.27	4.55	4.55	4.55	4.55
7	High technical confidence the facility can be available for testing as soon as possible	2	3.00	0.15	4.55	0.45	1.36	0.45	1.36	1.36	0.45	0.45
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	2	3.00	0.15	4.55	2.27	4.55	2.27	2.27	4.55	4.55	4.55
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	4	1.00	0.05	1.52	1.52	1.52	1.52	0.45	1.52	0.45	0.76
10	Provides capabilities that support experimental high-temperature testing	2	3.00	0.15	4.55	1.36	1.36	1.36	4.55	4.55	4.55	4.55
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	2	3.00	0.15	4.55	4.55	4.55	4.55	4.55	4.55	4.55	4.55
12	Lower Capital Investment (Total Project Cost)	1	5.00	0.25	7.58	7.58	3.79	3.79	2.27	0.76	0.76	0.76
13	Lower Annual Operating and Maintenance Costs during operations	1	5.00	0.25	7.58	7.58	3.79	7.58	2.27	2.27	2.27	2.27
14	Lower present value of life cycle costs	1	5.00	0.25	7.58	7.58	3.79	7.58	2.27	0.76	0.76	0.76
15	Shortest schedule to initiate operations	1	5.00	0.25	7.58	7.58	3.79	7.58	2.27	2.27	0.76	0.76
16	Ease of meeting security requirements	4	1.00	0.05	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52
17	Greater ease and confidence of compliance with codes, standards, regulations	1	5.00	0.25	7.58	7.58	7.58	7.58	2.27	7.58	0.76	0.76
18	Higher confidence in stakeholder acceptance	2	3.00	0.15	4.55	0.00	0.45	0.45	1.36	4.55	0.45	0.45
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	2	3.00	0.15	4.55	0.00	0.45	0.45	2.27	4.55	4.55	4.55
20	Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)	2	3.00	0.15	4.55	**0.00**	**1.36**	**0.45**	**2.27**	**4.55**	**4.55**	**4.55**
	Total Calculated Score (using weighted criteria)			3.300	100.00	**57.73**	**51.21**	**55.30**	**59.24**	**72.58**	**58.18**	**58.48**

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Table H-11. VTR AoA Evaluation of Alternatives – Scenario 4 – Linear Scaling of Weights – Evaluation Score

	Requirement	Importance	Weight	Relative Weight	Normalized Weight	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users.	1	4.00	0.20	6.15	0.00	0.30	0.10	1.00	1.00	1.00	1.00
2	Provides high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	1	4.00	0.20	6.15	0.10	0.30	0.30	1.00	1.00	1.00	1.00
3	Provides an irradiation length that is typical of fast reactor designs	1	4.00	0.20	6.15	1.00	1.00	0.50	1.00	1.00	1.00	1.00
4	Provides a large irradiation volume within the core region	1	4.00	0.20	6.15	0.10	0.10	0.10	1.00	1.00	1.00	1.00
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	1	4.00	0.20	6.15	0.10	0.30	0.30	1.00	1.00	1.00	1.00
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	2	3.00	0.15	4.62	0.50	0.50	0.50	1.00	1.00	1.00	1.00
7	High technical confidence the facility can be available for testing as soon as possible	1	4.00	0.20	6.15	0.10	0.30	0.10	0.30	0.30	0.10	0.10
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	1	4.00	0.20	6.15	0.50	1.00	0.50	0.50	1.00	1.00	1.00
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	4	1.00	0.05	1.54	1.00	1.00	1.00	0.30	1.00	0.30	0.50
10	Provides capabilities that support experimental high-temperature testing	1	4.00	0.20	6.15	0.30	0.30	0.30	1.00	1.00	1.00	1.00
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	3	2.00	0.10	3.08	1.00	1.00	1.00	1.00	1.00	1.00	1.00
12	Lower Capital Investment (Total Project Cost)	2	3.00	0.15	4.62	1.00	0.50	0.50	0.30	0.10	0.10	0.10
13	Lower Annual Operating and Maintenance Costs during operations	3	2.00	0.10	3.08	1.00	0.50	1.00	0.30	0.30	0.30	0.30
14	Lower present value of life cycle costs	2	3.00	0.15	4.62	1.00	0.50	1.00	0.30	0.10	0.10	0.10
15	Shortest schedule to initiate operations	2	3.00	0.15	4.62	1.00	0.50	1.00	0.30	0.30	0.10	0.10
16	Ease of meeting security requirements	4	1.00	0.05	1.54	1.00	1.00	1.00	1.00	1.00	1.00	1.00
17	Greater ease and confidence of compliance with codes, standards, regulations	1	4.00	0.20	6.15	1.00	1.00	1.00	0.30	1.00	0.10	0.10
18	Higher confidence in stakeholder acceptance	2	3.00	0.15	4.62	0.00	0.10	0.10	0.30	1.00	0.10	0.10
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	1	4.00	0.20	6.15	0.00	0.10	0.10	0.50	1.00	1.00	1.00
20	Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)	1	4.00	0.20	6.15	0.00	0.30	0.10	0.50	1.00	1.00	1.00
	Total Calculated Score (using weighted criteria)			3.250	100.00							

Table H-12. VTR AoA Evaluation of Alternatives – Scenario 4 – Linear Scaling of Weights – Alternative Score

	Requirement	Importance	Weight	Relative Weight	Normalized Weight	Alt 1 Status Quo	Alt 2 ATR	Alt 3 HFIR	Alt 4 FFTF	Alt 5 SFTR	Alt 6 LFTR	Alt 7 MSFTR
1	Provides a source of fast neutrons at a neutron flux, sufficient to enable research for an optimal base of prospective users.	1	4.00	0.20	6.15	0.00	1.85	0.62	6.15	6.15	6.15	6.15
2	Provides high neutron dose rate for materials testing [quantified as displacement per atom (dpa)]	1	4.00	0.20	6.15	0.62	1.85	1.85	6.15	6.15	6.15	6.15
3	Provides an irradiation length that is typical of fast reactor designs	1	4.00	0.20	6.15	6.15	6.15	3.08	6.15	6.15	6.15	6.15
4	Provides a large irradiation volume within the core region	1	4.00	0.20	6.15	0.62	0.62	0.62	6.15	6.15	6.15	6.15
5	Provides innovative testing capabilities through flexibility in testing configuration, testing closed loop environments	1	4.00	0.20	6.15	0.62	1.85	1.85	6.15	6.15	6.15	6.15
6	In addition to traditional measurement techniques, provides the ability to test advanced sensors and instrumentation for the core and test positions	2	3.00	0.15	4.62	2.31	2.31	2.31	4.62	4.62	4.62	4.62
7	High technical confidence the facility can be available for testing as soon as possible	1	4.00	0.20	6.15	0.62	1.85	0.62	1.85	1.85	0.62	0.62
8	Expedites experiment lifecycle by enabling easy access to existing support facilities for experiments fabrication and post-irradiation examination	1	4.00	0.20	6.15	3.08	6.15	3.08	3.08	6.15	6.15	6.15
9	Provides life-cycle management for both test fuels and driver fuel while minimizing cost and schedule impacts including management of discharged fuel	4	1.00	0.05	1.54	1.54	1.54	1.54	0.46	1.54	0.46	0.77
10	Provides capabilities that support experimental high-temperature testing	1	4.00	0.20	6.15	1.85	1.85	1.85	6.15	6.15	6.15	6.15
11	Provides capabilities for irradiation with neutrons of a lower energy spectrum	3	2.00	0.10	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08
12	Lower Capital Investment (Total Project Cost)	2	3.00	0.15	4.62	4.62	2.31	2.31	1.38	0.46	0.46	0.46
13	Lower Annual Operating and Maintenance Costs during operations	3	2.00	0.10	3.08	3.08	1.54	3.08	0.92	0.92	0.92	0.92
14	Lower present value of life cycle costs	2	3.00	0.15	4.62	4.62	2.31	4.62	1.38	0.46	0.46	0.46
15	Shortest schedule to initiate operations	2	3.00	0.15	4.62	4.62	2.31	4.62	1.38	1.38	0.46	0.46
16	Ease of meeting security requirements	4	1.00	0.05	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
17	Greater ease and confidence of compliance with codes, standards, regulations	1	4.00	0.20	6.15	6.15	6.15	6.15	1.85	6.15	0.62	0.62
18	Higher confidence in stakeholder acceptance	2	3.00	0.15	4.62	0.00	0.46	0.46	1.38	4.62	0.46	0.46
19	Greater ability to regain and sustain U.S. technology leadership and to enable the competitiveness of U.S.-based industry entities in the advanced reactor markets	1	4.00	0.20	6.15	0.00	0.62	0.62	3.08	6.15	6.15	6.15
20	Adequate availability to meet user needs and minimum conflict with other exiting missions (if any)	1	4.00	0.20	6.15	**0.00**	**1.85**	**0.62**	**3.08**	**6.15**	**6.15**	**6.15**
	Total Calculated Score (using weighted criteria)			3.250	100.00	**45.1**	**48.2**	**40.6**	**67.8**	**78.9**	**69.1**	**69.4**

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APPENDIX I SITE OBSERVATIONS

I.1 Introduction

This VTR AoA did not include a comprehensive site assessment for supporting the VTR mission, as the AoA is not a siting study. However, in performing this AoA, since several viable alternatives already have site-specific locations, several site conditions / characteristics became potentially relevant to the analysis. This appendix discusses the observations resulting from the collection and use of site-specific information during the AoA.

I.1.1 Background

Existing test reactors that constitute some of the potentially viable alternatives for this VTR AoA are located at three DOE sites: the ATR at INL, the HFIR at ORNL and the FFTF at Pacific Northwest National Laboratory (PNNL)/Hanford. Consequently, members of the VTR AoA Team visited each of these sites to collect information on the alternative, including the supporting infrastructure and operational environment. Additionally, the AoA considered potential site impacts for existing facilities that might discriminate potential alternatives in areas such as cost, schedule, regulation, and supporting infrastructure. Further, for this VTR AoA, it was preferable to consider whether there might be discriminating factors between the alternatives for several generic types of sites: a generic government-owned site as part of an existing reactor alternative, a government owned site without an existing reactor alternative, and a generic non-government owned site.

The three sites with existing reactor alternatives addressed the first category. A generic government-owned site without an existing reactor alternative could be any one of several with substantial nuclear infrastructure and a history of reactor technology, but no current test reactor. The SRS/Savannah River National Laboratory (SRNL) was visited and used for this purpose. The generic non-government site considered was a hypothetical location with representative characteristics.

I.1.2 Collection And Use

During the conduct of the VTR AoA, site information was obtained through the site visits, literature review, and team-member experience. The VTR AoA Team applied this body of knowledge to the analysis in the following ways:

- For viable technical alternatives using existing test reactors
  - Site-specific issues were considered when scoring the evaluation criteria
  - Site-specific requirements relevant to the AoA were included in cost estimates as appropriate
- For new build reactor designs
  - New reactors were evaluated in a non-site specific manner
  - Cost estimates did not reflect site-specific considerations
- Generic sites considerations explored to inform future project site selection
  - Advantages of generic DOE versus non-DOE sites
  - Site Infrastructure / facility needs relevant to the AoA identified

A variety of general site characteristics and supporting technologies and infrastructure needs were considered for hosting the VTR mission. The input on these topics were used to advise the scoring where appropriate in several of the evaluation criteria and in several of the risk analysis topics. These inputs were not used directly to create any scoring or evaluation of sites. The site characteristics and supporting technologies and infrastructure needs that were considered are listed in two tables at the end of this appendix; Table I-1 for site observations for facilities hosting existing reactor alternatives at each site, and Table I-2 for site observations related to hosting a 'new build' alternative at each site.

I.2 Site Characteristics

Site characteristics observed while visiting sites in support of the VTR AoA are discussed in the following sections.

I.2.1 INL

INL is a DOE NE landlord site and provides a comprehensive range of supporting infrastructure for nuclear technology. In all, 52 reactors have been built and operated at INL since it was established as the National Reactor Testing Station 70 years ago, including the Experimental Breeder Reactor II, a fast neutron test facility. The site has demonstrated capability for transportation, construction and operation, safety, security, nuclear material management, regulatory compliance, etc. The ATR facility is operated by DOE NE and has established fuel supply and management, test support and PIE capability. The TREAT facility was reactivated in 2018 to provide transient testing capability for advanced nuclear fuels and materials. It is the only such transient test facility in the U.S. The site has substantial infrastructure for nuclear operations, safety, security, material management, etc. Major support capabilities exist at the Materials and Fuels Complex including fuel fabrication, inert and air hot cells, irradiated materials characterization equipment and laboratories for chemistry, materials and instrumentation. State and local stakeholder support is also generally favorable.

ATR

The capabilities of ATR are described in Appendix D. When considering a new reactor build for VTR, the construction, operations, and maintenance experience at INL with the ATR would likely have a positive impact on cost and schedule for a new test reactor. The Test Train Assembly Facility (TTAF) next to ATR has fabrication equipment and experienced technicians that could be also be used in support of VTR.

Materials and Fuels Complex (MFC)

The MFC is a large, secure nuclear area at INL with many capabilities to support the VTR mission. It would be possible to site the VTR at MFC by extending the existing fence or Perimeter Intrusion Detection and Assessment System (PIDAS) into adjacent INL land. The numerous MFC facilities have supported advanced nuclear technology R&D for many decades and could absorb the VTR support mission in addition to current missions.

Fuel Manufacturing Facility (FMF)

The FMF is located in a Hazard Category 2 nuclear facility that has the capability to fabricate metal and ceramic fuels containing uranium, plutonium and other transuranic elements. It was used to fabricate driver fuel for EBR-II, experimental fuels for EBR-II and FFTF, and could be used to fabricate VTR driver fuels and experimental fuels containing transuranic elements. It contains several inert gloveboxes and a storage vault. Additional gloveboxes, injection casting lines and ventilation system upgrades would be required to support the VTR workload.

Experimental Fuels Facility and Fuel Assembly and Storage Building

These two facilities are used to fabricate experiment samples and fueled test rods for ATR and Transient Reactor and Test Facility (TREAT) experiments. They could also be used to support VTR experiment samples and test rods using low enriched uranium metal and ceramic fuels.

Zero Power Physics Reactor (ZPPR) Facility

The ZPPR reactor was shut down in 1992, but the facility remains in use for nuclear energy and national security support missions. It is a Hazard Category 2 nuclear facility. It has a large storage vault that could be used for storage of fresh VTR fuels containing highly enriched uranium (HEU) and/or plutonium. Additional equipment for assembling and final inspection of driver fuel and experimental fuels could be installed here.

Hot Fuels Examination Facility (HFEF)

HFEF is used to conduct non-destructive and destructive post-irradiation examinations of irradiated fuels and materials. It has the largest inert atmosphere hot cell dedicated to nuclear materials research in the U.S., with 15 separate work stations. Inert hot cells are critical to support the handling and examination of metal fuels including sodium-bonded fuels. It can receive and handle full length commercial fuel rods. A 300 kw Training, Research, Isotopes, General Atomics (TRIGA) reactor is in the HFEF basement and is used for neutron radiography. It has the capability to support PIE of anticipated VTR fuels and materials experiments.

Irradiated Materials Characterization Laboratory (IMCL)

IMCL is a new facility built to prepare and conduct microstructural-level investigations on irradiated fuels and materials transported from the nearby HFEF. It contains the most modern state-of-the-art equipment and capabilities available for detailed analysis, including scanning electron microscopes (SEM), shielded electron probe microscope (EPMA), transmission electron microscopes (TEM), electron backscattering diffraction, x-ray diffraction, electron micro-probe analysis, electron energy loss spectroscopy, energy-dispersive spectroscopy, and thermophysical property measurements.

Sample Preparation Laboratory (SPL)

The SPL is under construction next to IMCL and is expected to be completed in 2022. It will provide instrumentation and capabilities for analysis of irradiated materials, using techniques not currently available such as such as secondary ion mass spectrometry and x-ray photoelectron spectroscopy for chemical characterization of oxide films and fracture surfaces. The SPL will enable better understanding of material aging issues, seeking improved materials for use in advanced nuclear energy systems. It could be used to support VTR fuels and materials experiments.

Analytical Laboratory

This laboratory is used for chemical and isotopic analysis of fuels and materials. It could be used to support VTR fuels and experiment preparation.

Fuel Conditioning Facility (FCF)

The FCF is currently being used to treat sodium-bonded EBR-II and FFTF fuels by removing the sodium, separating the uranium, and putting the remaining components into a stable waste form for interim storage. This mission is expected to be completed by 2028, after which the facility could be used to treat VTR fuels for interim storage. Depending on the generation rate of spent VTR driver fuel, additional capacity might be required.

Radioactive Scrap and Waste Facility (RSWF)

The RSWF is located inside the MFC and is used for in-ground storage of EBR-II and FFTF treated fuel waste and other waste materials. It could be used for interim storage of VTR used fuel and experiment wastes. The site is large and additional storage positions could be created if needed. If the waste contains transuranic elements or HEU, a PIDAS would need to be erected, or the waste could be stored inside the VTR PIDAS.

I.2.2 ORNL

The Oak Ridge Site and ORNL is a DOE Office of Science (DOE SC) landlord site. ORNL provides a broad range of supporting infrastructure for construction and operation, safety, security, nuclear material management, regulatory compliance, etc. The HFIR facility is operated by the DOE Office of Science as a nuclear technology user facility and has established fuel supply and management, test support and significant PIE capability. DOE NE and other users have a significant presence utilizing the irradiation capabilities of HFIR including the fabrication of specimens, and PIE of irradiated materials including those from off-site (e.g., commercial nuclear fuel). The site has substantial infrastructure for nuclear operations, safety, security, material management, etc. State and local stakeholder support is generally favorable.

A brief description of the facilities highlighted during the site visit and extracted from the facility "fact sheets" follows.

HFIR

The capabilities of HFIR are described in Appendix D. The Gamma Irradiation Facility (GIF) utilizes spent fuel from HFIR as a gamma source for materials testing. The facilities and experienced personnel at ORNL support operations of HFIR including hot cells for PIE radiochemical labs, fabrication of test articles for irradiation (material, ceramic fuels, include particle, etc.) and instrumentation. These would support the use of HFIR/ORNL to support the VTR mission as well as a potential new test reactor on the site.

Radiochemical Engineering Development Center (REDC)

"The REDC is a multipurpose radiochemical processing and research facility that includes laboratories, glove boxes, and heavily shielded hot cells. The REDC includes personnel with radiochemical processing expertise and special equipment and systems to support the nation's research and development (R&D) needs in the production of unique radionuclides for use in research, defense, medical, and industrial applications. The REDC comprises two facilities – Building 7920, a two-level structure built in 1966, and Building 7930, a three-level structure built in 1968. Both buildings are classified as hazard category 2 nuclear facilities and include hot and cold laboratories, 16 hot cells, and high bay space."

Irradiated Material Examination and Testing Facility (IMET)

The IMET Facility, was designed and built in 1950 as a hot cell facility. It is a two-story block and brick structure with a two-story high bay that houses six heavily shielded cells and an array of sixty shielded storage wells. It includes the SPL with its associated laboratory hood and glove boxes, an Operating

Area, where the control and monitoring instruments supporting the in-cell test equipment are staged, a utility corridor, a hot equipment storage area, a tank vault room, office space, a trucking area with access to the high bay, and an outside steel building for storage. The tests and examination are conducted in six examination "hot" cells and/or in a laboratory hood or modified glove boxes in the SPL.

Activated Experiment Encapsulation Laboratory (AXEL)

The AXEL is a standalone facility located in the IMET hot cell facility. It is to encapsulate or re-encapsulate highly activated samples or other target materials into irradiation experiments in a hot cell environment.

Irradiated Fuels Examination Laboratory (IFEL)

The IFEL was initially designed and constructed in 1963 to permit the safe handling of increasing levels of radiation in the chemical, physical, and metallurgical examination of nuclear reactor fuel elements and reactor parts. The IFEL is classified as a Category 2 nuclear facility. It contains 6 hot cells, an SEM cell, etc. The facility can perform nondestructive and destructive testing of irradiated materials up to full-length LWR fuel elements for PIE.

Capsule Assembly Laboratory (CAL)

The CAL is a 1900 ft2 laboratory designed to support fabrication and assembly of materials irradiation experiments for the High Flux Isotope Reactor and other materials test reactors.

Personnel with extensive experience in all aspects of fuels and materials irradiation experiment design, assembly, and disassembly support the CAL and assure that experiments meet customer and reactor operation requirements.

Coated Particle Fuel Development Laboratory

The Coated Particle Fuel Development Laboratory is a modern, integrated facility certified for NQA-1 laboratory-scale fabrication and characterization of uranium-bearing coated particle fuel (CPF). Within this facility, tristructural isotropic (TRISO) coatings of carbon and silicon carbide are deposited on a variety of fuel kernels by chemical vapor deposition (CVD). Fuel elements are fabricated by packing the particles into graphite matrix forms, such as cylindrical compacts or spherical pebbles. State-of-the-art characterization is performed to determine fuel properties and defect populations prior to irradiation testing of the fuel performance.

Low Activation Materials Development and Analysis Laboratory (LAMDA)

The LAMDA facility is a multipurpose laboratory for evaluation of materials with low radiological threat without the need for remote manipulation. The LAMDA laboratories are equipped for analysis of samples at <100 mR/hr at 30 cm. This mode of operation allows for more precise and delicate sample handling than in traditional hot cells.

I.2.3 Hanford/PNNL

The Hanford site and PNNL are in eastern Washington State. The Hanford site is undergoing extended remediation following decades of defense mission use. The Fast Flux Test Facility (FFTF) is a deactivated fast-spectrum test reactor in the 400 Area of the site.

FFTF

The FFTF Restart Alternative involves the restart of a 400 MWth sodium-cooled fast reactor that was designed to provide extensive material and fuel irradiation testing in high-flux fast-neutron environments. FFTF used oxide driver fuel, tested metal fuel and operated from 1982 through 1992. It provided a peak flux of more than 4E+15 and a large test volume. It is currently shutdown, deactivated, and in a safe storage condition with all fuel and sodium removed and an argon cover gas applied to all systems. The building is closed and powered down, and visually inspected annually. When operational, FFTF was used to test fuels and materials for fast reactors and is potentially capable of being reactivated to meet the fast neutron irradiation requirements of the VTR project. There are significant technical and experimental challenges that would have to be addressed if this option were selected as the preferred alternative. These challenges include component age-related material degradation, repairs to and recertification of systems modified to support deactivation, upgrades to meet current codes and standards including seismic, and upgrades to meet potential user experimental needs. An extensive list of evaluations to address potential restart issues has been partially drafted in the past, but not acted on.

MASF and FMEF

During FFTF operation, the nearby Maintenance and Storage Facility (MASF) provided operational and experimental support. MASF is now fully engaged in the Hanford site remediation activities and may or may not be during the VTR mission timescale – and is considered ‘currently unavailable’. The nearby FMEF was built to support while FFTF was operating to support further testing, but the reactor was shut down prior to FMEF completion. FMEF is a large (~ 175,000 sq-ft) high-capacity facility that was designed to supply fuel fabrication, testing, post-irradiation examination and storage for both FFTF and the Clinch River Breeder Reactor. It contains an unused oxide fuel production line and extensive hot cells including large inert gas PIE facilities. FMEF was never fully furnished and operated but could potentially be reactivated, refurbished and equipped to provide support for driver and test fuel fabrication, pre- and post-irradiation examination of test fuels and materials and both fresh and spent fuel management.

PNNL, RPL and Hanford Site

The Hanford site and PNNL can provide some supporting infrastructure for transportation, construction and operation, safety, security, nuclear material management, regulatory compliance, etc. – although much of the site is in the process of environmental clean-up and closure. Substantial support capabilities exist elsewhere at PNNL including the Radiochemical Processing Laboratory (RPL) complex with hot cells for fuel PIE and laboratories for radio-chemistry, irradiated materials and instrumentation. The RPL includes the High Level Radiochemistry Facility (HLRF) and the Shielded Analytical Laboratory (SAL). The Hanford site and the PNNL laboratory support extensive staff with nuclear expertise, although much is focused on site remediation.

More discussion was observed at this site than others involving stakeholder support and is noted here. Stakeholder support is mixed. There are pockets of community support for the restart of FFTF or another nuclear mission; however, there is extensive state or regional opposition to anything that could potentially impact the environmental closure mission. While there is a mix of local and regional support and opposition for reuse of the FFTF, there was little support voiced for a new irradiation test reactor.

I.2.4 SRS/SRNL

The Savannah River Site/SRNL was considered as the generic government-owned site not having an existing research reactor alternative. The SRS and SRNL have extensive history in nuclear reactor operation and provide a full range of supporting infrastructure for transportation, construction and operation, safety, security, nuclear material management, regulatory compliance, etc. The storage and treatment of spent nuclear fuel from HFIR is an ongoing mission at SRS. There is also potential fuel supply currently stored at SRS, including FFTF fuel that was never used for that reactor. In addition, there is potential synergy with the ongoing surplus plutonium disposition mission of National Nuclear Security Administration (NNSA) that may offer an opportunity as a source of test reactor fuel. There are also substantial support capabilities currently available at SRNL, including hot cells and laboratories for chemistry, materials and instrumentation.

DOE EM is the landlord at SRS and its mission is environmental cleanup. However, NNSA is using some of the existing facilities for ongoing missions. The Mixed Oxide Fuel Fabrication Facility (MFFF) project was recently cancelled by the Administration, leaving a partially completed multi-billion-dollar facility available for repurpose. NNSA has proposed dedicating the MFFF to a plutonium pit production mission. NNSA is also embarking on a revised plutonium disposition strategy that focuses on dilution and disposal, in which SRS will play a key role. It currently appears that the MFFF will probably not be available to support VTR; however, there may be some capability for DOE NE to use some existing SRS facilities for VTR support in a synergistic manner with NNSA activities.

It is likely that there would be appropriate stakeholder acceptance for a new reactor focused mission at SRS; however, there is an ongoing issue with the State of South Carolina regarding plutonium storage at the site that could impact local acceptance of a new nuclear mission.

SRNL

The SRNL has 16 shielded hot cells in very good condition, some of which could be made available for VTR support. The cells could handle full size fuel rods for inspection and destructive PIE, by manipulating overhead concrete blocks or walls between adjacent cells. The hot cells contain air and are not configured for inert gas atmosphere, so handling sodium bonded fast reactor metal fuels would require modifications. Some PIE equipment such as TEM, SEM, FIB and mass spectrometers would need upgrading. NNSA plans to upgrade some of the analytical equipment for the pit production mission.

The SRNL has a 20,000 square foot unused space that was previously used to develop and fabricate prototype metal fuels for the SRS production reactors, all of which have been shut down for nearly 30 years. Equipment such as furnaces, arc melter, casting rigs, and metal fuel slug extrusion equipment are in the space but would need major refurbishment or replacement if they were to be used to support VTR fuel fabrication. SRNL is also close to the site boundary. If Pu based fuels are to be used for VTR, additional shielding and security would be required.

SRNL managers indicated that experienced staff are available to support advanced fuels development at SRNL. Construction workers in all nuclear trades are plentiful because of the nearby Vogtle reactor construction project.

SRS

The SRS site is very large (310 square miles) and has plenty of space available for new construction. It has many nuclear facilities, most of which were built to support the nuclear weapons program. Its focus today is on environmental cleanup, although there is ongoing NNSA work and new construction.

In addition, NNSA is looking at SRS for a dilute and dispose option for disposition of excess weapons grade plutonium, now that the mixed oxide fuel option has been dropped.

H Canyon

The H Canyon at SRS is being used to chemically separate uranium and impurities from spent fuel and downblend the uranium into LEU for commercial reactor applications. It could be modified to recover plutonium if needed. The HB Line atop H Canyon separated and blended transuranic materials for the space program and other missions. HB Line is currently being placed in standby awaiting any future missions. Both facilities have capabilities that could be applicable to the VTR program. However, H Canyon is over 60 years old and HB Line is nearly 40 years old, and it is not known how much longer these facilities will be available.

K Area

The K Area at SRS contains the shutdown K Reactor and support facilities plus additional storage facilities. It is currently being used to store excess plutonium, HEU and heavy water. There is a quantity of fresh FFTF MOX fuel stored there also. Its largest current mission is demonstrating the down-blending process for excess weapons plutonium in preparation for shipment to the Waste Isolation Pilot Plant (WIPP) in New Mexico. One glovebox is in operation and three more are being considered to accomplish the full down-blending mission, which could take over 30 years to complete.

K Area is a security Cat 1 nuclear facility with appropriate security in place. International Atomic Energy Agency (IAEA) inspections are authorized. K Area has large below grade areas available for storage of special nuclear material (SNM) that could be made available for a VTR mission with security and plant modifications. A 2014 study of excess plutonium disposition options analyzed K Area for fabrication of metal fuels for fast reactor application. If VTR were to require U-Pu-Zr metal fuels, they could be produced here in synergy with the "dilute and dispose" option. This would reduce the amount of plutonium that would need to be shipped to WIPP for disposal by up to one metric ton per year. The K Area landlord is DOE Environmental Management (DOE EM). NNSA pays for security, facility use and storage.

Mixed Oxide Fuel Fabrication Facility

Secretary Perry notified Congress in 2018 that the MFFF construction contract was being cancelled and that the facility would be repurposed and modified to support a Pu pit production mission. NNSA is currently developing their plans for this mission, which will require approval from Congress.

M Area

The **M Area** of SRS was used for production fuel and target fabrication. Some equipment including co-extrusion and powder metallurgy capability are still there, but their condition is not known. The M Area is not being used for any current mission.

L Area

The **L Area** is currently being used to store spent fuel containing HEU from foreign and domestic research reactors. The L Area is similar in size to K Area and could be used for interim storage of spent VTR fuels. There is no capability to handle sodium bonded metal fuels. The L Area does not currently have a PIDAS but is a security Cat 1 facility.

I.2.5 Other Generic Government Sites

A full siting analysis could analyze other potential government-owned sites; however, a review of other DOE sites by DOE NE did not identify other viable sites for consideration. Consideration factors included site mission, DOE landlord responsibility, historical nuclear reactor operation, and existence of ongoing nuclear energy research and development activities.

I.2.6 Generic Non-Government

A generic non-government site was considered for exploring any issues that might differentiate between the viable alternatives that require the construction of a new reactor. Issues for a non-government site could include stakeholder acceptance, availability of critical infrastructure, regulatory compliance, security, etc. It was determined that for most issues, the differences between government and non-government sites would be similar for each of the new reactor alternatives and thus would not differentiate those alternatives. The potential differences in regulatory framework were considered the most extensive. A non-government site may or may not come equipped with significant support capabilities. Industrial sites exist with fuel management and examination capabilities, but a 'greenfield' site would have to create the supporting infrastructure or obtain it in a distributed manner. Some of these key infrastructure items include but are not limited to site security, PIE, nuclear fuel handling / storage and hot cell capability / capacity.

I.2.7 Regulatory Protocol

This study assumed that a VTR facility built at a non-government site would fall under NRC regulatory jurisdiction. The NRC's Office of Nuclear Reactor Regulation (NRR) through the Research and Test Reactors Branches (RTRB) of the Division of Policy and Rulemaking is responsible for regulating the safe operation of Research and Test Reactors (RTRs). Currently, the NRC has oversight over 31 of these facilities within the United States.

There are several relevant regulatory guides for the licensing of non-power reactors that the reader is referred to for additional information. First, NUREG-1537 gives guidance to non-power reactor licensees and applicants on the format and content of applications to the NRC. Regulatory guides division 2 "Research and Test Reactors", division 5 "Materials and Plant Protection" are also relevant as well as guidance on technical specification development, quality assurance program requirements, and emergency planning. ANS/ANSI Research Reactor Standards ANS 15 Series (15.1, 15.2, 15.4, 15.8, 15.11, and 15.16) are also referenced by guidance.

I.3 Additional General Observation

The VTR AoA Team also observed that extensive potential technology and facility capabilities that could support the VTR mission are distributed across several sites, and that opportunities for further expansion of such support is also distributed. It is reasonable to consider that the VTR mission might benefit from a support base utilizing multiple sites.

I.4 Summary of Site Information

The site information observed during this AoA has been summarized into a cursory compilation of the attributes of the locations that were visited for hosting the VTR mission. In some cases, there are different observations that are relevant to the use of existing facilities for the VTR mission vs hosting the construction of a new reactor for the VTR mission. Observations regarding sites that host existing reactor alternatives are shown in Table I-1, and observations regarding visited sites for potentially hosting a new reactor build are shown in Table I-2. Because no attempt is made to qualify or quantify this information (as it is outside of this AoA scope and will most likely be addressed in the NEPA effort), it is offered as a potential starting point for a siting analysis. (The generic non-government site is not included as there is no actual site information and any characteristics are hypothetical.)

Table I-1. Site Observations for Facilities Hosting Existing Reactor Alternatives for the VTR Mission

Observed Characteristics	Idaho National Laboratory	Oak Ridge National Laboratory	Hanford Reservation (with FMEF)	Explanatory Comments and Observations
Site Characteristics				
Suitability of infrastructure (e.g., roads, utilities)				All sites have an adequate infrastructure base.
Availability of additional support facilities				INL has the most substantial facilities, other sites have significant facilities.
Historic land use/below ground conditions				Hanford site is undergoing remediation, with potential contamination in 400 area.
Access to construction workforce				For use of existing facilities, there is no significant construction workforce shortage.
Access to operations workforce				For use of existing facilities, the operations workforce is in place, except for FFTF and FMEF at Hanford.
Supporting Technologies and Infrastructure				
Nuclear Material/Fuel Feedstock Secure Vault Type Storage				FMEF is not operational and PNNL has some capacity. INL has large secure vault capability at FMF and ZPPR.
Appropriate Security Posture				Existing (old) PIDAS at FFTF. INL has existing PIDAS around FMF and ZPPR. Would need to expand or build new PIDAS adjacent to existing one for new reactor.
Fresh Fuel Fabrication (driver and test fuels)				INL has ability to fabricate all fuels. FMEF is not operational and PNNL has little capability. ORNL cannot fabricate metallic fuels with existing facilities, but can fabricate full-spectrum of ceramic test fuels.
Fresh Fuel Storage				INL has secure storage capacity for fresh fuel at FMF and ZPPR. FMEF is not operational and PNNL has little capability.
Experiment Fabrication				INL has extensive capability. ORNL has extensive capability.

Table I-1. Site Observations for Facilities Hosting Existing Reactor Alternatives for the VTR Mission

Observed Characteristics	Idaho National Laboratory	Oak Ridge National Laboratory	Hanford Reservation (with FMEF)	Explanatory Comments and Observations
				FMEF is not operational and PNNL has some capability.
Hot Cells with both Air and Inert Atmosphere				INL has both. FMEF is not operational but PNNL has some capability. ORNL currently has no hot cells with inert atmosphere but can be installed if needed in dormant hot cell.
Fuel and Experiment Disassembly and Inspection / PIE Capabilities				INL has extensive capability. ORNL has extensive capability. FMEF is not operational but PNNL has significant capability.
Interim Storage				INL has large in ground storage capacity at RSWF. ORNL has a fuel management chain for existing facilities. FMEF is not operational and PNNL has little capability.
Packaging for Longer Term Dry Storage				INL uses FCF to prepare and package sodium-bonded metal fuels for in-ground dry storage. FMEF is not operational and PNNL has some capability. ORNL currently has no need for this; discharged fuel from core stored in spent fuel pool or sent off-site when pool is full.
Long Term Dry Storage				INL has large in ground dry storage capacity at RSWF. ORNL currently has no need for this; discharged fuel from core stored in spent fuel pool or sent off-site when pool is full. There is a Canister Storage Building at Hanford that is currently used for dry spent nuclear fuel storage; the capacity that may be available to support the VTR mission was not assessed during the AoA.
Sodium Handling Facilities (either driver or test fuels)				INL has inert hot cells for handling sodium bonded fuels and test fuels. FMEF is not operational and PNNL has limited capability.
Roads and Railways				All sites have adequate systems in place.

Key

	Nonexistent or inadequate facility or conditions; requires significant capital investment and time to establish capability to support a VTR mission new build.
	Marginal or some existing capability; requires moderate capital investment and time to establish capability to support a VTR mission new build.
	Existing facility capable or adequate conditions; requires minimal to no capital investment and time to establish capability to support a VTR mission new build.

Table I-2. Site Observations for Hosting a New Reactor to Support the VTR Mission

Observed Characteristics	Idaho National Laboratory	Oak Ridge National Laboratory	Hanford Reservation (with FMEF)	Savannah River Site	Explanatory Comments and Observations
Site Characteristics					
Suitability of infrastructure (e.g., roads, utilities)					All sites have an adequate infrastructure base.
Availability of additional support facilities					INL has the most substantial facilities, other sites have significant facilities.
Historic land use/below ground conditions					Hanford site is undergoing remediation.
Access to construction workforce					INL has many ongoing construction projects. ORNL has constraints. SRS will have access to nearby Plant Vogtle workforce.
Access to operations workforce					Competition with other NE and NR work would result in some operations workforce challenges at INL. Need to make consistent for ORNL based on risk tables. SRS has not operated reactors for 30 years.
Supporting Technologies and Infrastructure					
Nuclear Material/Fuel Feedstock Secure Vault Type Storage					FMEF is not operational and PNNL has some capacity. INL has large secure vault capability at FMF and ZPPR. SRS has large storage capacity, but the secure storage is currently being used for other missions.
Appropriate Security Posture					Existing (old) PIDAS at FFTF. INL has existing PIDAS around FMF and ZPPR. Would need to expand or build new PIDAS adjacent to existing one for new reactor. SRS has appropriate security posture.
Fresh Fuel Fabrication (driver and test fuels)					INL has ability to fabricate all fuels. FMEF is not operational and PNNL has little capability. ORNL cannot fabricate metallic fuels with existing facilities but can fabricate full-spectrum of ceramic test fuels. SRS fuel fabrication equipment is old and was originally used for aluminum clad fuels. If NNSA decides to use K Area for a Pu dilute and dispose mission, synergy with VTR fuel fabrication could be achieved.
Fresh Fuel Storage					INL has secure storage capacity for fresh fuel at FMF and ZPPR. FMEF is not operational and PNNL has little capability. SRS has secure storage but there would be competition from NNSA missions for its availability. ORNL Likely not currently available for full-cores of new VTR – same as above
Experiment Fabrication					INL has extensive capability. ORNL has extensive capability. FMEF is not operational and PNNL has some capability. SRNL/SRS has some capability.

Table I-2. Site Observations for Hosting a New Reactor to Support the VTR Mission

Observed Characteristics	Idaho National Laboratory	Oak Ridge National Laboratory	Hanford Reservation (with FMEF)	Savannah River Site	Explanatory Comments and Observations
Hot Cells with both Air and Inert Atmosphere					INL has both. FMEF is not operational and PNNL has some capability. ORNL currently has no hot cells with inert atmosphere but can be installed if needed in dormant hot cell. SRNL/SRS has atmospheric hot cells only.
Fuel and Experiment Disassembly and Inspection / PIE Capabilities					INL has extensive capability. FMEF is not operational and PNNL has some operational capability. SRNL has some capability. PIE equipment needs upgrading. ORNL has some operational capability.
Interim Storage					INL has large in ground storage capacity at RSWF. FMEF is not operational and PNNL has little capability. SRS has storage capacity in K and L Areas.
Packaging for Longer Term Dry Storage					INL uses FCF to prepare and package sodium-bonded metal fuels for in-ground dry storage. FMEF is not operational and PNNL has some capability. ORNL currently has no need for this; discharged fuel from core stored in spent fuel pool or sent off-site when pool is full. SRS has capacity for packaging all but sodium-bonded metal fuels.
Long Term Dry Storage					INL has large in ground dry storage capacity at RSWF. There is a Canister Storage Building at Hanford that is currently used for dry spent nuclear fuel storage; the capacity that may be available to support the VTR mission was not assessed during the AoA. ORNL currently has no need for this; discharged fuel from core stored in spent fuel pool or sent off-site when pool is full. SRS has capacity in K and L Areas but no capability at present for sodium-bonded fuels.
Sodium Handling Facilities (either driver or test fuels)					INL has inert hot cells for handling sodium bonded fuels and test fuels. FMEF is not operational and PNNL has little capability. SRNL/SRS has no inert hot cells. ORNL has no inert hot cells.
Roads and Railways					All sites have adequate systems in place.

Key

	Nonexistent or inadequate facility or conditions; requires significant capital investment and time to establish capability to support a VTR mission new build.
	Marginal or some existing capability; requires moderate capital investment and time to establish capability to support a VTR mission new build.
	Existing facility capable or adequate conditions; requires minimal to no capital investment and time to establish capability to support a VTR mission new build.

I.4 Summary of Observations

As stated above, the VTR AoA did not include a comprehensive site assessment. It was not a siting study. The VTR AoA Team focused on independently evaluating the various potential alternatives against the VTR mission needs / requirements. As such, this analysis required the Team members to conduct detailed literature reviews, site visits, and numerous interviews. It is from that collective effort that this Appendix was put together.

While the sites visited during the VTR AoA could potentially support elements of the VTR Mission, as can be seen from a quick review of Tables I-1 and I-2 above, the INL, appears to be the best equipped to handle the new VTR Mission. The INL is under DOE NE landlord stewardship and possesses substantial capability in PIE, fuel fabrication, fuel handling, long term dry storage, inert hot cell availability and a nuclear workforce.

APPENDIX J LINES OF INQUIRY

J.1 ORNL Integrated LOIs

VERSATILE TEST REACTOR – ANALYSIS OF ALTERNATIVES

LINES-OF-INQUIRY

OAK RIDGE NATIONAL LABORATORY
HIGH FLUX ISOTOPE REACTOR (HFIR)

Purpose

The U.S. Department of Energy (DOE) Office of Nuclear Energy (NE) has approved a Mission Need Statement (see attached) to provide a 'Versatile Test Reactor' (VTR) capability. As an early step in this process, a Team from NE is conducting a formal 'Analysis of Alternatives' (AoA) in accordance with DOE Order 413.3B as part of the major systems acquisition process. As part of that effort, members of the NE AoA Team are visiting the Oak Ridge National Laboratory (ORNL) to evaluate the potential to enhance the High Flux Isotope Reactor (HFIR). As such, the AoA team requests:

1. A tour of the HFIR and support facilities that are expected to be used for the HFIR (current or potentially modified) to meet the VTR mission. During the tour, explain how the existing facilities could be used for the VTR mission.
2. Briefings/discussions to pursue the lines of inquiry discussed below. These inquiries are divided into the following general categories:
    - The status of the HFIR and support facilities
    - The potential technical performance of the HFIR with potential modifications to increase the fast flux (e.g., a "flux booster").
    - Cost and schedule estimates for any modifications to HFIR and support facilities to support the VTR mission.
    - Potential risk factors, technical and non-technical including socio-political/stakeholder/acceptance, etc.
3. Relevant background documents for reference, such as conceptual design studies and cost/schedule estimates of previous HFIR fast spectrum capabilities. The AoA Team has the presentations made in 2006/2007 in connection with the Global Nuclear Energy Partnership (GNEP) program (attached) which discuss the potential of HFIR to meet GNEP requirements, including mentioning the possibility of the addition of "flux boosters" which was not explored at that time.
4. Suggested contacts for further inquiry as needed.

Status

- Please describe/summarize fuel and materials irradiations being performed in support of the Advanced Fuels Campaign (AFC):
    - Fuel w/ w/o thermal shield
    - Material w/ w/o thermal shield
    - Specimen geometry/sizes (pellets, rodlets, coupons)
    - Irradiation duration(s)
    - Flux/fluence/dpa as appropriate as function of irradiation location
- What locations are available for new irradiations? Number? Volumes? Thermal flux? Shielded fast flux?
- What facilities are used for specimen fabrication and post irradiation examination (PIE)? What is total/available capacity?

Page 1 of 4

Technical Performance

In what follows, "modified" refers to options such as a "flux booster" requiring "capital" investment, and potential licensing, operations, etc.

1. What is the maximum fast flux achievable currently? Modified if feasible?
2. What would be typical/maximum annual dose achievable (in dpa/year)?
3. What length test articles can be accommodated? In what locations/fluxes?
4. What volume is available for test articles? Number and range of individual volumes? Total?
5. What testing configurations would be available (open loop, closed loop, rabbits, etc.)? What coolants (Na, Pb, Pb-Bi, He, molten salts)?
6. What capability does the current HFIR have for testing advanced sensors and instruments for the core and test positions? Modified HFIR?
7. What technical confidence do you have that utilization of the HFIR for the expanded scope required to support the VTR mission can be available for testing as soon as possible? What modification (e.g., a "flux booster") is deemed to be feasible/viable?
8. Where are the nearest support facilities for experiment fabrication and PIE?
   a. What is the age of each support facility? How long is each expected to be in commission?
   b. Does each support facility have the capability to support the VTR mission requirements (e.g., experiment fabrication, PIE)? If not, what modifications would be needed to the support facility to meet its support mission for VTR?
   c. What is the current workload on each support facility? Can each support the throughput needed for VTR experiments in addition to its current work?
9. Can the HFIR (current or modified) support facilities provide economical life cycle management capability for both test fuels and any "booster" fuels? To what extent can these "piggy-back" on the current fuel management?
   a. Where will "booster fuels" (if needed) and test fuels be fabricated? How will they be transported to the HFIR complex?
   b. Assuming fuel feedstock is available, describe the technical challenges in fabricating "booster fuel" if used.
   c. How will you manage discharged "booster fuel" and test fuels?
   d. How is the spent fuel from the HFIR managed/disposed?
   e. How will you minimize cost and schedule impacts on fuels life cycle management?
10. What are the capabilities of HFIR (current and potentially modified) for high-temperature experiment testing?
11. What capability does the HFIR provide for lower energy neutron spectra irradiations (Flux, dpa/year, experiment volume, etc.) to support thermal reactor needs?
12. How does HFIR management ensure compliance with codes, standards and regulations for different experiment rigs?
13. To what degree will HFIR (current and modified) meet expected VTR user needs? What will be the potential impact on other missions using the HFIR?
14. Has there been any work after that described in the attachments from the GNEP-related activities?

Page 2 of 4

Cost/Schedule

1. Are local/state taxes applicable to projects at your site, and, if so, what are current rates and to what are those rates applied?
2. What are the current/forecasted overhead/G&A adders to be used for project cost estimates at the site?
3. What are current utility charges (electric, water, gas) incurred/charged to operating facilities at your site?
4. What, if any, supporting existing infrastructure would require upgrades/modifications to accommodate the VTR mission?
5. What existing ancillary equipment is available to support the VTR mission and what is its facility condition/remaining useful life?
6. Are their opportunities to improve schedule and cost performance from leveraging safety documentation prepared for the existing facility?
7. In the presentations in 2007 an estimated schedule to begin GNEP 3- or 7-pin irradiations was 18-24 months.
   - Given the several following years of performing irradiations for AFC what is the updated estimate? What would be the estimate to study, design, and potentially implement significant modifications (e.g., the "booster" option)?
   - Are the bases for that schedule available and, if so, can they be shared with us?
   - Are the individuals who developed that (or more recent) schedule available for interview/discussion?
8. In the 2007 presentations, an annual cost for performing the irradiations to support the GNEP requirements was expected to be in the range of \$5M - \$8M per year, and the cost for the facility upgrade to accommodate an upgraded 7-pin irradiation vehicle (to increase irradiation volume) was estimated to be \$9.8M.
   - Given the several following years of performing irradiations for AFC what is the updated estimate? What would be the estimate to study, design, and potentially implement significant modifications (e.g., the "booster" option)?
   - Are the estimate details and backup for that cost range available and, if so, can they be shared with us?
   - Are the individuals who developed that (or more recent) estimate available for interview/discussion?
9. What is the current annual operating cost for the HFIR and what elements comprise that annual total?
   - What is the total current staffing level for the HFIR?
   - What impact on current operating costs and staffing levels would there be to support the VTR mission as described above? What would be the impact of the addition of a significant modification (e.g., the "booster" option)?
   - To what degree are annual costs impacted by the number and types of experiments conducted at the HFIR now and after potentially expanded utilization to support the VTR mission? Are there incremental costs/charges per experiment?

Risk

Technical

1. Would construction or operation of any potential significant modifications to HFIR present any environment, safety and health concerns that would require additional personnel to achieve effective oversight?
2. What is the availability of individuals with fuels, materials, and detectors analysis expertise to support project operations?
3. Describe how HFIR meets safeguards and security requirements. What safeguards and security modifications, if any, would be necessary to accommodate any potential modifications such as a "flux booster"?

Cost/Schedule

4. Is there any possibility of domestic or foreign industrial partnering that could yield cost savings?

Political

5. What are the political issues, if any, surrounding any significant modifications to HFIR such as a "flux booster" that would impact its implementation?
6. What is your opinion regarding international acknowledgement of U.S. nuclear technology leadership if DOE moves forward with this option?

J.2 Hanford Site LOIs

VERSATILE TEST REACTOR – ANALYSIS OF ALTERNATIVES

LINES-OF-INQUIRY

HANFORD SITE – FFTF RESTART

Purpose

The U.S. Department of Energy (DOE) Office of Nuclear Energy (NE) has approved a Mission Need Statement (see attached) to provide a 'Versatile Test Reactor' (VTR) capability. As an early step in this process, a Team from NE is conducting a formal 'Analysis of Alternatives' (AoA) in accordance with DOE Order 413.3B as part of the major systems acquisition process. As part of that effort, members of the NE AoA Team are visiting the Hanford Site to evaluate the potential to refurbish and restart the Fast Flux Test Facility (FFTF) to meet this Mission Need. As such, the AoA team requests:

1. A visit to the FFTF and relevant support facilities
2. Briefings/discussions to pursue lines of inquiry discussed below. These inquiries are divided into the following general categories:
    - The current status of the FFTF and potential support facilities
    - The potential technical performance of a restarted FFTF
    - Cost and schedule for FFTF restart
    - Potential risk factors, technical and non-technical including socio-political/stakeholder/acceptance, etc.
3. Relevant background documents for reference
4. Suggested contacts for further inquiry as needed

Status of the FFTF and Potential Support Facilities

a. Please describe/summarize the current status of the FFTF.
    - What is the condition of the reactor vessel and internals (core support, fuel guide tubes, control rods, shield, etc.)? Most recent inspection?
    - What is the condition of the reactor primary and secondary coolant systems?
    - What is the status of the fuel handling equipment?
    - What is the status of control systems?
    - What is the status of the containment and auxiliary buildings?

b. Potential technical issues regarding potential for restart of FFTF.
    - Facility refurbishment
    - System/component replacement requirements
    - What would be a pathway to production of new fuel?
    - How would discharged fuel be managed?

c. Please describe/summarize the current status of primary potential support facilities.
    - Current condition and use of the MASF
    - Current condition and use of the FMEF
    - What are other nearby support facilities for experiment fabrication and post irradiation examination (PIE)?
    - For each of the above:
        - What is the age of each support facility? How long is each expected to be in commission?
        - Does each support facility have the capability to support the VTR mission requirements (e.g., experiment fabrication, PIE)? If not, what modifications would be needed to the support facility to meet its support mission for VTR?

- What is the current workload on each support facility? Can each support the throughput needed for VTR mission experiments in addition to its current work?

Potential Technical Performance of a Restarted FFTF

d. Following shutdown, a proposal was developed to refurbish FFTF for an additional 20 years of operation. Since then, there have been multiple evaluations of potential restart for differing missions. What has changed (if anything) since these prior evaluations?

e. What would be the potential performance of a restarted FFTF?
   - Are there beneficial modifications/upgrades that should be considered in refurbishment?
   - What is the maximum fast flux achievable?
   - Available irradiation test volume
   - Available irradiation test length
   - What testing configurations would be available (open loop, closed loop, rabbits, etc.)? What coolants (Na, Pb, Pb-Bi, He, molten salts) and range of temperatures could be provided?
   - What capability would FFTF have for testing advanced sensors, detectors and instruments for the core and test positions?
   - What capability could FFTF provide for lower energy neutron spectra (Flux, dpa/year, experiment volume)?
   - What is a reasonable working lifetime for a refurbished/restarted FFTF?

f. Operational questions for FFTF restart and VTR mission
   - Is there enough qualified staff to support the VTR mission, or reasonable ability to develop such staff?
   - Other site infrastructure issues, such as access, security, utilities, environmental support, etc.
   - Potential impacts, both positive and negative of FFTF restart and the VTR mission on other site operations.
   - Describe how the FFTF would meet security requirements.
   - How could you ensure compliance with codes, standards and regulations for different experimental rigs?

Cost and Schedule for FFTF Restart

g. Estimated cost to restart FFTF, assuming institutional support and fuel material availability. An estimate was provided in a GNEP report in 2007 – what has changed from that estimate?)
   - Reactor refurbishment
   - Fuel
   - NEPA compliance
   - Support facilities
   - Staff

h. Estimated annual operating cost for the FFTF and what elements comprise that annual total?
   - Operating staff?
   - Support facilities

i. Estimated schedule to initiate operations.
   - Validity and/or changes from old estimates (such as 2007 GNEP report)
   - Are the bases for that schedule available and, if so, can they be shared with us?

j. Standard questions for cost/schedule for an AoA of this type (numbered items):
   1. Are local/state taxes applicable to projects at your site, and, if so, what are current rates and to what are those rates applied?

2. What are current utility charges (electric, water, gas) incurred/charged to operating facilities at your site?
3. If M&O execution is planned, what are the current/forecasted overhead/G&A adders to be used for project cost estimates at the site?
4. How are major acquisition projects (engineering, procurement, construction, commissioning) currently handled at your site (i.e., is the M&O Contractor responsible for all phases of project execution or is it possible that DOE may/could contract one or more elements directly?
5. What, if any, supporting existing infrastructure would require upgrades/modifications to accommodate a VTR mission?
6. What security measures already exist (e.g., existing PIDAS) that will minimize costs and schedule for locating the VTR mission at your site?
7. What additional work scope would be needed to reactivate FFTF and add the necessary support facilities needed for a VTR mission at the site?
8. What would be required for NEPA compliance with FFTF restart?

Potential Risk Factors Technical and Non-technical Including Socio-political/Stakeholder/Acceptance, etc.

Both technical and non-technical risk factors affecting potential FFTF restart and performance of the VTR mission

Technical

k. Standard questions regarding risk for an AoA of this type (numbered items):
    1. What on-going/current site-wide activities/operations may adversely impact FFTF restart and VTR mission operation at your site?
    2. What materials or equipment present availability concerns that would impact cost or schedule?
    3. Does FFTF restart and VTR mission operation at your site present any environment, safety and health concerns that would require additional personnel to achieve effective oversight?
    4. Are there site access concerns for people or construction materials and equipment?
    5. What are restart and VTR mission personnel clearance requirements for working at your site?
    6. What are the operator personnel clearance requirements at your site and what is the availability of such operator personnel?
    7. What is the availability of individuals with fuels, materials, and detectors analysis expertise to support project operations?
    8. Will the VTR mission impact existing site-wide activities?
    9. What safeguard and security modifications will be necessary to accommodate FFTF restart and the VTR mission?
    10. Is there any possibility of domestic or foreign industrial partnering that could yield cost savings?
    11. What unforeseen site conditions may exist, such as below-ground contamination, hazards, utilities, and artifacts of historical significance, that could impact FFTF restart the VTR mission?
    12. What risk handling strategies do you foresee as necessary to mitigate potential threats at your site?

Non-technical:

l. There have been arguments for and against potential FFTF restart, such as (but not limited to) the multiple prior reviews of potential restart, the 2007 Columbia Basin Consulting Group report, a 2018 DOE report and multiple ongoing social discussions. Please offer any factual response available to such past arguments, and any new insights relevant today.
m. Who are the most interested stakeholders in the question of restart, and your understanding of their positions and/or concerns.
n. What is the level of support and/or opposition to FFTF restart in support of the VTR mission?
    - DOE Headquarters
    - DOE Field Office
    - DOE Site Office
    - Lab management
    - Local government
    - State government
    - Congressional delegation
    - Non-government organizations
    - Other?
o. Are there questions you have that you want to ask of the AoA team?
p. Is there other information that might be relevant to the VTR AoA effort (what should we have asked?).

J.3 INL LOIs

VERSATILE TEST REACTOR – ANALYSIS OF ALTERNATIVES

LINES OF INQUIRY

IDAHO NATIONAL LABORATORY
ADVANCED TEST REACTOR (ATR) WITH FAST FLUX BOOSTER

Purpose

The U.S. Department of Energy (DOE) Office of Nuclear Energy (NE) has approved a Mission Need Statement (see attached) to provide a 'Versatile Test Reactor' (VTR) capability. As an early step in this process, a Team from NE is conducting a formal 'Analysis of Alternatives' (AoA) in accordance with DOE Order 413.3B as part of the major systems acquisition process. As part of that effort, members of the NE AoA Team are visiting the Idaho National Laboratory (INL) to evaluate the potential to enhance the Advanced Test Reactor (ATR) to meet this Mission Need. As such, the AoA team requests:

1. A tour of the ATR and support facilities that are expected to be used for the ATR with Fast Flux Booster option to meet the VTR mission. During the tour, explain how the existing facilities could be used for the VTR mission.
2. Briefings/discussions to pursue the lines of inquiry discussed below. These inquiries are divided into the following general categories:
    - The status of the ATR and support facilities
    - The potential technical performance of the ATR with a boosted fast flux loop (BFFL).
    - Cost and schedule estimates for a BFFL.
    - Potential risk factors, technical and non-technical including socio-political/stakeholder/acceptance, etc.
3. Relevant background documents for reference, such as conceptual design studies and cost/schedule estimates of previous ATR fast spectrum capabilities. The AoA Team has INL/EXT-09-16413, Boosted Fast Flux Loop Final Report, dated September 2009
4. Suggested contacts for further inquiry as needed.

Status

- Please describe/summarize fuels and materials irradiations currently being performed in ATR in support of the Advanced Fuels Campaign (AFC):
    - Fuels with and without thermal shield
    - Materials with and without thermal shield
    - Test specimen geometry/sizes (pellets, rodlets, coupons)
    - Irradiation duration(s)
    - Flux/fluence/dpa as appropriate as function of irradiation location
- What facilities are currently being used for test specimen fabrication and post irradiation examination (PIE)?

Technical Performance

1. What is the maximum fast flux achievable in ATR with the Fast Flux Booster?
2. What would be typical/maximum annual dose achievable (in dpa/year)?
3. What length test articles could be placed into the ATR with the Booster?

4. What volume is available for test articles?
5. What testing configurations would be available (open loop, closed loop, rabbits, etc.)? and what coolants (Na, Pb, Pb-Bi, He, molten salt?
6. What capability would the modified ATR have for testing advanced sensors and instruments for the core and test positions?
7. What technical confidence do you have that the Modified ATR with the Fast Flux Booster can be available for testing as soon as possible?
8. Where are the nearest support facilities for experiment fabrication and PIE?
   a. What is the age of each support facility? How long is each expected to be in commission?
   b. Does each support facility have the capability to meet its mission in support of the VTR program (e.g., experiment fabrication, PIE)? If not, what modifications would be needed to the support facility to meet its support mission for VTR?
   c. What is the current workload on each support facility? Can each support the throughput needed for VTR experiments in addition to its current work?
9. Can ATR with Fast Flux Booster and support facilities provide economical life cycle management capability for both test fuels and booster fuels?
   a. Where will booster fuel and test fuels be fabricated? How will they be transported to the ATR complex?
   b. Assuming booster fuel feedstock is available, describe the technical challenges in fabricating the booster fuel.
   c. How would you manage discharged booster fuel and test fuels?
10. What capability would the ATR with Fast Flux Booster have for high-temperature experiment testing?
11. What capability does the ATR provide for lower energy neutron spectra (Flux, dpa/year, experiment volume)?
12. How does the ATR management team ensure compliance with codes, standards and regulations for different experiment rigs?
13. Will the ATR with Fast Flux Booster option meet expected VTR user needs? What will be the potential impact on other missions using the ATR?
14. In 2009 INL issued a report on the Fast Flux Booster (INL/EXT-09-16413, Boosted Fast Flux Loop Final Report, September 2009). Is there an update to the report or additional technical information on the BFFL concept since 2009? If so, can we get it? Is the BFFL concept still viable?

Cost/Schedule

General

1. Are local/state taxes applicable to projects at your site, and, if so, what are current rates and to what are those rates applied?
2. What are the current/forecasted overhead/G&A adders to be used for project cost estimates at the site?
3. What are current utility charges (electric, water, gas) incurred/charged to operating facilities at your site?

BFFL Specific

4. What, if any, supporting existing infrastructure would require upgrades/modifications to accommodate the BFFL? Provide the latest cost and schedule information on implementing BFFL.
5. Are there opportunities to improve schedule and cost performance from leveraging safety documentation prepared for the existing facility?

Page 2 of 3

6. In the "Boosted Fast Flux Loop Final Report" (September 2009) an estimated cost range of $50M to $75M was provided.
    - Has this cost estimate been re-visited or updated since that report?
    - Are the estimate details and backup for that cost range available and, if so, can they be shared with us?
    - Are the individuals who developed that (or more recent) estimate available for interview/discussion?
7. What is the current annual operating cost for the ATR and what elements comprise that annual total?
    - What is the total current staffing level for the ATR?
    - What impact on current operating costs and staffing levels would there be after addition of the BFFL?
    - To what degree are annual costs impacted by the number and types of experiments conducted at the ATR now and after BFFL implementation? Are there incremental costs/charges per experiment?
8. In the "Boosted Fast Flux Loop Final Report" (September 2009) an estimated schedule of 7 years was provided.
    - Has this schedule been re-visited or updated since that report? If so, can you provide it?
    - Are the bases for that schedule available and, if so, can they be shared with us?
    - Are the individuals who developed that (or more recent) schedule available for interview/discussion?

Risk

Technical

1. Would construction or operation of a BFFL for ATR present any environment, safety and health concerns that would require additional personnel to achieve effective oversight?
2. What is the availability of individuals with fuels, materials, and detectors analysis expertise to support project operations?
3. Describe how ATR meets safeguards and security requirements. What safeguards and security modifications, if any, would be necessary to accommodate the BFFL?

Cost/Schedule

4. *Is there any possibility of domestic or foreign industrial partnering that could yield cost savings?*

Political

5. What are the political issues, if any, surrounding the BFFL project that would impact its implementation?

6. What is your opinion regarding international acknowledgement of U.S. nuclear technology leadership if DOE moves forward with this option?

J.4 SRS LOIs

Lines of Inquiry – Savannah River Site
04-22-2019

Background

In addition to considering existing facilities, the Analysis of Alternatives (AoA) for the Versatile Test Reactor (VTR) will consider construction of a new fast spectrum reactor to meet the approved mission need (attached). While the AoA is not a formal siting evaluation, potential site issues, both positive and negative, are relevant to considering the new reactor alternatives. It is assumed that a new reactor would be designed to meet the technical performance needs of the VTR testing mission. This leaves questions regarding site benefits and constraints for AoA consideration, such as: infrastructure, costs, other missions, local/regional support/resistance, etc. The AoA Team would be particularly interested in the evaluation of and potential ability to make use of existing Mixed Oxide (MOX) facilities, Savannah River National Laboratory (SRNL), and Savannah River Site facilities. These Lines of Inquiry (LOI) based on the above are detailed below.

LOI

- What supporting infrastructure is available to support a new VTR, including security, electricity, water, environmental management, hazards control, etc.?
    - Are there potential site infrastructure constraints, and how could they be mitigated?
    - Are there potential synergisms?
    - How might infrastructure costs be different from other similar sites?
    - Are there unusual constraints on heavy construction?
    - Are there unusual constraints on nuclear operations?
- With respect to the MOX Fuel Fabrication Facility and infrastructure, what are its capabilities for re-use in support of a new VTR mission?
- What capabilities does the K-Area complex have for support of a new VTR mission and how, in light of the VTR mission, it might stack up against MFFF. This question needs to include an examination of cost and schedule for security, NEPA, capital/renovation, transportation, etc. How might a VTR mission differ from a surplus weapons material disposition mission using fast reactors? (Reference: *Analysis of Surplus Weapon-Grade Plutonium Disposition Options*; DOE: April 2014)
- Does H Canyon, HB Line or other SRS facility have the capability to support limited separations of used driver fuel components or treatment of sodium bonded metal fuels?
- What are potential impacts on other site missions, both positive and negative?
- What capabilities exist that could be used for nuclear PIE of test materials, fuels, detectors, etc.
    - Age and condition of such facilities
    - Current and projected workload
    - Potential upgrades or modifications
- What capabilities exist to support VTR driver fuel fabrication? Fuels could contain enriched uranium and/or plutonium. Could the excess weapons grade Pu be considered for potential feedstock for VTR driver fuel?
- What capabilities exist to support experiment fabrication?
- What facilities/capabilities does SRNL have with respect to hot cells, PIE support, fuel and test fabrication to support testing?
- What onsite wet and dry storage capability does the site have for interim storage of spent driver fuel and test fuels?
- Can additional capabilities be created as needed?

Page 1 of 2

- What cost differentials might exist for construction and operation of a VTR at this site compared to similar sites?
- What might be the social and political issues regarding a potential VTR project at your site?
  - What is the level of Lab management, local and state government, and Congressional delegation acceptance of a new VTR?
  - What, if any, concerns exist or are anticipated from the surrounding populace, including residents and stakeholders, about their proximity to a test reactor that could possibly delay project start/completion?
- Other issues you feel would be relevant to this AoA?

Site Infrastructure Needs

The table below outlines the types of infrastructure / facilities / capabilities that would be required to support the VTR Mission. For each facility at SRNL or SRS that might be used to provide the VTR support functions listed above, please provide building condition, size (square feet), staffing level, annual operating cost for current missions.

Nuclear Material/Fuel Feedstock Secure Vault Type Storage
Appropriate Security Posture
Fresh Fuel Fabrication
Fresh Fuel Storage
Experiment Fabrication
Irradiated Fuel Sodium Wash
Hot Cells with both Air and Inert Atmosphere
Fuel and Experiment Disassembly and Inspection / PIE Capabilities
Interim Storage
Packaging for Longer Term Dry Storage
Long Term Dry Storage
Sodium Components Maintenance Facilities
Roads and Railways
Electrical Power Supply and Distribution
Mockup, Laydown, and Warehouse Facilities

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APPENDIX K INDEPENDENT REVIEW TEAM MEMBERS BIOS AND SIGNED NON-DISCLOSURE AGREEMENTS

K.1 BIOS

JEFFREY E. GIANGIULI
Executive Vice President and Chief Operating Officer, TechSource, Inc.
VTR AoA – Team Leader

Mr. Jeff Giangiuli is a dynamic technical consultant with a proven track record of delivering complex, multi-faceted projects for the Departments of Defense and Energy. He is trained in and experienced at leading other executives in technical (nuclear, environmental, and operational) environment. As Executive Vice President and Chief Operating Officer of TechSource, Inc., he is the principal company executive responsible for all corporate administrative and technical delivery operations. In a consulting capacity, Mr. Giangiuli is a recognized subject matter expert (SME) in the development of strategies and management systems to overcome the issues associated with military base closure and cleanup, nuclear facilities operation and disposition, and nuclear materials stabilization. He supports, as an SME, the Department of Defense (DoD) (Navy Base Realignment and Closure (BRAC) Program Management Office and Army BRAC Program) to accelerate the closure, cleanup and transfer of excess DoD facilities. He served as the Navy's 30 (b) (6) (expert witness) for the Department of Justice's litigation against Steadfast Insurance for failure to pay cleanup and closure costs at the former Mare Island Naval Shipyard. As a GovCon executive, he was also key member of the CALIBRE leadership team that grew top line revenue from $58 million to $235 million and saw stock value rise from $179/share to $1380/share over his 13-year run. He was a key contributor to CALIBRE receiving "Government Contractor of the Year" award twice in the past 4 years (2011 and 2015). He served as a Board Member on the Association of Defense Communities. Mr. Giangiuli is also an Adjunct Professor in the Engineering Management Program at the Catholic University of America where he instructs graduate students in Engineering Risk Management, Engineering Economics and Decision Analysis.

Mr. Giangiuli earned a M.S. in Engineering Management from the Catholic University and a B.S. in Systems Engineering from the U.S. Naval Academy and was a Naval Nuclear Propulsion Program Officer, Qualified Engineer.

CARTER (BUZZ) SAVAGE
Nuclear Technology and Management Consultant, TechSource, Inc.
VTR AoA – Management and Technology

Mr. Savage has over 40 years' experience as a nuclear science and technology subject matter expert. Over the last nine years Mr. Savage has provided technical advice and support on numerous U.S. Department of Energy, Office of Nuclear Energy (DOE NE) related projects. These tasks have included: Chairman of a technical review team that evaluated and prioritized Accident Tolerant Nuclear Fuel proposals ; chairman of a technical review team that evaluated the Idaho National Laboratory's Nuclear Science and Technology Directorate programs; led an independent review team in the preparation of a report to DOE NE on Generic Design Alternatives for Dry Storage of Spent Nuclear Fuel; led team of technical experts in development of a Project Plan for a Pilot Consolidated Used Nuclear Fuel (UNF) Storage Facility; and was chairman of a Relevancy Review of the Advanced Fuels Campaign for the Fuel Cycle R&D Program.

As Deputy Assistant Secretary for Fuel Cycle Technologies at DOE NE Mr. Savage was responsible for integrating all research and development activities associated with advanced nuclear fuel cycles and commercial used nuclear fuel management. In 2010 he actively led the transition of the Yucca Mountain project work force and its responsibilities for commercial used fuel disposition into the Office of Nuclear

Energy. He was a senior manager for the Global Nuclear Energy Partnership initiative and oversaw the development and publication of the Programmatic Environmental Impact Statement for the program. He also managed the Advanced Fuel Cycle Initiative for four years, overseeing research on thermal and fast reactors and high powered accelerators for destruction of transuranic elements and long-lived fission products. He also served in the Department as a project manager in the New Production Reactors program, responsible for the research and development of tritium target systems and fabrication facilities for an advanced gas-cooled reactor.

Mr. Savage managed nuclear energy R&D programs and projects as a senior consultant and vice president for JUPITER Corporation for nine years. He managed projects in several different technical areas, including Environmental Management, Nonproliferation and International Safeguards, Nuclear Weapons Defense Programs, Science, and Nuclear Energy. He provided technical and management support for numerous nuclear energy programs including the advanced light water reactor design certification program, commercial light water reactor improvement programs, and Generation IV advanced nuclear energy systems. He led integrated teams in detailed evaluations of several Department of Energy programs and projects, helping to improve the readiness of systems to operate safely as designed.

Mr. Savage served in the U.S. Navy as a nuclear propulsion program officer for 20 years. He served on four nuclear powered surface ships, including two tours as chief engineer. He trained and led his crews in safe, reliable operations, maintenance and repair of multiple pressurized water reactors and all auxiliary systems.

Mr. Savage earned a B.S. in Physics from the U.S. Naval Academy and an M.S. in Nuclear Physics from the U.S. Naval Postgraduate School.

DR. WILLIAM (BILL) HALSEY

Nuclear Technology, Materials, Waste Management and Systems Analysis, TechSource, Inc.
VTR AoA – Technology and Siting

Dr. William (Bill) Halsey worked for over 35 year in Advanced Nuclear Energy R&D at Lawrence Livermore National Lab. His recent focus has been on development of advanced nuclear energy technologies and leading the Nuclear Fuel Cycle R&D at LLNL. This includes research for the U.S. Department of Energy Office of Nuclear Energy, Science and Technology in the areas of fuel cycle alternatives, advanced fuels and reactors, spent fuel management, safety and security, small modular reactors and fusion-fission hybrids. Through this work he seeks to enable the safe, secure and sustainable use of nuclear energy throughout the 21st century. Earlier in his career, Bill worked in areas including Laser Fusion, Nuclear Testing, Radioactive Waste Management and Fissile Material Disposition.

Dr. Halsey was a Core member of the Evaluation Team for "Nuclear Fuel Cycle Evaluation and Screening", and led the pilot study for that effort and for development of the evaluation metrics. This was a major evaluation of all nuclear fuel cycle options conducted by DOE NE, 2011-2014. Earlier he performed systems analysis and developed evaluation criteria for the Accelerator Transmutation of Waste studies and the Generation-IV Reactor Evaluation, and then led the lead-cooled reactor R&D for the Gen-IV program. Working for over a decade on the Yucca Mountain Project, Dr. Halsey led the formal container material selection process and served as Associate Program Leader for Waste Package and Waste Form Performance Assessment. In the Fissile Material Disposition Program, Dr. Halsey initiated the geologic disposal studies and led the Deep Borehole Disposition Alternative. Earlier, Dr. Halsey led target fabrication and experimental campaigns in laser fusion, participated in nuclear field testing at NTS and worked on the Strategic Defense Initiative. He has had decades of participation in international cooperation activities, including work with Russia, Japan, China, S. Korea, Taiwan, UK, Canada, France, Spain and the OECD-NEA.

Dr. Halsey attended Michigan Tech and the University of Michigan, and earned a B.S. in Nuclear Engineering, M.S. in Nuclear Engineering, a second M.S. in Metallurgy and a Ph.D. in Nuclear Engineering Materials from the University of Michigan.

CHRISTOPHER O. GRUBER
Independent Consultant — Program/Project Management, Cost Estimating, Project Control, and Risk Management/Assessment, TechSource, Inc.
VTR AoA – Cost

Mr. Gruber has over 45 years of progressively more responsible experience in all facets of cost engineering, cost management, and project management and control related to the construction, operation and decommissioning of complex capital projects while employed by engineering and consulting organizations and working as an independent consultant. This includes extensive experience performing independent reviews, independent cost estimates and validations of projects for the U.S. Department of Energy (DOE), the U.S. Army Corps of Engineers, the International Atomic Energy Agency, and various private sector companies, including several in the electric utility, chemical and process industries. Mr. Gruber has over 30 years of experience with DOE/NNSA projects and programs, during which time he was a team member or sub-team leader charged with analyses of alternatives, project reviews (internal and external), independent cost estimates/reviews, and assessment/analysis of risks for many of DOE's most complex and challenging projects. He has supported DOE/NNSA management by completing reviews of processes and capabilities, conducting training of Federal Project Directors, preparation of government cost estimates, supporting program planning, project planning and execution, and development or review of policies and guidance documents. Mr. Gruber was the lead author of DOE cost estimating, life cycle cost analysis, and risk management guides, and developer of the DOE Project Manager Career Development Program Cost Estimating and Risk Management Training courses (Basic and Advanced). Mr. Gruber currently serves as the instructor for DOE's Advanced Risk Management course.

Mr. Gruber received a B.A. in Business Economics from Albright College, Reading, PA and a Master in Business Administration–Finance degree from St. Joseph's University, Philadelphia, PA.

DAVE BERKEY
TechSource, Inc.
VTR AoA – Risk

Mr. Berkey has 40 years of experience assisting senior-level managers in public and private sector organizations solve difficult problems in the energy; environment, safety and health; emergency management; and transportation arenas. His areas of expertise include economic analysis, benefit-cost and cost-effectiveness analyses, safety and risk analysis, policy and regulatory analysis, quality assurance, and organizational management. His work performed for the DOE and NNSA is very broad and extensive. It includes participation in more than 300 management system evaluations addressing, nuclear safety, technical safety and quality assurance; evaluations of emergency management and response systems; analyses of the root causes associated with hoisting and rigging incidents; statistical analyses of nuclear reactor pressure tube failures; developing and implementing a plan to evaluate DOE's facility fire and wildfire safety programs; preparing independent cost estimates (ICEs) of construction and environmental restoration projects and new nuclear weapons systems; participation in independent cost reviews (ICRs), external independent reviews (EIRs), and independent project reviews (IPRs); and developing cost estimating relationships and supporting databases. He participated in nine extensive independent business case analyses (BCAs) to support NNSA's Complex Transformation decision-making process, analyzed the capital project support costs incurred by management and operating contractors at NNSA sites, and has participated in analyses of alternatives (AoAs) for nuclear weapons-related facilities and other DOE projects. Additionally, he has participated in or led reviews at most of the DOE and NNSA principal sites and associated facilities. He was one of the principal authors of the "Guiding Principles" for safety management continue to provide the basis of the DOE's integrated safety management (ISM) program. Additionally, he developed the initial DOE Functions, Responsibilities, and Authorities, Manual (FRAM) and provided input to the initial Departmental directive for Quality Assurance, DOE Order 5700.6A. Noteworthy is Mr. Berkey's participation in special environment, safety and health evaluations of the Department's three gaseous diffusion plants that considered the time period from their initial start-up in the mid-1940s and early 1950s to the present. A goal of this White House-endorsed effort was to provide information that would assist federal government officials determine how to compensate either past and current employees afflicted with serious workplace-induced health problems, or the surviving families of these individuals. He also participated in the development of safety management and quality assurance polices and plans for the Department's Elimination of Weapons-Grade Plutonium Production Program.

Mr. Berkey holds Bachelor's and Master's degrees in Economics from the State University of New York and the University of Maryland, respectively. He has completed additional coursework at the University of Maryland towards a Ph. D. in Economics.

Dr. MICHAEL TODOSOW

Senior Nuclear Engineer, Brookhaven National Laboratory
VTR AoA – Technology & Siting

Dr. Todosow has more than 40-years of expertise in nuclear design and analysis/assessment of commercial and advanced reactors, target/blankets for Accelerator-Driven Systems, Particle Transport, Reactor Physics, Criticality Safety, and Fuel Cycle Analyses. In his role with the Nuclear Sciences and Technology Department of Brookhaven National Laboratory his major technical and management responsibilities have included: Heading the Nuclear Science and Technology Division and Manager for DOE NE programs in advanced reactors and fuel cycles (Advanced Fuel Cycle Initiative/Fuel Cycle R&D/Fuel Cycle Technologies, Generation-IV, GNEP, and Space Reactor Technology Development); Core member of Evaluation & Screening Team for DOE NE effort to evaluate and screen advanced fuel cycle options which offer significant performance benefits relative to current LWR once-through. He also provides support to the DOE NE Advanced Fuels Campaign (AFC) assessing impacts of advanced fuel concepts on reactor performance and safety for thermal, intermediate and fast spectrum reactors (current focus on fuels/cladding with enhanced accident tolerance (Accident Tolerant Fuels)and is the LWR Computational Analysis Lead in AFC; design of Particle Bed Reactor engine and test facility under Space Nuclear Thermal Propulsion (SNTP). He also served on DOE review/evaluation committees for Advanced Reactor Concepts, accelerator-driven target systems (SNS), and the Spent Fuel, and Pu Vulnerability Assessment Groups in criticality safety; also provided technical consulting to the U.S. Nuclear Regulatory Commission on reactor physics and neutron transport problems, including pressure vessel damage fluence calculations, and review of licensee reload and topical report submittals on nuclear analyses. Dr. Todosow participated in several DOE/NE planning groups, including long-term R&D and TOPS for NERAC. He was a member of the Steering Committee which managed the Roadmap for Accelerator Transmutation of Waste (ATW) in FY99 and was a member of BNL's Reactor Safety Committee overseeing safe operation of on-site reactors (1985-2000). Dr. Todosow has had extensive technical interactions with the Former Soviet Union (Russia, Kazakhstan) in space nuclear power, nuclear design/safety with focus on thorium-based seed-blanket reactor concept, treatment of fuel processing "wastes", etc. Interactions with Russia effectively ended in ~2009. In 1970-1972 as a Nuclear Engineer with Combustion Engineering, provided neutronics analyses in fuel management, core design and safety.

Dr. Todosow received a Ph.D. in Nuclear Engineering from Massachusetts Institute of Technology and a B.S./M.S. in Nuclear Engineering from Columbia University School of Engineering and is a Fellow of the American Nuclear Society (ANS).

JASON GWALTNEY

MPR Associates, Inc.
VTR AoA – Schedule,

Mr. Gwaltney has prepared and analyzed project schedules and cost estimates for fossil fuel power plant and nuclear industry projects as well as performing independent schedule analyses and reviews for DOE projects as part of EIR, ICR and AoA Teams. These reviews included projects at the Savannah River Site, Los Alamos National Laboratory, Hanford, Oak Ridge National Laboratory, Fermi National Lab, SLAC National Accelerator Laboratory, Nevada National Security Site and Idaho National Laboratory. On the commercial side, Mr. Gwaltney assisted in the development of a logic-driven, critical path, resource-loaded schedule for the engineering and construction of a new Advanced Boiling Water Reactor (ABWR). He is experienced in the use of Primavera, Primavera Risk Analysis (formerly PertMaster), Microsoft Project, and @Risk. Mr. Gwaltney is a registered professional engineer in the Commonwealth of Virginia, a Project Management Professional (PMP) with PMI, and a Certified Cost Professional (CCP) with AACE. He completed his Bachelor of Science degree in Chemical Engineering at Virginia Tech and his MBA degree at Georgetown University.

SHAWN CAMPBELL

Nuclear Systems Engineer (Severe Accidents), NRC
VTR AoA – Technology & AoA Quality Control

Dr. Shawn Campbell is a Reactor Systems engineer at the Nuclear Regulatory Commission's Office of Research. In this role, he plans, develops, and manages analytical and experimental research projects to develop, validate and maintain state-of-the-art computer codes, models, experimental data bases, and technical expertise needed. He performs confirmatory thermal-hydraulic simulations of severe accident progression for new and operating nuclear reactors, acts as a subject matter expert in aerosol phenomenology, and collaborates with universities, domestic and international regulatory and research institutions to advance the scientific and technical knowledge base of nuclear safety.

Some of his recent relevant activities include: supporting the licensing activities of the APR 1400 by performing confirmatory analysis of the applicant's severe accident simulations; participating in a phenomena identification and ranking table (PIRT) panel on steam generator tube rupture (SGTR) severe accidents in Paris, France to rank the importance of aerosol transport phenomena to support future research in South Korea; participating in an aerosol pool scrubbing international workshop (IPRESCA) in Frankfurt, Germany as a subject matter expert on the advisory panel. Dr. Campbell also is supporting the NuScale DCA review by leading the NRC's in-house MELCOR independent confirmatory analysis in support of the Chapter 19 DCA review; and supporting the Standardized Plant Analysis Risk (SPAR) Models Level 2 Success Criteria project by constructing a MELCOR model of the Duane Arnold Energy Center boiling water reactor.

Dr. Campbell earned a PhD in Nuclear Science and Engineering and an M.S. in Applied Mathematics from the University of Missouri – Columbia; and earned a B.A. in Mathematics and Physics from Westminster College Fulton, Missouri.

K.2 Non-Disclosure Agreements

ATTACHMENT 4. Nondisclosure Agreement

I understand that, in the course of my assignment to provide technical, engineering, and administrative support for the DOE/NNSA, I may be exposed to information which may be proprietary and highly sensitive to various other contractors and their suppliers, sensitive information (as defined below) provided to, or generated by, the Project Staff which could significantly impact the Company's or DOE/NNSA's future acquisition processes.

Accordingly, I agree not to disclose, outside of the Project Staff of which I am a part, and the associated client staff, for any purpose other than contract performance, any DOE/NNSA sensitive information, by whatever means gained, unless so directed by the cognizant Contracting Officer via direction from the Contract Representative that is submitted in writing to the Program Manager.

Sensitive information means information such as plans, policies, reports, studies, financial plans, internal data protected by the Privacy Act of 1974 (Pub. L.93-579), or data which has not been released or otherwise been made available to the public; or "Source Selection Information" and "Proprietary Information" of third party Contractors, as those terms are defined in Section 27 of the Office of Federal Procurement Policy Act (41 U.S.C. 423), the "Procurement Integrity Act" and other information that has been identified by DOE/NNSA to be sensitive information.

In addition, all such sensitive information shall not be released, duplicated, used, or disclosed, in whole or in part, for any purpose other than in the performance of the contract to which I am assigned, unless so directed by the cognizant Contracting Officer through written direction from the Contract Representative.

I agree to use and examine such information exclusively in the performance of work required to carry out my duties associated with the contract to which I am assigned, and agree to take suitable steps to prevent the disclosure of such information to any party other than those performing this contract, the appropriate Contract Representative as identified by the Program Manager, or appropriate client personnel as identified to the Program Manager by the Contract Representative. At the conclusion of my performance on this contract, or upon the request of the Program Manager, I agree to surrender to the Program Manager all contract information, notes, records, or data of any nature gathered or generated during my assignment. I will have no ownership or right to possess such data and information except to fulfill specific contract work assignments. The rights and obligations of the parties to this agreement shall not be assignable or used to the benefit of third parties. I agree that I shall not use or disclose to any third party any DOE/NNSA sensitive information acquired through assignment to this contract at any time following my employment on the contract to which I am assigned. I further agree that I will report to my management any known or suspected violations of the spirit or the intent of the procedures established for the protection of sensitive information.

I agree that I shall not solicit or accept any gift or other item from any person or entity seeking official action from, doing business with, or conducting activities related to the evaluations and work performed under this contract. I further agree not to engage in financial transactions using non-public information or allow improper use of such information to further any private interest.

Jeff Giangiuli

TECHSOURCE A Science & Engineering Consultancy

Corporate OCI Plan

I agree I shall disqualify myself from participating in matters involving former employers, or their representatives, who might present an OCI and from whom I have worked within the past one year.

I, the undersigned, having read and fully understanding the above agreement and this Organizational Conflict of Interest Avoidance/Mitigation Plan, agree to abide by the provisions of the agreement.

[signature]	12/4/18
Signature	Date
JEFFREY E. GIANGIULI, EVP & COO	TechSource, INC
Printed Name and Title	Company)
[signature] (Pres/CEO)	12/4/2018
Signature (Program Manager)	Date

Page 2 of 2

Cater "Buzz" Savage

I agree I shall disqualify myself from participating in matters involving former employers, or their representatives, who might present an OCI and from whom I have worked within the past one year.

I, the undersigned, having read and fully understanding the above agreement and this Organizational Conflict of Interest Avoidance/Mitigation Plan, agree to abide by the provisions of the agreement.

[signature]	12/4/2018
Signature	Date
C. R. Savage Consultant	Tech Source
Printed Name and Title	Company)
[signature] EVP & COO	12/4/2018
Signature (Program Manager)	Date

Bill Halsey

I agree I shall disqualify myself from participating in matters involving former employers, or their representatives, who might present an OCI and from whom I have worked within the past one year.

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William G. Halsey	12/4/2018
Signature	Date
WILLIAM G. HALSEY	TECH SOURCE
Printed Name and Title	Company)
EVP & COO	12/4/2018
Signature (Program Manager)	Date

Chris Gruber

I agree I shall disqualify myself from participating in matters involving former employers, or their representatives, who might present an OCI and from whom I have worked within the past one year.

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12/4/18

Signature Date

Christopher O. Gruber, Independent Consultant TechSource

Printed Name and Title Company)

EVP & COO 12/4/18

Signature (Program Manager) Date

Dave Berkey

TECHSOURCE A Science & Engineering Consultancy

Corporate OCI Plan
VTR AoA

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David M. Berkey | 12/10/2018

Signature | Date

DAVID M. BERKEY, SENIOR PROGRAM MANAGER | TECH SOURCE

Printed Name and Title | (Company)

12/10/2018

Signature (Program Manager) | Date

Page 2 of 2

Pam Lawson

TECHSOURCE
A Science & Engineering Consultancy

Corporate OCI Plan
VTR AoA

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I, the undersigned, having read and fully understanding the above agreement and this Organizational Conflict of Interest Avoidance/Mitigation Plan, agree to abide by the provisions of the agreement.

Pamela L[illegible]
Signature

12/10/2018
Date

Pamela Lawson, Document Production & Control
Printed Name and Title

TechSource, Inc.
(Company)

Signature (Program Manager)

12/10/2018
Date

Page 2 of 2

Jason Gwaltney

TECHSOURCE A Science & Engineering Consultancy

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VTR AoA

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I, the undersigned, having read and fully understanding the above agreement and this Organizational Conflict of Interest Avoidance/Mitigation Plan, agree to abide by the provisions of the agreement.

1/23/2019

Signature | Date

R. Jason Gwaltney (Engineer) | MPA Associates Inc.

Printed Name and Title | (Company)

1/23/19

Signature (Program Manager) | Date

Page 2 of 2

Zachary Thatcher

TECHSOURCE A Science & Engineering Consultancy

Corporate OCI Plan
VTR AoA

I agree I shall disqualify myself from participating in matters involving former employers, or their representatives, who might present an OCI and from whom I have worked within the past one year.

I, the undersigned, having read and fully understanding the above agreement and this Organizational Conflict of Interest Avoidance/Mitigation Plan, agree to abide by the provisions of the agreement.

1/25/19

Signature **Date**

Zachary Thatcher (engineer) MPR Associates, Inc.

Printed Name and Title **(Company)**

1/25/19

Signature (Program Manager) **Date**

Page 2 of 2

Vicky Kenamond

TECHSOURCE A Science & Engineering Consultancy

Corporate OCI Plan

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V. Kenamond — 12-10-18
Signature — Date

Vicky Kenamond, QAS — TechSource
Printed Name and Title — Company)

EVP & COO — 12/10/18
Signature (Program Manager) — Date

Page **2** of 2

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APPENDIX L REFERENCES

Ref Number	Reference Title (superscript Ref Number used to designate reference within text).
1	Nuclear Energy Advisory Committee, Assessment of Missions and Requirements for a New U.S. Test Reactor, Nuclear Energy Advisory Committee report to DOE NE, February 2017
2	U.S. Department of Energy, Office of Nuclear Energy, Mission Need Statement for the Versatile Test Reactor (VTR) Project, A Major Acquisition Project, December 2018
3	GAO 16-22, Appendix I: Best Practices for the Analysis of Alternatives Process, October 28, 2015
4	HEDL-400, A Summary Description of the Fast Flux Test Facility, December 1980
5	INL/EXT-16-37867, Advanced Demonstration and Test Reactor Options Study, Rev. 3, January 2017
6	Boosted Fast Flux Loop Final Report, INL/EXT-09-16413, September 2009
7	Fast Spectrum Molten Salt Reactor Options, ORNL/TM-2011/105, July 2011
8	Independent Cost Review of the Versatile Test Reactor Project, Critical Decision-0, Approve Mission Need, December 2018
9	INL Letter CCN 243271 to Dr. John Herczeg, DOE, Re: Contract No. DE-AC07-05ID14517 – Preliminary Evaluation of the FFTF Restart Alternative, Rev. 1, August 22, 2018
10	Input to the DOE CD-0 Cost Estimate Range for the Versatile Test Reactor, January 11, 2019
11	Overview of Corrosion Issues for the Design and Operation of high Temperature Lead and Lead-Bismuth Cooled Reactor Systems, R. Ballinger and J. Lim, *Nuclear Technology Vol. 147*, September 2004
12	Record of Decision for Accomplishing Expanded Civilian Nuclear Energy R&D and Isotope Production Missions in the U.S., Including the Role of the Fast Flux Test Facility, January 26, 2001 (66 FR 7877)
13	Record of Decision for the DOE Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington, December 13, 2013 (78 FR 75913
14	Response to Request for Information Boosted Fast Flux Loop, Fuels and Materials Performance Department, Idaho National Laboratory, August 14, 2007
15	Review of Domestic Fast Neutron Test Capability PNNL-17140
16	Siting Study for Hanford Advanced Fuels Test and Research Center, Columbia Basin Consulting Group, DE-FG07-07ID14798, April 30, 2007
17	Versatile Test Reactor Requirements Document, INL/LTD-17-43230, Rev. 0, April 2, 2018

Ref Number	Reference Title (superscript Ref Number used to designate reference within text).
18	Mission Validation Independent Review Report for Versatile Test Reactor (VTR) January 2019. (Signed by John Herczeg)
19	Tri-Party Agreement among DOE, the Environmental Protection Agency, and the Washington State Department of Ecology regarding the Hanford site, 1989
20	Nuclear Regulatory Commission, NUREG 568, PRISM Fast Reactor Preliminary Safety Evaluation Report (PSER), 1994
21	Nuclear Technology, 199, 111-128, August 2017

Ref Number	Reference Material Accessed During Document Preparation, Not Cited within Document (NCXX)
NC 22	Accelerated Testing of Fuel Systems for the Advanced Fuels Campaign, Geoffrey Beausoleil II, Idaho National Laboratory, Battelle Energy Alliance
NC 23	Advanced Test Reactor Update, INL Laboratory, Sean O'Kelly, Associate Laboratory Director, May 21, 2018
NC 24	Capital Asset Plan and Business Case, Exhibit 300, Draft
NC 25	DOE Brookhaven Letter to Oliver A. Farabee, FFTF Project, RE: Review Cost and Schedule Estimates for Startup and Deactivation for the Fast Flux Test Facility (FFTF), June 4, 2001
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