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This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

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# Updated Estimate of Tritium Permeation from TPBAR Disposal Containers in ILV (U) 

Maximilian B. Gorensek
April 7, 2021
SRNL-TR-2020-00298, Revision 0

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## Printed in the United States of America

Prepared for
U.S. Department of Energy

Keywords: TPBAR disposal, Tritium
Source Term, Performance Assessment, Intermediate Level Vaults

Retention: Permanent

# Updated Estimate of Tritium Permeation from TPBAR Disposal Containers in ILV (U) 

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April 7, 2021

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

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## EXECUTIVE SUMMARY

A tritium source term analysis was performed for TPBAR disposal in the E-Area Intermediate Level Vaults for the E-Area Low-Level Waste Facility Performance Assessment (PA). This analysis is based on an earlier source term analysis which treated the bulk of the tritium residual as tightly bound by the TPBAR getter material, with only a small fraction existing as tritiated moisture in the lithium aluminate ceramic pellets. Together with atmospheric moisture trapped in the free volume, the tritiated water vapor is assumed to corrodesteel surfaces inside the disposal container, covering them with a magnetite film while generating hydrogen. The carbon steel walls of the disposal container are permeable to hydrogen, providing a pathway for tritium to escape containment. The rate of hydrogen generation is assumed to be limited by the rate of corrosion, which is assumed to be governed by parabolic reaction kinetics obtained from the literature. This relies on the further assumption that the water vapor consumed by the corrosion reaction is continually replaced by moisture from the lithium aluminate pellets until all of that moisture is gone. In addition to tritium permeation, the analysis also includes a slow leak through the disposal container walls at the maximum allowable leak rate, $1 \times 10^{-4}$ standard $\mathrm{cm}^{3} / \mathrm{s}$. Results were obtained for four different combinations of internal and container wall temperatures, established in an earlier thermal analysis that considered two different vault loadings and two different TPBAR activity levels (Table ES-1). Instantaneous release rates for these four cases are plotted in Figure ES-1 below.

Table ES-1. Temperatures Used in Source Term Calculations.

| Case | Description | Internal <br> Temperature, ${ }^{\circ} \mathbf{C}$ | Wall <br> Temperature, ${ }^{\circ} \mathbf{C}$ |
| :---: | :---: | :---: | :---: |
| Case 1 | 1-y old TPBARS, 8 containers per ILV | 140 | 130 |
| Case 2 | 5-y old TPBARS, 8 containers per ILV | 109 | 95 |
| Case 3 | 1-y old TPBARS, 4 containers per ILV | 96 | 89 |
| Case 4 | 5-y old TPBARS, 4 containers per ILV | 79 | 71 |



Figure ES-1. Instantaneous Tritium Release Rates over Time for the 4 ILV Disposal Cases.

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## LIST OF ABBREVIATIONS

| IAEA | International Atomic Energy Agency |
| :--- | :--- |
| IBRAE | Institut problem Bezopasnogo Razvitiya Atomnoi Energetiki, transl. |
| Nuclear Safety Institute (of the Russian Academy of Sciences) |  |
| ILV | Intermediate Level Vaults |
| RH | Relative humidity |
| SRNL | Savannah River National Laboratory |
| SRS | Savannah River Site |
| TEF | Tritium Extraction Facility |
| TPBAR | Tritium-producing burnable absorber rod |
| TVA | Tennessee Valley Authority |
| UDQE | Unreviewed Disposal Question Evaluation |

### 1.0 Introduction

Tritium for the US Defense Program is produced in the Tennessee Valley Authority's (TVA's) Watts Bar Nuclear Plant, a commercial nuclear power generating station that had its operating license amended for this purpose [1]. Westinghouse pressurized water reactors like those at Watts Bar use boron in so-called burnable absorber rods that are placed in the core to absorb neutrons and control reactivity. When boron10 nuclei absorb a neutron, they split to form lithium-7 and helium-4. To make tritium at Watts Bar, the boron is replaced with lithium- 6 in the form of lithium aluminate in a limited number of so-called tritiumproducing burnable absorber rods (TPBARs). Lithium-6 nuclei split into tritium and helium- 4 upon absorbing a neutron. Since all hydrogen isotopes can permeate metals, TPBARs also incorporate Zircaloy4 getter material that chemically binds hydrogen to trap tritium atoms. Nevertheless, it is difficult to keep tritium from diffusing out of the TPBARs and into the pressurized water coolant, which can carry it throughout the plant and ultimately into the environment. Consequently, TPBARs can only be used in restricted numbers at Watts Bar to avoid exceeding the strict regulatory limits on tritium release.

Irradiated TPBARs containing tritium are shipped to the Tritium Extraction Facility (TEF) at the Savannah River Site (SRS). Here they are processed in an extraction furnace at high temperature and under a vacuum to remove and collect their tritium content. Spent TPBARs emit gamma radiation because their stainlesssteel cladding has been activated by neutron irradiation in the Watts Bar reactor. Consequently, they must be disposed of inside shielded containers that are then buried in the Intermediate Level Vaults (ILV) in EArea at SRS.

Spent TPBARs inevitably contain some residual tritium due to their use of Zircaloy-4 getters that have such a high affinity for hydrogen that complete removal is unattainable. However, the tritium trapped in the spent TPBARs can slowly escape over time and permeate the thick walls of the disposal container, eventually reaching ground water. Tritium could then be carried out of E-Area by ground water transport, potentially violating ILV permits.

This report provides an analysis of tritium release over time from spent TPBARs in the E-Area ILV. The release profile generated is intended to serve as the tritium source term in a separate analysis of tritium migration in E-Area ground water. Conservatism is ensured by picking the scenario with the greatest or fastest release potential whenever presented with a choice. This helps guarantee that the result is a truly bounding, or worst-case analysis.

### 2.0 Analysis

The approach used for this analysis is based on the one developed by Lanning and Gilbert in 2005 [2]. Lanning and Gilbert posited that the rate of tritium release from the TPBARs to the ILV environment is controlled by the rate at which hydrogen is generated due to corrosion of steel surfaces by moisture trapped inside the disposal containers and by the rate at which the hydrogen thus generated permeates the container walls. This analysis adds one additional release path: a hypothetical leak at a rate equivalent to the maximum allowableleak between the interior and exterior of the disposal containers as set by the containers' procurement specification (M-SPP-H-00418, Rev. 2) [3].

### 2.1 Tritium Distribution in the TPBARS

TPBARs are clad in Type 316 stainless steel. To prevent inward diffusion of hydrogen from the coolant as well as outward diffusion of tritium from the TPBAR, an aluminide coating is placed on the cladding inner surface. Tritium is generated in annular sintered, high-density, lithium aluminate $\left(\mathrm{LiAlO}_{2}\right)$ ceramic pellets. A metal getter tube composed of nickel-plated Zircaloy-4 is placed between the cladding and the lithium aluminate pellets. The getter absorbs molecular tritium $\left(\mathrm{T}_{2}\right)$ generated during irradiation. Nickel plating on both sides of the getter prevents oxidation of the Zircaloy-4 surfaces, which would reduce the tritium
absorption rate. An unplated Zircaloy-4 tube, or liner is placed inside the annular pellets. This reactive metal liner is needed to reduce any $\mathrm{T}_{2} \mathrm{O}$ species made in the pellets to molecular tritium and to provide mechanical support during TPBAR handling [4].

Irradiated TPBARs are chopped open at one end and subjected to high temperatures and vacuum during the extraction process so that as much tritium as possible can be recovered. This means that any residual tritium is very tightly bound in the getter, where it originally accumulated as it was being made in the reactor. The maximum temperature reached by the TPBARs in ILV disposal due to the combined heating effects of radioactive decay and grout curing is so low in comparison, that the amount that could desorb and permeate the disposal container walls is nearly negligible, as will be shown further below.

Lanning and Gilbert's analysis assumes that the TPBARs, which are chopped open for tritium extraction, could be exposed to moist air at some point following extraction so that these pellets could pick up moisture. It further assumes that the absorbed moisture would undergo isotopic exchange with the tritium residual, making a small amount of THO. This tritiated moisture would become available to corrode any steel surface inside the disposal container once it is sealed. Corrosion of iron into magnetite yields hydrogen as a byproduct, providing a means by which tritium could escape the disposal container, thanks to the mobility of molecular hydrogen [2].

### 2.2 Tritium Release from Getter Material

Residual tritium is so tightly bound in the getter material, that the amount that can escape by desorption is negligible. This was one of the outcomes of Lanning and Gilbert's analysis [2], which relied on a 1976 IAEA-published binary zirconium-hydrogen phase diagram with equilibrium hydrogen pressures [5] as reproduced in a 1999 Russian Academy of Sciences Nuclear Safety Institute(Institut problem Besopasnogo Razvitiya Atomnoi Energetiki, IBRAE) paper [6]. Lanning and Gilbert extrapolated the equilibrium partial pressure of tritium (as hydrogen) that can exist in equilibrium with the residual in the Zircaloy-4 getter from the IBRAE graph to $150^{\circ} \mathrm{F}(339 \mathrm{~K})$ and found it to be $4.78 \times 10^{-20}$ atm [2]. If this partial pressure were to be maintained inside the disposal container, their analysis showed that the steady-state permeation rate would be only $20 \mu \mathrm{Ci} / \mathrm{y}$ [2], essentially rendering it negligible.

An independent check of this conclusion was undertaken for this analysis. The solubility of hydrogen isotopes in metals is known to obey Sieverts' Law [7-9]:

$$
c=K_{S}(T) \sqrt{p}
$$

Here, $c$ is the absorbed hy drogen content expressed as the hy drogen to metal atom ratio (atom $\mathrm{H} /$ atom Zr ), $K_{S}$ the temperature-dependent Sieverts constant (atomH/atomZr-Pa ${ }^{-1 / 2}$ ), $T$ the absolute temperature (K), and $p$ the partial pressure of hydrogen $(\mathrm{Pa})$. The Sieverts constant has an Arrhenius temperature dependence:

$$
K_{S}(T)=k_{S}^{o} e^{-\Delta H_{S} / R T}
$$

Here, $k_{S}^{o}$ is the preexponential factor (atom $\mathrm{H} /$ atom $\mathrm{Zr}-\mathrm{Pa}^{-1 / 2}$ ), $\Delta H_{S}$ the enthalpy of solution of hydrogen in zirconium ( $\mathrm{J} / \mathrm{gmol}$ ), and $R$ the universal gas constant ( $8.314463 \mathrm{~J} / \mathrm{gmol}-\mathrm{K}$ ).

Values of $k_{S}^{o}$ and $\Delta H_{S}$ measured for hydrogen absorption in $\alpha$-zirconium are shown in Table 2-1 below. (The Sieverts constant reported by Kearns is actually in units of atom fraction $\mathrm{H}_{-\mathrm{Pa}^{-1 / 2}}$ [7], but is included with the other sources [8,9] for comparison. This difference could be the reason why the magnitude of the apparent enthalpy of solution measured by Kearns is the smallest of the five.) In general, the solubility of hydrogen in zirconium alloys (Zircaloy-2 and Zircaloy-4) was found to be similar to that in pure zirconium [7]. An isotopic effect was observed such that the Sieverts constant for deuterium absorption in $\alpha$-zirconium over the $770-1020 \mathrm{~K}$ temperature range is about $11-12 \%$ higher than for protium [8]. This means that the equilibrium partial pressure for deuterium absorbed at the same $\mathrm{H} / \mathrm{Zr}$ atom ratio would be about $23-25 \%$
higher than for protium. A similar effect could be expected for tritium, implying that the equilibrium partial pressure for tritium absorbed at the same $\mathrm{H} / \mathrm{Zr}$ atom ratio would be no more than about $50 \%$ higher. Finally, the publication in which Tada and Huang's Sieverts constant parameters were originally published could not be identified from the citation provided by Yamanaka et al., so the values shown are actually those reported by Yamanaka et al. [9].
Table 2-1. Experimentally Determined Sieverts Constant Temperature Dependence Parameters for Hydrogen Solubility in $\alpha$-Zirconium.

| Source | $k_{S}^{o}\left(\right.$ atom $\mathrm{H} /$ atom $\left.\mathrm{Zr}^{\text {- }} \mathrm{Pa}^{1 / 2}\right)$ | $\Delta H_{S}(\mathrm{~J} / \mathrm{gmol})$ | Temperature range, $K$ |
| :---: | :---: | :---: | :---: |
| Kearns (1967) [7] | $1.21 \times 10^{-5^{*}}$ | -49,540 | 683-1003 |
| Tada and Huang (1971) as reported in [9] ${ }^{\dagger}$ | $1.67 \times 10^{-5}$ | -51,900 | 673-1173 |
| Watanabe (1985) - protium [8] | $5.735 \times 10^{-6}$ | -54,590 | 756-1025 |
| Watanabe (1985) - deuterium [8] | $5.294 \times 10^{-6}$ | -54,380 | 772-1022 |
| Yam anaka, Higuchi, and Miyake (1995) [9] | $6.79 \times 10^{-6}$ | -54,700 | 773-1123 |

The solubility of hydrogen in $\alpha$-zirconium at $1 \mathrm{~Pa}\left(9.9 \times 10^{-6} \mathrm{~atm}\right)$ partial pressure is plotted as a function of temperature based on these Sieverts constant correlations in Figure 2-1 below. Solid curves depict correlated solubilities over the experimental temperature ranges for the five sources in Table 2-1, while dashed curves extrapolate the correlations to lower temperatures. Kearns' correlation is meaningless below about $250^{\circ} \mathrm{C}$ at this partial pressure because extrapolation results in H atom fractions greater than 1. The other correlations asymptotically approach an H atom fraction of 1 as the temperature decreases.

[^0]

Figure 2-1. Hydrogen Solubility at 1 Pa Partial Pressure in $\alpha$-Zirconium as a Function of Temperature.
The highest temperature that the TPBARs will reach in ILV disposal due to decay heat and grout curing is $140^{\circ} \mathrm{C}(413 \mathrm{~K})$ [10]. That corresponds to a $1 / \mathrm{T}$ value of $24.2 \times 10^{-4} \mathrm{~K}^{-1}$, for which the lowest solubility is predicted by Watanabe's correlation for deuterium, which gives an atom fraction of 0.975 - clearly an unrealistic value, reflecting how tightly zirconium binds hydrogen.

The tritium residual in spent TPBARs is $133 \mathrm{Ci} / \mathrm{TPBAR}$ and the mass of Zircaloy-4 getter is 154.18 $\mathrm{g} / \mathrm{TPBAR}$ [11]. Given that the getter is $\alpha$-zirconium, with an atomic weight of $91.224 \mathrm{~g} \mathrm{Zr} / \mathrm{gmol} \mathrm{Zr}$, and that the atomic weight and molar activity of tritium are $3.016049 \mathrm{~g} \mathrm{~T} / \mathrm{gmol} \mathrm{T}$ and $9,621.03 \mathrm{Ci} / \mathrm{g} \mathrm{T}$, respectively [12], the equivalent $\mathrm{H} / \mathrm{Zr}$ atom ratio of the residual in the getter is 0.002576 atom $\mathrm{H} /$ atom Zr . Kearns's correlation predicts a Sieverts constant of 528.8 atom fraction $\mathrm{H}-\mathrm{Pa}^{-1 / 2}$ at $150^{\circ} \mathrm{F}$, or 339 K (it is the least soluble of the correlations in Table 2-1 at this temperature), which results in a partial pressure of 2.36 $\times 10^{-11} \mathrm{~Pa}\left(2.33 \times 10^{-16} \mathrm{~atm}\right)$ at equilibrium. While this is $31 / 2$ orders of magnitude higher than the value extrapolated by Lanning and Gilbert, it is still so small as to result in a nearly negligible permeation rate. Consequently, the tritium bound in the getter is nearly immobile and is considered separately from the small fraction isotopically exchanged with moisture in the pellets, further detailed below.

### 2.3 Tritium Release Due to Corrosion

If spent TPBARs are exposed to moist air, the lithium aluminate pellets inside can absorb atmospheric moisture. The protium atoms in the absorbed water molecules could then undergo isotopic exchange with the tritium residual, providing an alternative mechanism by which tritium could escape confinement.

This mechanism was proposed by Lanning and Gilbert in their analysis of tritium release from TPBAR disposal [2]. It relies on the corrosion of steel surfaces inside the disposal containers by moisture inadvertently picked up prior to disposal. The corrosion reaction converts iron metal to magnetite, $\mathrm{Fe}_{3} \mathrm{O}_{4}$, as shown below:

$$
3 \mathrm{Fe}+4 \mathrm{H}_{2} \mathrm{O} \rightarrow \mathrm{Fe}_{3} \mathrm{O}_{4}+4 \mathrm{H}_{2}
$$

Hydrogen is a co-product of this reaction. Since the water is partially tritiated by isotopic exchange within the pellets, the hydrogen will be as well, allowing tritium to permeate the steel walls of the disposal container. Tritium release from the disposal containers occurs primarily by this mechanism, which is treated separately from getter desorption as noted in Section 2.2 above.

Lanning and Gilbert's analysis assumes that corrosion is the rate-limiting step for hydrogen production. They allow for the disposal container to be sealed with ambient air at $70 \%$ relative humidity (RH), providing an initial amount of water that can immediately corrode the steel surfaces inside. The lithium aluminate pellets are considered to be an active moisture source, maintaining water vapor at a constant level by offsetting depletion due to the corrosion reaction. Justification for this is provided by Lanning and Gilbert's observation that the consequent release rate from the pellets is on the order of $0.001 \mu \mathrm{Ci} / \mathrm{g} / \mathrm{s}$, which is said to be comparable to literature vales for lithium aluminate pellets at similar temperatures as reported by Nishikawa et al [13]. Corrosion continues unabated until all of the moisture is consumed [2].

Two different types of steel are present inside the disposal containers. One is carbon steel, which is what the containers themselves are made of. The other is stainless steel, which is used for the TPBAR cladding and to make the consolidation containers and extraction baskets. At least four different types of stainless steel are used: Type 316 for the TPBAR cladding [4], Type RA-330 and Type 304L for the bulk of the consolidation containers and extraction baskets [14-16], and 17-4 for miscellaneous parts [14-16]. Lanning and Gilbert's analysis took into account corrosion of the disposal container walls and TPBAR cladding only, apparently ignoring the considerable surface area contributed by the consolidation containers and extraction baskets [2]. Theye used corrosion rate information from Robertson [17] to estimate the rate at which magnetite was being made, which in turn established the hydrogen generation rate.

Robertson observed that carbon steel corrodes in water to form duplex films of magnetite in which diffusion control gives an oxide film whose thickness, $x(\mathrm{~cm})$ varies parabolically with time, $t(\mathrm{~s})$ :

$$
x^{2}=k_{p} t
$$

Here $k_{p}\left(\mathrm{~cm}^{2} / \mathrm{s}\right)$ is a parabolic corrosion rate constant that is proportional to the underlying diffusion constant. As a result, $k_{p}$ can be expected to exhibit an Arrhenius temperature dependence. Robertson collected data from several different sources to develop linear plots of the logarithm of $k_{p}$ as functions of inverse absolute temperature. Differentlinear correlations were found for steam and water as the sources of corrosion, and surface finish was seen to affect corrosion rates as well, with a rougher finish resulting in faster rates. A straight-line $\log k_{p}$ versus 1000/Tcurve obtained by digitizing the line in Figure 2 in Robertson [17] for corrosion of milled surface carbon steel by water fitted to the data of Warzee et al. [18] is shown in Figure 2-2 below (blue line). Corrosion of the disposal container walls was assumed to be governed by this parabolic rate constant extrapolated to the temperatures encountered in ILV disposal.


Figure 2-2. Temperature dependence of parabolic corrosion rate constants for carbon and stainless steels from Robertson [17].
Figure 2-2 also shows a red curve for the for corrosion of milled surface stainless steel by water. This curve plots the effective value of $k_{p}$ at $1,000 \mathrm{~h}$ calculated from a two-phase model fitted by Robertson [17] to the data of Warzee et al. [18] for milled surface Type 304 stainless steel. Corrosion of all the stainless-steel surfaces inside the disposal container was assumed to be governed by Robertson's two-phase corrosion model at the temperatures encountered in ILV disposal.

It should be noted that the oxygen present in the free volume when the disposal containers are sealed could also cause corrosion of the interior surfaces in competition with the moisture content. In fact, when internal temperatures are above the moisture dew point, dry oxidation is the more likely corrosion mechanism [19]. However, ignoring the possibility of corrosion by oxygen is conservative and valid for bounding purposes.

### 2.4 Disposal Container Dimensions and Specifications

The dimensions and specifications of the TPBAR disposal containers are similar to those detailed in Clark's 2004 analysis [20], reflected in Lanning and Gilbert's analysis [2], and most recently used in a calculation of the rate of tritium release due to permeation during onsite transfer [21] and an Unreviewed Disposal Question Evaluation (UDQE) that assessed the impact of a leak rate that exceeds the procurement specification limit [22]. Figure 2-3 below illustrates a TPBAR container lying on its side [23]. An exploded view of the top of a container is shown in Figure 2-4 [20].


Figure 2-3. TPBAR Disposal Container Side View [6].


Figure 2-4. TPBAR Disposal Container Top Exploded View [2].

Each container holds four 16 - ft tall, 12 -in diameter extraction baskets. Two such baskets can be seen in Figure 2-3 (the two gray cylinders- the other two lie directly behind). Each basket encloses a consolidation container filled with 300 TPBARs. The four sides and bottom of the container are made from 13 -in thick normalized carbon steel (SA516 Grade 70, Fine Grain Practice) slabs, held together with full penetration welds on all containment boundary joints [23]. The top of the container has a 12 -in thick steel shielding plate that is secured with threaded fasteners. An elastomeric seal provides interim sealing of the contents
after loading operations until the final closure plate ( 1 -in thick carbon steel) is seal welded in place to meet the leak rate requirements [23]. The container dimensions (in) used in Clark's [20] and subsequent tritium permeation analyses $[2,21,22]$ are summarized in Table 2-2 together with their values converted to cm . Clark assumed a void fraction of 0.2 , based on the internal dimensions, for the fractional volume inside the container occupied by air [20]. The disposal container procurement specification stipulates that the assembled container must have a leak rate less than $1 \times 10^{-4}$ standard $\mathrm{cm}^{3}$ air/s [3].

Table 2-2. Disposal Container Dimensions Used in Permeation Analysis.

| Description | Dimension |  |
| :--- | :---: | :---: |
|  | in | cm |
| Container Wall Thickness: | 13 | 33.02 |
| Container Internal Dimensions: |  |  |
| Bottom Section: |  |  |
| Height | 139 | 353.06 |
| Length | 32 | 81.28 |
| Width | 32 | 81.28 |
| Top Section: | 62.5 | 158.75 |
| Height | 36 | 91.44 |
| Length | 36 | 91.44 |
| Width | 49.5 | 125.73 |
| ContainerOuter Lid Dimensions: | 49.5 | 125.73 |
| Lenth | 1 | 2.54 |
| Width |  |  |
| Thickness | 198 | 502.92 |
| SealWeld Dimensions: | 0.5 | 1.27 |
| Length | 0.5 | 1.27 |
| Width |  |  |
| Thickness |  |  |

The side walls of the container have an additional 1-in thick carbon steel plate welded on all four sides of the bottom section, and 2 -in thick carbon steel plate on all four sides of the top section, so the actual side wall thickness is closer to 14 in . However, the thickness of the container bottomis only 13 in ; consequently, credit is taken only for that thickness for conservatism.

### 2.5 Tritium Permeation Analysis

Clark, Lanning and Gilbert, and others considered three permeation paths: 1) through the side walls and bottom of the container; 2) through the outer seal lid (taking no credit for the bolted upper lid with elastomeric seal); and 3) through the weld used to attach the outer seal lid. With regard to the welded lid, they all conservatively assumed that all internal seals fail and that the inside surfaces of the welded lid and the weld are exposed to the same tritium partial pressure as the interior walls.

The permeability of tritium, $\Phi$ is defined by

$$
\Phi \equiv D \times S
$$

where $D$ is the diffusivity of tritium in the material $\left(\mathrm{cm}^{2} / \mathrm{s}\right)$ and $S$ is the solubility of tritium in that material ( $\mathrm{gmol} \mathrm{H}_{2} / \mathrm{cm}^{3}$ material). Thus, the units of $\Phi$ are $\mathrm{gmol} \mathrm{H}_{2} / \mathrm{cm}-\mathrm{s}$ material. The maximum permeation rate through a material of thickness $L(\mathrm{~cm})$ for a given partial pressure of tritium on oneside occurs when tritium is removed as soon as it reaches the other side and a steady-state concentration profile is established along $L$. This is the so-called steady-state flux, $J_{\infty}$ :

$$
J_{\infty}=\frac{\Phi}{L}
$$

The flux is the amount of tritium ( $\mathrm{gmol} \mathrm{H} / \mathrm{H}_{2} / \mathrm{cm}^{2}$-s) that permeates the material per unit area and time. Because hydrogen diffusivity in carbon steel is so rapid, Clark found that steady-state permeation of tritium through the 13 -in thick walls could be achieved in about one week, and even faster along the much shorter seal lid ( $1-\mathrm{in}$ ) and weld paths ( $1 / 2-\mathrm{in}$ ) [20]. Consequently, the steady-state equation can accurately describe tritium permeation through carbon steel occurring over a period of years.

Clark and subsequent analysts used equation 2-4 to calculate the permeability of tritium in carbon steel from its diffusivity and solubility. They used correlations for protium in iron published by Quick and Johnson [24], reasoning that tritium diffusivity would actually be lower due to its threefold higher atomic mass, providing additional conservatism. In fact, Quick and Johnson measured solubilities, diffusivities, and permeabilities in iron for both protium and deuterium over a wide temperature range, finding that protium permeability was consistently higher than that of deuterium by a factor of 1.3-1.9 [24]. This confirms the implicit conservatism of using protium permeability to estimate that of tritium. It also underscores the fact that Quick and Johnson published a correlation for permeability, allowing it to be calculated directly instead of from correlated values of diffusivity and solubility via equation 2-4. This is more straightforward and is the method that was used in this work.

Quick and Johnson's correlation for protium permeability in iron is

$$
\Phi=\varphi(T) \sqrt{p}
$$

where

$$
\varphi(T)=\varphi_{0} e^{-E_{\varphi} / R T}
$$

Here $\varphi_{0}=2.53 \times 10^{17}$ atom $\mathrm{H} / \mathrm{cm}-\mathrm{s}-\mathrm{atm}^{1 / 2}, p$ is the partial pressure of protium (atm), $E_{\varphi}=8520 \mathrm{cal} / \mathrm{gmol}, R$ is the universal gas constant ( $1.987 \mathrm{cal} / \mathrm{gmol}-\mathrm{K}$ ), and $T$ is the absolute temperature (K) [24]. The square root dependence of protium permeability on partial pressure is consistent with its Sieverts' Law solubility: protium exists in diatomic form as a gas, but dissolves in iron in monatomic form.

The units for $\varphi_{0}$ used by Quick and Johnson are not convenient. They can be converted to $\mathrm{gmol} \mathrm{H}_{2} / \mathrm{cm}-\mathrm{s}-$ $\mathrm{atm}^{1 / 2}$ by dividing by Avogadro's number ( $6.022 \times 10^{23}$ atom $\left.\mathrm{H} / \mathrm{gmol} \mathrm{H}\right)$ and by the stoichiometric ratio 2 gmol H/gmol H . This yields $\varphi_{0}=2.10 \times 10^{-7} \mathrm{gmol} \mathrm{H}_{2} / \mathrm{cm}-\mathrm{s}-\mathrm{atm}^{1 / 2}$.

The partial pressure of hy drogen equivalent to the amount of tritium in the free space inside the container at any time can be calculated by material balance and the ideal gas relationship. Once that value is established, the tritium flow rate $\dot{n}(\mathrm{gmol} / \mathrm{s})$ through each of the three permeation paths can be calculated from the permeability - equations 2-6 and 2-7 - and the cross sectional area $A\left(\mathrm{~cm}^{2}\right)$ and length of the permeation path:

$$
\dot{n}=J_{\infty} A=\frac{A \Phi}{L}=\frac{A \sqrt{p} \varphi_{0} e^{-E_{\varphi} / R T}}{L}
$$

Based on the dimensions detailed in Table 2-2, the cross sectional areas for tritium permeation through the 1) bottom, ledge, and sides, 2 ) outer lid, and 3) seal weld are 1$) 4 \times[(353.06 \times 81.28)+(158.75 \times 91.44)]$ $\left.+91.44 \times 91.44=181,212.5 \mathrm{~cm}^{2}, 2\right) 125.73 \times 125.73=15,808.0 \mathrm{~cm}^{2}$, and 3) $502.92 \times 1.27=638.71 \mathrm{~cm}^{2}$, respectively. The corresponding permeation path lengths are 1) $33.02 \mathrm{~cm}, 2) 2.54 \mathrm{~cm}$, and 3$) 1.27 \mathrm{~cm}$.

A shortcoming of this approach is that it does not take corner effects into account. The surface area of the container exterior is almost twice that of the interior. However, the expected increase in calculated
permeation rate, if corner effects were to be included, is much smaller, on the order of $10 \%$ or less. Since no analytic solution for permeation through the walls of a vessel with square cross section could be found, and since extensive conservatism is already built into the calculation, no additional analysis is warranted.

One final check confirms the validity of using the steady-state equation to describe the permeation of hydrogen through the container walls over the time scale of this analysis. By analogy with the identical heat transfer problem solved in Carslaw and Yeager [25], Lanning and Gilbert developed an equation for the flux at the outer surface of a wall of thickness $L, J_{t}\left(\mathrm{gmol} \mathrm{H}_{2} / \mathrm{cm}^{2}\right.$-s) , as a fraction of the steady-state flux over time:

$$
\frac{J_{t}}{J_{\infty}}=1-\frac{4}{\pi} \sum_{n} \frac{(-1)^{n}}{2 n+1} e^{-D(2 n+1)^{2} \frac{\pi^{2} t}{4 L^{2}}}
$$

Using Lanning and Gilbert's value of the diffusivity of tritium in SA516 carbon steel alloy, $3.1 \times 10^{-10} \mathrm{~m}^{2} / \mathrm{s}$ [2], attributed to Ichitani and Kanno [26], the flux of tritium through a 13-in thick carbon steel wall takes years to approach the steady-state value, as shown by the red curve in Figure 2-5 below.


Figure 2-5. Tritium Flux through a 13 -in Thick SA316 Carbon Steel Wall as a Fraction of the Steady-state Value over Time (Inset Shows 0.5-y Close-up).
However, using the higher, and, therefore, more conservative values of the diffusivity of hydrogen in iron calculated from the correlation reported by Quick and Johnson $\left(1.36 \times 10^{-8} \mathrm{~m}^{2} / \mathrm{s}\right.$ at $71^{\circ} \mathrm{C}$, blue line, and 1.95 $\times 10^{-8} \mathrm{~m}^{2} / \mathrm{s}$ at $130^{\circ} \mathrm{C}$, black line) [24], the steady-state flux is approached much more quickly, achieving $98 \%$ in 0.3 y at the higher temperature. Of course, the steady-state flux through the 1 -in thick lid and $1 / 2$-in thick weld is achieved in an even much shorter time period. In reality, the hydrogen partial pressure inside
the disposal container continually increases as the metal surfaces inside corrode. Once all the moisture has been consumed, the hydrogen partial pressure decreases due to permeation of the container walls, eventually approaching zero. Using the steady-state flux for the permeation calculation will over-estimate the permeation rate during the period of increasing hydrogen partial pressure, speeding up the early release of tritium and adding conservatism to the prediction.

### 2.6 Tritium Leak Analysis

The very slow ( $1 \times 10^{-4}$ standard $\mathrm{cm}^{3} / \mathrm{s}$ ) maximum allowable air leak through the 13 -in thick steel wall of the cask can be assumed to be isothermal, given the overwhelmingly larger thermal mass of the solid. In the absence of any conflicting information, it can also be assumed that the leak path ( $\geq 13-\mathrm{in}$ ) is orders of magnitude longer than its hydraulic diameter (necessarily microscopic in size). Although velocities and Mach numbers are small, compressibility effects are important when the total pressure drop is a large fraction of the inlet pressure, as it is here. (Both the helium leak test and the vacuum decay test used in acceptance testing of TPBAR disposal containers impose a 1 -atm absolute pressure on the cask exterior and a near vacuum on the interior to force a measurable leak [3].) Perry's Handbook, 7th ed., gives an equation describing isothermal compressible flow in long transport lines (equation 6-114, page 6-22) that can be applied to this analysis [27].

According to Perry's Handbook, for an ideal gas with $\rho=p M_{w} / R T$, and assuming a constant friction factor $f$ over a length $L$ of a flow channel of constant cross section and hydraulic diameter $D_{H}$, integration of the momentum balance equations yields

$$
p_{1}^{2}-p_{2}^{2}=G^{2} \frac{R T}{M_{w}}\left[\frac{4 f L}{D_{H}}+2 \ln \left(\frac{p_{1}}{p_{2}}\right)\right]
$$

where the mass flux $G=w / A=\rho V$ is the mass flow rate per unit cross-sectional area of the channel. (Here $w$ is the mass flow rate, $A$ the cross-sectional area of the flow channel, $\rho$ the mass density of the gas, and $V$ its velocity.) Applying this equation to the leak test, $p_{1}$ and $p_{2}$ are the absolute pressures at the inlet and outlet of the leak path, respectively, $R$ is the universal gas constant, $T$ the test temperature, and $M_{w}$ the average molecular weight of air. The assumption that the leak path has a constant cross section and friction factor is no less realistic than the assumption that the leak path functions as a throttling valve with an effective flow coefficient.

The leak test measures the leak as a volumetric flow rate $Q$ and treats air as an ideal gas. The maximum allowable leak rate is $1 \times 10^{-4}$ standard $\mathrm{cm}^{3} / \mathrm{s}$, with standard conditions defined as 1 atm pressure and 298 K temperature. Applying the ideal gas law, this is equivalent to a molar leak rate of

$$
\dot{n}=\frac{p_{s} Q}{R T_{s}}=\frac{(1 \mathrm{~atm})\left(1 \times 10^{-4} \mathrm{~cm}^{3} / \mathrm{s}\right)}{\left(82.0574 \mathrm{~cm}^{3} \cdot \mathrm{~atm} / \mathrm{gmol} \cdot \mathrm{~K}\right)(298 \mathrm{~K})}=4.09 \times 10^{-9} \mathrm{gmol} / \mathrm{s}
$$

To convert equation 2-10 to a molar flow basis, the following relationship can be applied:

$$
G=\frac{\boldsymbol{w}}{A}=\frac{\dot{\boldsymbol{n}} M_{w}}{A}
$$

This gives:

$$
p_{1}^{2}-p_{2}^{2}=\left(\frac{\dot{n} M_{w}}{A}\right)^{2} \frac{R T}{M_{w}}\left[\frac{4 f L}{D_{H}}+2 \ln \left(\frac{p_{1}}{p_{2}}\right)\right]
$$

Solving for $\dot{n}$,

$$
\dot{n}=p_{1} A \sqrt{\frac{D_{H}}{M_{w} R T}} \sqrt{\frac{1-\left(\frac{p_{2}}{p_{1}}\right)^{2}}{4 f L-2 D_{H} \ln \left(\frac{p_{2}}{p_{1}}\right)}}
$$

Assuming a cylindrical leak path,

$$
A=\frac{\pi D_{H}^{2}}{4}
$$

Substituting into equation 2-14 and simplifying,

$$
\dot{n}=\frac{\pi p_{1} D_{H}^{5 / 2}}{8 \sqrt{M_{w} R T}} \sqrt{\frac{1-\left(\frac{p_{2}}{p_{1}}\right)^{2}}{f L-1 / 2 D_{H} \ln \left(\frac{p_{2}}{p_{1}}\right)}}
$$

The apparent hydraulic diameter can be calculated from the conditions of the vacuum decay test ( $\dot{n}=4.09$ $\times 10^{-9} \mathrm{gmol} / \mathrm{s}=4.09 \times 10^{-12} \mathrm{kmol} / \mathrm{s}, p_{1}=1 \mathrm{~atm}=101325 \mathrm{~Pa}, p_{2}=800 \mathrm{millitorr}=106.7 \mathrm{~Pa}, T=298 \mathrm{~K}$ ), solving iteratively for $D_{H}$ using equation 2-16. Here $M_{w}=28.964 \mathrm{~kg} / \mathrm{kmol}$ (dry air [28]), $R=8.314463 \mathrm{Pa-}$ $\mathrm{m}^{3} / \mathrm{kmol}-\mathrm{K}$. The leak flow path length, $L$ can be assumed to be equal to the wall thickness, $13 \mathrm{in}=0.3302$ m , while the friction factor, $f$ can be arbitrarily set at 0.01 . This approach results in a value of $1.907 \times 10^{5}$ m.

Applying this analysis to the leak, the volumetric flow rate of in-leakage as a function of internal pressure is depicted in Figure 2-6 below. The same relationship will be assumed to apply in the reverse direction, i.e., for the case where the cask internal pressure exceeds the external pressure due to internal heat generation resulting from radioactive decay. Equation 2-16 will be assumed to govern the leak rate to the exterior, with $L=0.3302 \mathrm{~m}, f=0.01$, and $D_{H}=1.907 \times 10^{-5} \mathrm{~m}$.


Figure 2-6. In-leakage of air as a function of disposal container internal pressure.

### 3.0 Implementation

The analysis detailed in Section 2.0 was implemented in a spreadsheet workbook (New Tritium Source Term Calculation r2.xlsx) that allows easy recalculation of the tritium release rate as a function of time for different input assumptions. It functions as a forward integration in $0.1-\mathrm{y}$ time steps. The set-up of the spreadsheet is explained below. Inputs are identified by their "Tab! Cell" locations in the workbook.

The calculation assumes that each disposal container is instantaneously loaded with fresh TPBAR extraction baskets and welded shut at time zero with an internal atmosphere of moist air ( $70 \%$ relative humidity, RelCalcSetUp!D9) at the ambient temperature and pressure. It then immediately heats up to the maximum temperature as determined by a separate thermal analysis of TPBAR disposal in the ILV [10], with instantaneously established steady-state hydrogen concentration profiles along all three carbon steel permeation paths. Corrosion of the internal surfaces begins immediately, with the water thus consumed being continually replenished by desorption of the moisture tied up in the lithium aluminate pellets. This is a conservative approach because the maximum temperatures may not be achieved for several months and pseudo-steady-state hydrogen concentration profiles may take several hours to several months to be established along all three permeation paths. Consequently, the actual tritium release curve should have a much lower peak release rate.

The thermal analysis established maximum TPBAR extraction basket and maximum disposal container wall temperatures for four different scenarios [10]. Each is characterized by a different combination of peak basket and wall temperatures. This analysis assumes that the air inside the disposal container is
maintained at the maximum extraction basket temperature and the walls, lid, and weld at the maximum wall temperature, beginning at time zero. The highest maximum temperatures were calculated for the case in which the TPBARs had been discharged from the Watts Bar reactor only one year prior, and the ILV had been loaded with eight disposal containers. In this case, the maximum basket and wall temperatures were found to be $140^{\circ} \mathrm{C}$ (RelCalcSetUp!D29) and $130^{\circ} \mathrm{C}$ (RelCalcSetUp!D31), respectively [10]. These are the values that will be used in the calculations that follow.

The free volume of the disposal container determines how much air is trapped when the container is welded shut. This analysis uses Clark's and Lanning and Gilbert's estimate of the fraction of the volume contained by the permeation boundary that is free as 0.2 (DispCont!D25) [2,20], which is calculated as $731,964 \mathrm{~cm}^{3}$. Assuming an ambient temperature of $76^{\circ} \mathrm{F}$ (RelCalcSetUp!D3) and pressure of 1 atm (RelCalcSetUp!D6), the quantity of moist air trapped in the free volume is 29.9742 gmol.

The residual tritium in each individual rod is assumed to be $133 \mathrm{Ci} /$ rod (DispContSetUp!E6), each extraction basket is assumed to hold $300 \mathrm{rod} / \mathrm{basket}$ (DispContSetUp!E5), and each disposal container is assumed to hold 4 basket/container (DispContSetUp!E4). Thus, the total tritium inventory is $159,600 \mathrm{Ci}$. Using the activity density, $9621.03 \mathrm{Ci} / \mathrm{g} \mathrm{T}$ (Constants! B4) and atomic mass of tritium, $3.01605 \mathrm{~g} / \mathrm{gmol}$ T (Constants!B12) [12], this can be converted to the more convenient quantity of 5.50013 gmol T . Of this amount, a fraction of 0.05 (DispContSetUp!E10), or 0.275006 gmol T is assumed to have entered the moisture in the lithium aluminate via isotope exchange.

Each TPBAR contains 180.02 g of lithium aluminate pellets (DispContSetUp!E8) [11], resulting in a total pellet inventory of $216.024 \mathrm{~kg} \mathrm{LiAlO}_{2}$ per disposal container. Assuming an absorbed moisture content of 300 ppm (DispContSetUp!E9), this means the pellets hold 64.8072 g , or $3.597402 \mathrm{gmol} \mathrm{H} \mathrm{H}_{2} \mathrm{O}$. An additional 0.634980 gmol is present as water vapor, calculated from $70 \% \mathrm{RH}$ at initial conditions. Thus, the total H content of the water available for corrosion is 7.194804 gmol H . Assuming that the tritiated moisture in the pellets instantaneously redistributes itself throughout the total water inventory, the initial tritium atom fraction (T/H total) is 0.032488

Thus, the total molar quantity of dry air in the free volume at time zero is 29.33921 gmol air, the quantity of water vapor is 0.634980 gmol $\mathrm{H}_{2} \mathrm{O}$, and the quantities of hydrogen, helium- 3 , and "produced" oxygen are zero (helium- 3 and "produced" oxygen are tracked explicitly as TH and THO decay products to maintain material balance). Given a free volume temperature of $140^{\circ} \mathrm{C}$ and assuming the ideal gas law, the internal pressure immediately increases to 1.388299 atm . The average molecular weight of the gas in the free volume is $28.7321 \mathrm{~g} / \mathrm{gmol}$, calculated from the sum of the products of the individual component molecular weights, $M_{w, i}\left(28.964 \mathrm{~g} / \mathrm{gmol}\right.$ air, Constants! B27; $18.0154 \mathrm{~g} / \mathrm{gmol} \mathrm{H}_{2} \mathrm{O}$, Constants! C20; $2.0160 \mathrm{~g} / \mathrm{gmol} \mathrm{H}_{2}$, Constants! C22; $3.01603 \mathrm{~g} / \mathrm{gmol}{ }^{3} \mathrm{He}$, Constants! B 15 ; and $31.9988 \mathrm{~g} / \mathrm{gmol} \mathrm{O}_{2}$ Constants! C 24 ) and their mole fractions, $y_{i}$.

$$
M_{w}=\sum_{i} y_{i} M_{w, i}
$$

Isotopic differences between protium and tritium are ignored in calculating the average molecular weight for simplicity. The effect on the results should be negligible.

Ninety-five percent of the residual tritium is assumed to be tied up in the getter. Based on the previously cited mass of Zircaloy-4 material ( $154.18 \mathrm{~g} /$ TPBAR, DispContSetUp!E97, Section 2.2 [11]) that translates to a $2.58 \times 10^{-3} \mathrm{~T} / \mathrm{Zr}$ atom ratio, for which the equilibrium $\mathrm{T}_{2}$ partial pressure at $140^{\circ} \mathrm{C}$ is $1.33 \times 10^{-13} \mathrm{~atm}$. The permeability coefficient for tritium can be calculated from equation 2-7 and the cask wall temperature, $130^{\circ} \mathrm{C}$, to get $\varphi=5.05467 \times 10^{-12} \mathrm{gmol} \mathrm{T}_{2} / \mathrm{cm}-\mathrm{s}-\mathrm{atm}^{1 / 2}$. Using the calculated tritium partial pressure and equation 2-6, this gives a tritium permeability of $1.84 \times 10^{-18} \mathrm{gmol} \mathrm{T} 2 / \mathrm{cm}-\mathrm{s}$. The rate of tritium permeation
through the walls, lid, and sealing weld can now be calculated using the permeation area (DispContSetUp!D45:D47) and length (DispContSetUp!D50,D52,D54) values derived in Section 2.5 and the relationship $\dot{n}=A \Phi / L$ to get

- $\dot{n}_{\text {walls }}=3.19 \times 10^{-7} \mathrm{gmol} \mathrm{T}_{2} / \mathrm{y}$,
- $\dot{n}_{\text {lid }}=3.62 \times 10^{-7} \mathrm{gmol} \mathrm{T} 2 / \mathrm{y}$, and
- $\dot{n}_{\text {weld }}=2.92 \times 10^{-8} \mathrm{gmol} \mathrm{T}_{2} / \mathrm{y}$,
- $\dot{n}_{\text {perm, total }}=7.10 \times 10^{-7} \mathrm{gmol} \mathrm{T} 2 / \mathrm{y}=0.0412 \mathrm{Ci} / \mathrm{y}$,
assuming $1 \mathrm{y}=365.25 \mathrm{~d}$ (Constants!B51). While this is more than three orders of magnitude higher than the permeation rate predicted by Lanning and Gilbert, it is still much smaller than the rate resulting from the tritiated hydrogen generated via corrosion, as will be shown below. The reasons for the higher rate are: 1) use of the steady-state instead of the transient permeation rate equation; 2) higher permeability correlation used for tritium transport through container walls; and 3) lower tritium solubility correlation used for Zircaloy-4 getter material. Since the tritium bound in the getter is released at a rate and magnitude that is orders of magnitude smaller than the tritium released by corrosion, it is tracked separately. Once the moisture is depleted and the tritium released by corrosion has escaped the container or decayed away, the low level of tritium release from the getter becomes the dominant, albeit minuscule release mechanism.

Having established the initial conditions inside the container and the initial permeation rate, the effects of all the ongoing phenomena over a time step can now be calculated. The leak rate is computed at the conditions at the beginning of the time step, using equation 2-16, with $p_{1}=1.388299 \mathrm{~atm}=140669 \mathrm{~Pa}$ (calculated above), $p_{2}=1 \mathrm{~atm}=101325 \mathrm{~Pa}$ (default external pressure), $T=130^{\circ} \mathrm{C}=403.15 \mathrm{~K}$ (the wall temperature), and $M_{W}=28.7321 \mathrm{~g} / \mathrm{gmol}$ (calculated above). As noted at the end of Section 2.6, $L=0.3302$ m (RelCalcSetUp!D51), $f=0.01$ (RelCalcSetUp!D52), and $D_{H}=1.907 \times 10^{-5} \mathrm{~m}$ (RelCalcSetUp!D53). The resulting leak rate is $3.4108 \times 10^{-9} \mathrm{gmol} / \mathrm{s}$, which causes 0.0107636 gmol (RelSchedZ7) to exit the container over the $3,155,760-$ s (Constants! B55) duration of the time step.

At the same time, the metal surfaces inside the disposal container are being corroded by moisture in the gas phase. As explained in Section 2.3, all carbon steel and stainless-steel surfaces are involved. The actual areas under corrosive attack are calculated on four different tabs: DispCont, TPBARs, Basket, and Consol. The exposed surface area of the carbon steel disposal container is found to be $189,573.8 \mathrm{~cm}^{2}$ (DispCont!C40). Three different components contribute to the stainless-steel surface area undergoing corrosion. First, the TPBARs are clad in Type 316 stainless steel [4], contributing $139.1765 \mathrm{~m}^{2}$ (TPBARs! F11) of surface area. Second, the extraction baskets are fabricated primarily out of Types RA300 and 304L stainless steel, with some 17-4 alloy parts [14, 15]. They contribute a combined total of $121.1461 \mathrm{~m}^{2}$ (Basket!E165) of surface area. Finally, the consolidation containers are made out of Type 304 stainless steel with some 17-4 alloy parts [16], contributing an additional $25.5928 \mathrm{~m}^{2}$ (Consol!F 129) of surface area. (Details of the surface area calculations are omitted here for brevity but can be found on the four tabs of the spreadsheet workbook noted above.) The combined total of all of the stainless-steel surfaces inside the disposal container is $2,859,155 \mathrm{~cm}^{2}$ (DispContSetUp!D59).

The quantity of magnetite generated over the time step due to corrosion is calculated with the help of two corrosion tables, one for carbon steel (tab CSCorrosionTable) and the other for stainless steel (tab SSCorrosionTable). The two worksheets contain tables of oxide film thickness in elapsed time increments of 0.1 y calculated based on the temperature of the corroding material. Equation 2-3, with

$$
k_{p}=2.5069 \times 10^{-11} e^{-5387.8 / T, \mathrm{~K}} \mathrm{~cm}^{2} / \mathrm{s},
$$

obtained by digitizing the line in Figure 2 in Robertson [17] for corrosion of milled surface carbon steel was used to calculate oxide film thickness over time for carbon steel, while the two-phase model developed
by Robertson [17] for milled surface Type 304 stainless steel was used to calculate oxide film thickness over time for stainless steel. Carbon steel grows a $0.1115-\mu$ (CSCorrosionTable! C11) thick film over the first $0.1-\mathrm{y}$ time increment, while stainless steel grows a $0.0277-\mu$ (SSCorrosionTable! C9) thick film. Converting the thicknesses to cm , multiplying by the corresponding surface areas in $\mathrm{cm}^{2}$, adding together the resulting volumes, multiplying by the density of magnetite ( $5.17 \mathrm{~g} / \mathrm{cm}^{3}$, Constants! E 73 ), and dividing by its molecular weight ( $231.533 \mathrm{~g} / \mathrm{gmol}$, Constants! E74), the quantity of $\mathrm{Fe}_{3} \mathrm{O}_{4}$ produced over the first 0.1 y time increment is 0.2241536 gmol (RelSched! AA7). Four times as many moles of hydrogen are produced (RelSched!AB7) and moles of water vapor consumed (RelSched!AC7).

Ignoring the extremely low partial pressure of tritium that exists at equilibrium with the getter, no hydrogen is present in the free volume at the very beginning (RelSched!Q6). Consequently, the permeability is zero (RelSched!R6) and zero hydrogen permeates over the initial time step (RelSched!AG7).

The total amount of hydrogen released from the disposal container over the time step can be calculated from the product of the hydrogen mole fraction and total molar amount of the leak plus the quantity permeated through the container itself. The water vapor is also tritiated, so the molar quantity passed by the leak needs to be added (RelSched!AR7). Multiplying by the moisture tritium atom fraction, this results in a tritium release of 0.000015 gmol (RelSched!AS7) or 0.429919 Ci (RelSched!AT7).

The tritium inside the container is continually undergoing $\beta$-decay to helium- 3 , which is monatomic. Thus, 1 gmol of diatomic tritium decays to make 2 gmol of monatomic helium,

$$
\mathrm{T}_{2} \rightarrow 2 \mathrm{He},
$$

while 1 gmol of di-tritium oxide decays to make 2 gmol of monatomic helium and $1 / 2 \mathrm{gmol}$ of oxygen,

$$
\mathrm{T}_{2} \mathrm{O} \rightarrow 2 \mathrm{He}+1 / 2 \mathrm{O}_{2} .
$$

(For the sake of simplicity, it is assumed that tritium exists in the disposal container as $\mathrm{T}_{2}$ and $\mathrm{T}_{2} \mathrm{O}$ rather than TH and THO. The net effect is the same, regardless which form it actually occurs in.) These reactions result in changes in the molar quantity of gaseous species (both helium and the oxygen liberated by decay are tracked separately in the spreadsheet), which affects the pressure inside the disposal container and needs to be accounted for. The amount that actually decays is determined by the half-life, $t_{7 / 2}$, which is 12.32 y [12] (Constants! B8) and the elapsed time interval, $t, 0.1 \mathrm{y}$. Specifically, the fraction decayed in one 0.1-y time interval is

$$
\text { fraction decayed }=\left(1-0.5^{0.1 / 12.32}\right)=0.00561040
$$

(Constants!D56). Applying this to the tritiated moisture, the tritium atom fraction at the end of the time step (RelSched!T7) is reduced by this fractional amount. The tritium content of the getter at the end of the time step (RelSched!U7) is reduced by the same fraction. The effects of the container leak, permeation losses, corrosion reaction, and tritium decay can now be applied to calculate the contents of the free volume following the time step.

The molar quantity of air remaining in the free volume (RelSched!B7) is calculated by subtracting the product of the total moles of gas leaked and the mole fraction of air at the beginning of the time step (RelSched!H6) from the molar quantity at the beginning of the time step (RelSched!B6).

Determining the molar quantity of water vapor at the end of the time step (RelSched!C7) is a little more complicated. As indicated earlier, it is assumed that water vapor consumed by the corrosion reaction is immediately replaced with moisture desorbed from the $\mathrm{LiAlO}_{2}$ pellets. Consequently, the availability of that moisture needs to be checked. Furthermore, a small fraction of the water vapor is tritiated and will undergo decay. Thus, the molar quantity of water vapor remaining is calculated by first subtracting the product of the total moles of gas leaked and the mole fraction of water vapor at the beginning of the time
step (RelSched!I6) from the molar quantity of water vapor at the beginning of the time step (RelSched! C6). The molar quantity of water consumed due to corrosion over the time step (RelSched! AC7) is compared to the quantity of moisture available in the pellets (RelSched!O6). If there is enough moisture, no correction is made, otherwise the difference between RelSched! AC7 and RelSched!O6 is subtracted from the quantity of water vapor remaining. Finally, a correction is applied to account for the fraction of tritiated moisture that decays to helium and oxygen. The total molar quantity of water vapor is multiplied by 1 minus the difference between the moisture tritium atom fraction at the beginning, $\digamma_{0}$ (RelSched!T6) and at the end, $\AA_{1}$ (RelSched!T7) of the time step, (1-( $\left.f_{0}-f_{1}\right)$ ).

Calculating the molar quantity of hydrogen in the free volume at the end of the time step (RelSched!D7) is also somewhat complicated. The effects of the leak, corrosion reaction, permeation, and tritium decay all need to be accounted for. As with the other gaseous species, the molar quantity of hydrogen remaining is calculated by first subtracting the product of the total moles of gas leaked and the mole fraction of hydrogen at the beginning of the time step (RelSched! J6) from the molar quantity of hydrogen at the beginning of the time step (RelSched!D6). The total molar quantity of hydrogen generated by corrosion (RelSched!AB7) is then added, and the quantity removed by permeation (RelSched!AG7) subtracted. The resulting molar quantity of hydrogen is multiplied by $\left(1-\left(f_{0}-f_{1}\right)\right)$ to give the final value.

Calculating how much helium and "produced" oxygen has accumulated in the free volume due to tritium decay requires knowing how much of the tritiated moisture, water vapor, and hydrogen, as well as the how much of the tritium bound in the getter has decayed. Multiplying the molar quantity of water vapor at the end of the time step by the ratio $\left(f_{0}-f_{1}\right) /\left(1-\left(f_{0}-f_{1}\right)\right)$ provides the molar quantity of tritiated water vapor that has decayed (RelSched!AI7). Similarly, multiplying the molar quantity of hydrogen at the end of the time step by $\left(f_{0}-f_{1}\right) /\left(1-\left(f_{0}-f_{1}\right)\right)$ provides the molar quantity of tritiated hydrogen that has decayed (RelSched!AJ7). The molar quantity of moisture remaining in the $\mathrm{LiAlO}_{2}$ pellets (RelSched!O7) is calculated by subtracting the amount of water consumed by corrosion over the time step (RelSched!AC7) from the amount present at the beginning of the step (RelSched!O6) and multiplying the result by ( $1-$ ( $f_{0}$ $\left.-f_{1}\right)$ ). If the quantity of water consumed by reaction is greater than the quantity available at the beginning of the step, the moisture in the pellets has been depleted and the molar quantity is set to zero. The molar quantity of absorbed moisture remaining is multiplied by $\left(f_{0}-f_{1}\right) /\left(1-\left(f_{0}-f_{1}\right)\right)$ to obtain the molar quantity of tritiated moisture that has decayed (RelSched!AH7). Finally, the molar quantity of bound tritium that has decayed (RelSched! AQ7) is calculated from the difference between the tritium content of the getter at the beginning and at the end of the time step.

The molar quantity of helium in the free volume (RelSched!E7) is calculated by subtracting the product of the total moles of gas leaked and the mole fraction of helium at the beginning of the time step (RelSched!K6) from the molar quantity of helium at the beginning of the time step (RelSched!E6) and adding the molar quantity generated by tritium decay, which is twice ( $\mathrm{T}_{2}$ and $\mathrm{T}_{2} \mathrm{O}$ decay both yield 2 He ) the molar quantity of tritiated absorbed moisture, water vapor, and hydrogen lost to decay (RelSched!AH7:AJ7) plus the molar quantity of bound tritium (each T decays to He) lost to decay (RelSched! AQ7).

The molar quantity of "produced" oxygen in the free volume (RelSched!F7) is calculated by subtracting the product of the total moles of gas leaked and the mole fraction of "produced" oxygen at the beginning of the time step (RelSched!L6) from the molar quantity of "produced" oxygen at the beginning of the time step (RelSched!F6) and adding the molar quantity generated by tritium decay, which is one half ( $\mathrm{T}_{2} \mathrm{O}$ decays to yield $1 / 2 \mathrm{O}_{2}$ ) of the molar quantity of tritiated absorbed moisture and water vapor lost to decay (RelSched!AH7:AI7).

Having determined the molar quantities of all gaseous species in the free volume at the end of the time step, the total molar quantity (RelSched!G7), species mole fractions (RelSched!H7:L7), internal pressure (RelSched!M7), average molecular weight (RelSched!N7), and hydrogen partial pressure (RelSched!Q7) can be recalculated at the end of the time step in the same way as they were at the beginning. The total molar water inventory (RelSched!P7) can now be updated by adding the amount of water vapor remaining (RelSched!C7) to the amount of moisture remaining in the pellets (RelSched! O7). The total molar quantity of tritium contained in this water (RelSched!S7) can also be updated by multiplying the total water inventory by twice the fraction tritiated (RelSched!T7). Multiplying the permeability coefficient of the container walls (RelCalcSetUp!D41) by the square root of the hydrogen partial pressure updates the hydrogen permeability (RelSched!R7).

With regard to the tritium bound in the getter, the T/Zr atom ratio at the end of the time step (RelSched!V7) can be calculated from the remaining residual (RelSched!U7), allowing the corresponding equilibrium $\mathrm{T}_{2}$ partial pressure (RelSched! W7) to be computed from its Sieverts' Law solubility. When divided by the total pressure (RelSched!M7), this gives the mole fraction of tritium that could exist in the free volume at equilibrium with that bound in the getter at the end of the time step (RelSched!X7). Multiplying the permeability coefficient of the container walls by the square root of the bound tritium partial pressure updates the bound tritium permeability (RelSched!Y7).

The molar quantities of bound tritium permeated through the three permeation paths (RelSched! AK7:AM7) is calculated in the same way as it is for hydrogen, using the above-determined bound tritium permeability. The total amount permeated (RelSched! AN7) is added to the quantity passed by the leak (RelSched!AN7) and multiplied by the activity (Constants! B6) to establish the bound tritium released in units of Ci (RelSched! AP7).

Adding together the amounts of bound (RelSched!AP7) and mobile (RelSched!AT7) tritium released over the time step gives the total released (RelSched! AU7). Dividing by the length of the time interval yields the average instantaneous release rate over the interval (RelSched!AV7) and adding together successive releases provides the cumulative release (RelSched!AW7).

With the free volume, $\mathrm{LiALO}_{2}$ pellet, and Zircaloy-4 getter contents following the preceding time step thus established, the spreadsheet begins the next time step by repeating the leak, permeation, corrosion, Sieverts' Law, and decay calculations. The process is repeated for as much elapsed time as needed. Depending on the internal temperature, the moisture will eventually be all consumed and hydrogen generation cease. However, the bound tritium content in the getter, which accounts for the bulk, will be released very slowly over time and at a very low rate.

### 4.0 Results

Bounding cumulative tritium release curve were calculated for the four different cases developed in the thermal analysis [10]. The cases are summarized in Table 4-1 below.

Table 4-1. Temperatures Used in Source Term Calculations.

| Case | Description | Internal <br> Temperature, ${ }^{\circ} \mathbf{C}$ | Wall <br> Temperature, ${ }^{\circ} \mathbf{C}$ |
| :---: | :---: | :---: | :---: |
| Case 1 | 1-y old TPBARS, 8 containers per ILV | 140 | 130 |
| Case 2 | 5-y old TPBARS, 8 containers per ILV | 109 | 95 |
| Case 3 | 1-y old TPBARS, 4 containers per ILV | 96 | 89 |
| Case 4 | 5-y old TPBARS, 4 containers per ILV | 79 | 71 |

Cumulative release curves for all four are shown in Figure 4-1. The red curve plots the values for Case 1, the green for Case 2, the blue for Case 3, and the purple for Case 4. Tabular data are provided in Table A-1 in Appendix A.


Figure 4-1. Cumulative Tritium Release over Time for the 4 ILV Disposal Cases.
Instantaneous release curves for the four cases are plotted in Figure 4-2, using the same color scheme.


Figure 4-2. Instantaneous Tritium Release Rates over Time for the 4 ILV Disposal Cases.
Case 1 has the highest cumulative release of tritium. Only $5 \%$ of the tritium residual, $7,980 \mathrm{Ci}$, is mobile. The rest is tightly held by the getter. Roughly $81.5 \%$ of that amount, $6,507 \mathrm{Ci}$, is released before the moisture trapped in the disposal container is completely consumed and the resulting tritiated hydrogen either permeates and/or leaks out or decays away. This occurs at the 10-y mark. The difference, roughly $1,473 \mathrm{Ci}$ is lost to radioactive decay. Once the mobile tritium is gone, the bound tritium continues to permeate and/or leak at a very low rate, initially around $0.02 \mathrm{Ci} / \mathrm{y}$ at 10 y , and decreasing by an order of magnitude to $0.0025 \mathrm{Ci} / \mathrm{y}$ at the $50-\mathrm{y}$ mark.

Case 1 also has the highest instantaneous release rate, $1,182 \mathrm{Ci} / \mathrm{y}$, which occurs at the $1.8-\mathrm{y}$ mark. This is below the peak value predicted by Lanning and Gilbert's analysis, $2.210 \mathrm{Ci} / \mathrm{y}$, which occurred at the $3.5-\mathrm{y}$ mark [2]. Lanning and Gilbert assumed lower temperatures for the interior ( $200^{\circ} \mathrm{F}, 93.3^{\circ} \mathrm{C}$ ) and the container wall $\left(165^{\circ} \mathrm{F}, 73.9^{\circ} \mathrm{C}\right)$, yet found that all of the mobile tritium would be gone by 5.1 y .

The other three cases have lower interior and wall temperatures. That means lower corrosion, permeation, and leak rates, so the tritium release rate is significantly slower, providing more time for radioactive decay. The mobile tritium is completely gone after 31.7 y for Case 2 and 46.7 y for Case 3, and mostly gone after 50 y for Case 4. The corresponding cumulative releases are $4,225 \mathrm{Ci}, 3,279 \mathrm{Ci}$, and $1,578 \mathrm{Ci}$, respectively.

### 5.0 Conclusions

A bounding calculation was performed for the rate at which tritium will be released from spent TPBARs placed in ILV for disposal. The analysis estimated how much tritium would escape an individual shielded disposal container holding 4 fully loaded extraction baskets containing 300 spent TPBARs each. An earlier thermal analysis [10] established maximum internal and container wall temperatures for four different disposal scenarios, depending on the number of containers placed per vault ( 4 or 8 ) and the elapsed time
since the TPBARs were pulled from the Watts Bar reactor ( 1 or 5 years). The approach used was based on an earlier analysis performed by Lanning and Gilbert [2], which assumed that the bulk of the tritium residual was tightly bound in the TPBAR getter material and only a small fraction was mobile, initially existing as tritiated moisture in the TPBAR lithium aluminate pellets. Corrosion of the internal steel surfaces by this moisture, resulting in tritiated hydrogen generation with subsequent container wall permeation was the primary means by which tritium could escape the disposal container. The analysis also included a leak in the container walls at the maximum allowable leak rate, $1 \times 10^{-4} \mathrm{standard} \mathrm{cm}^{3} / \mathrm{s}$. The rate of tritiumleaving the container via this leak was found to be roughly two orders of magnitude smaller than the permeation rate.

As expected, the highest tritium release rates and largest cumulative tritium release were found for the disposal scenario with the highest temperatures. This was for the higher vault loading ( 8 containers) and higher TPBAR activity ( 1 year since irradiation) case. The maximum internal and container wall temperatures were 140 and $130^{\circ} \mathrm{C}$, respectively [10]. Under these conditions, the peak tritium release rate was found to be $1,182.3 \mathrm{Ci} / \mathrm{y}$, occurring 1.8 y following placement in ILV. The water content was completely consumed by corrosion 2.5 y after disposal, and the mobile tritium completely escaped or decayed after 10 y . The total quantity of tritium released at this point was $6,507.1 \mathrm{Ci}$. An additional 0.4 Ci was found to escape over the next 40 y due to residual tritium desorption from the getter with subsequent permeation.

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Appendix A. Instantaneous Tritium Source Term Release Rates and Cumulative Releases

Table A-1. Instantaneous Tritium Release Rates and Cumulative Releases over the 50-y Period of the Source Term Analysis.

|  |  | Instantaneous tritium release rate, $\mathrm{Ci} / \mathrm{y}$ |  |  |  | Cumulative tritium release, Ci |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Elapsed time, y | Interval midpoint, $y$ | Case 1 | Case 2 | Case 3 | Case 4 | Case 1 | Case 2 | Case 3 | Case 4 |
| 0.0 |  |  |  |  |  | 0 | 0 | 0 | 0 |
| 0.1 | 0.05 | 4.340383 | 3.7686434 | 3.4599839 | 3.0581795 | 0.4340383 | 0.3768643 | 0.3459984 | 0.3058179 |
| 0.2 | 0.15 | 755.17303 | 161.34709 | 108.07169 | 43.864614 | 75.951341 | 16.511573 | 11.153168 | 4.6922794 |
| 0.3 | 0.25 | 877.33619 | 188.73123 | 126.26577 | 51.117393 | 163.68496 | 35.384696 | 23.779745 | 9.8040187 |
| 0.4 | 0.35 | 951.95926 | 206.05214 | 137.78117 | 55.755795 | 258.88089 | 55.98991 | 37.557861 | 15.379598 |
| 0.5 | 0.45 | 1004.5518 | 218.69063 | 146.18913 | 59.176379 | 359.33606 | 77.858973 | 52.176774 | 21.297236 |
| 0.6 | 0.55 | 1044.0606 | 228.53656 | 152.74388 | 61.869792 | 463.74212 | 100.71263 | 67.451162 | 27.484215 |
| 0.7 | 0.65 | 1074.7852 | 236.49915 | 158.04881 | 64.072135 | 571.22064 | 124.36254 | 83.256043 | 33.891429 |
| 0.8 | 0.75 | 1099.1581 | 243.09326 | 162.44557 | 65.917134 | 681.13645 | 148.67187 | 99.500601 | 40.483142 |
| 0.9 | 0.85 | 1118.7032 | 248.64183 | 166.14846 | 67.488673 | 793.00677 | 173.53605 | 116.11545 | 47.23201 |
| 1.0 | 0.95 | 1134.4452 | 253.36216 | 169.30166 | 68.843214 | 906.45129 | 198.87227 | 133.04561 | 54.116331 |
| 1.1 | 1.05 | 1147.1098 | 257.4083 | 172.00737 | 70.020785 | 1021.1623 | 224.6131 | 150.24635 | 61.11841 |
| 1.2 | 1.15 | 1157.2316 | 260.89383 | 174.34097 | 71.050911 | 1136.8854 | 250.70248 | 167.68045 | 68.223501 |
| 1.3 | 1.25 | 1165.2172 | 263.90524 | 176.35982 | 71.956072 | 1253.4072 | 277.09301 | 185.31643 | 75.419108 |
| 1.4 | 1.35 | 1171.3838 | 266.51004 | 178.10873 | 72.753826 | 1370.5455 | 303.74401 | 203.1273 | 82.69449 |
| 1.5 | 1.45 | 1175.9839 | 268.76208 | 179.62341 | 73.458179 | 1488.1439 | 330.62022 | 221.08964 | 90.040308 |
| 1.6 | 1.55 | 1179.2226 | 270.7051 | 180.93288 | 74.080509 | 1606.0662 | 357.69073 | 239.18293 | 97.448359 |
| 1.7 | 1.65 | 1181.2685 | 272.37515 | 182.06105 | 74.630199 | 1724.193 | 384.92824 | 257.38904 | 104.91138 |
| 1.8 | 1.75 | 1182.2625 | 273.80234 | 183.0279 | 75.115089 | 1842.4193 | 412.30848 | 275.69182 | 112.42289 |
| 1.9 | 1.85 | 1181.7707 | 275.01213 | 183.8503 | 75.541806 | 1960.5963 | 439.80969 | 294.07685 | 119.97707 |
| 2.0 | 1.95 | 1180.2837 | 276.02624 | 184.54268 | 75.916012 | 2078.6247 | 467.41231 | 312.53112 | 127.56867 |
| 2.1 | 2.05 | 1178.0821 | 276.86338 | 185.11743 | 76.242582 | 2196.4329 | 495.09865 | 331.04287 | 135.19293 |
| 2.2 | 2.15 | 1175.2395 | 277.53979 | 185.58534 | 76.525751 | 2313.9569 | 522.85263 | 349.6014 | 142.8455 |
| 2.3 | 2.25 | 1171.8204 | 278.06967 | 185.95582 | 76.769226 | 2431.1389 | 550.6596 | 368.19698 | 150.52243 |
| 2.4 | 2.35 | 1167.881 | 278.46553 | 186.23716 | 76.976269 | 2547.927 | 578.50615 | 386.8207 | 158.22005 |

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| 2.5 | 2.45 | 1163.4712 | 278.73842 | 186.4367 | 77.14977 | 2664.2741 | 606.37999 | 405.46437 | 165.93503 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2.6 | 2.55 | 1145.6889 | 278.89819 | 186.56097 | 77.292302 | 2778.843 | 634.26981 | 424.12047 | 173.66426 |
| 2.7 | 2.65 | 1124.032 | 278.95366 | 186.61581 | 77.406168 | 2891.2462 | 662.16518 | 442.78205 | 181.40488 |
| 2.8 | 2.75 | 1102.5942 | 278.91272 | 186.60647 | 77.493438 | 3001.5056 | 690.05645 | 461.44269 | 189.15422 |
| 2.9 | 2.85 | 1081.3736 | 278.7825 | 186.53767 | 77.555979 | 3109.643 | 717.9347 | 480.09646 | 196.90982 |
| 3.0 | 2.95 | 1060.3683 | 278.56948 | 186.4137 | 77.595486 | 3215.6798 | 745.79165 | 498.73783 | 204.66937 |
| 3.1 | 3.05 | 1039.5763 | 278.27951 | 186.23845 | 77.613495 | 3319.6375 | 773.6196 | 517.36168 | 212.43072 |
| 3.2 | 3.15 | 1018.9956 | 277.91795 | 186.01547 | 77.611412 | 3421.537 | 801.41139 | 535.96322 | 220.19186 |
| 3.3 | 3.25 | 998.62429 | 277.48967 | 185.748 | 77.590522 | 3521.3994 | 829.16036 | 554.53802 | 227.95091 |
| 3.4 | 3.35 | 978.46055 | 276.99917 | 185.43902 | 77.552002 | 3619.2455 | 856.86028 | 573.08193 | 235.70611 |
| 3.5 | 3.45 | 958.50246 | 276.45056 | 185.09125 | 77.496937 | 3715.0957 | 884.50533 | 591.59105 | 243.4558 |
| 3.6 | 3.55 | 938.74815 | 275.84764 | 184.70722 | 77.426329 | 3808.9706 | 912.0901 | 610.06177 | 251.19844 |
| 3.7 | 3.65 | 919.19576 | 275.19391 | 184.28924 | 77.341101 | 3900.8901 | 939.60949 | 628.4907 | 258.93255 |
| 3.8 | 3.75 | 899.84345 | 274.49262 | 183.83948 | 77.24211 | 3990.8745 | 967.05875 | 646.87464 | 266.65676 |
| 3.9 | 3.85 | 880.68941 | 273.74677 | 183.35992 | 77.130152 | 4078.9434 | 994.43343 | 665.21064 | 274.36977 |
| 4.0 | 3.95 | 861.7318 | 272.95917 | 182.85242 | 77.005967 | 4165.1166 | 1021.7293 | 683.49588 | 282.07037 |
| 4.1 | 4.05 | 842.96885 | 272.1324 | 182.31871 | 76.870243 | 4249.4135 | 1048.9426 | 701.72775 | 289.75739 |
| 4.2 | 4.15 | 824.39877 | 271.2689 | 181.7604 | 76.723626 | 4331.8534 | 1076.0695 | 719.90379 | 297.42976 |
| 4.3 | 4.25 | 806.01979 | 270.37093 | 181.17899 | 76.566717 | 4412.4553 | 1103.1066 | 738.02169 | 305.08643 |
| 4.4 | 4.35 | 787.83016 | 269.44061 | 180.57588 | 76.400079 | 4491.2384 | 1130.0506 | 756.07928 | 312.72644 |
| 4.5 | 4.45 | 769.82813 | 268.47992 | 179.9524 | 76.22424 | 4568.2212 | 1156.8986 | 774.07452 | 320.34886 |
| 4.6 | 4.55 | 752.01199 | 267.49073 | 179.30977 | 76.039698 | 4643.4224 | 1183.6477 | 792.00549 | 327.95283 |
| 4.7 | 4.65 | 734.38 | 266.47477 | 178.64915 | 75.846919 | 4716.8604 | 1210.2952 | 809.87041 | 335.53752 |
| 4.8 | 4.75 | 716.93047 | 265.43368 | 177.97164 | 75.646343 | 4788.5534 | 1236.8385 | 827.66757 | 343.10216 |
| 4.9 | 4.85 | 699.66172 | 264.36903 | 177.27826 | 75.438383 | 4858.5196 | 1263.2754 | 845.3954 | 350.64599 |
| 5.0 | 4.95 | 682.57205 | 263.28225 | 176.56998 | 75.223431 | 4926.7768 | 1289.6037 | 863.0524 | 358.16834 |
| 5.1 | 5.05 | 665.65981 | 262.17472 | 175.8477 | 75.001856 | 4993.3428 | 1315.8211 | 880.63717 | 365.66852 |
| 5.2 | 5.15 | 648.92333 | 261.04773 | 175.1123 | 74.774007 | 5058.2351 | 1341.9259 | 898.1484 | 373.14592 |
| 5.3 | 5.25 | 632.36098 | 259.90252 | 174.36457 | 74.540215 | 5121.4712 | 1367.9162 | 915.58486 | 380.59995 |
| 5.4 | 5.35 | 615.97112 | 258.74024 | 173.6053 | 74.300793 | 5183.0683 | 1393.7902 | 932.94539 | 388.03002 |

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| 5.5 | 5.45 | 599.75211 | 257.56198 | 172.83521 | 74.056039 | 5243.0435 | 1419.5464 | 950.22891 | 395.43563 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5.6 | 5.55 | 583.70236 | 256.36878 | 172.05498 | 73.806233 | 5301.4138 | 1445.1833 | 967.43441 | 402.81625 |
| 5.7 | 5.65 | 567.82024 | 255.16163 | 171.26528 | 73.551644 | 5358.1958 | 1470.6994 | 984.56093 | 410.17142 |
| 5.8 | 5.75 | 552.10416 | 253.94146 | 170.46673 | 73.292526 | 5413.4062 | 1496.0936 | 1001.6076 | 417.50067 |
| 5.9 | 5.85 | 536.55252 | 252.70915 | 169.6599 | 73.029122 | 5467.0615 | 1521.3645 | 1018.5736 | 424.80358 |
| 6.0 | 5.95 | 521.16375 | 251.46555 | 168.84537 | 72.761661 | 5519.1778 | 1546.511 | 1035.4581 | 432.07975 |
| 6.1 | 6.05 | 505.93627 | 250.21145 | 168.02366 | 72.490365 | 5569.7715 | 1571.5322 | 1052.2605 | 439.32878 |
| 6.2 | 6.15 | 490.86849 | 248.94762 | 167.19528 | 72.215441 | 5618.8583 | 1596.4269 | 1068.98 | 446.55033 |
| 6.3 | 6.25 | 475.95885 | 247.67479 | 166.36071 | 71.93709 | 5666.4542 | 1621.1944 | 1085.6161 | 453.74404 |
| 6.4 | 6.35 | 461.20579 | 246.39363 | 165.52042 | 71.655501 | 5712.5748 | 1645.8338 | 1102.1681 | 460.90959 |
| 6.5 | 6.45 | 446.60774 | 245.10481 | 164.67483 | 71.370858 | 5757.2355 | 1670.3443 | 1118.6356 | 468.04667 |
| 6.6 | 6.55 | 432.16313 | 243.80895 | 163.82436 | 71.083334 | 5800.4519 | 1694.7252 | 1135.0181 | 475.15501 |
| 6.7 | 6.65 | 417.8704 | 242.50664 | 162.96942 | 70.793094 | 5842.2389 | 1718.9758 | 1151.315 | 482.23432 |
| 6.8 | 6.75 | 403.72798 | 241.19847 | 162.11037 | 70.500299 | 5882.6117 | 1743.0957 | 1167.526 | 489.28435 |
| 6.9 | 6.85 | 389.7343 | 239.88496 | 161.24759 | 70.205099 | 5921.5851 | 1767.0842 | 1183.6508 | 496.30486 |
| 7.0 | 6.95 | 375.88777 | 238.56664 | 160.38141 | 69.907641 | 5959.1739 | 1790.9408 | 1199.6889 | 503.29562 |
| 7.1 | 7.05 | 362.18682 | 237.244 | 159.51217 | 69.608064 | 5995.3926 | 1814.6652 | 1215.6402 | 510.25643 |
| 7.2 | 7.15 | 348.62983 | 235.91752 | 158.64018 | 69.306501 | 6030.2556 | 1838.257 | 1231.5042 | 517.18708 |
| 7.3 | 7.25 | 335.21518 | 234.58764 | 157.76575 | 69.003081 | 6063.7771 | 1861.7158 | 1247.2807 | 524.08738 |
| 7.4 | 7.35 | 321.94123 | 233.2548 | 156.88915 | 68.697926 | 6095.9712 | 1885.0412 | 1262.9697 | 530.95718 |
| 7.5 | 7.45 | 308.80633 | 231.91941 | 156.01067 | 68.391153 | 6126.8518 | 1908.2332 | 1278.5707 | 537.79629 |
| 7.6 | 7.55 | 295.80876 | 230.58187 | 155.13057 | 68.082876 | 6156.4327 | 1931.2914 | 1294.0838 | 544.60458 |
| 7.7 | 7.65 | 282.94679 | 229.24255 | 154.24909 | 67.773204 | 6184.7274 | 1954.2156 | 1309.5087 | 551.3819 |
| 7.8 | 7.75 | 270.21864 | 227.90181 | 153.36649 | 67.46224 | 6211.7493 | 1977.0058 | 1324.8453 | 558.12812 |
| 7.9 | 7.85 | 257.62246 | 226.56 | 152.483 | 67.150083 | 6237.5115 | 1999.6618 | 1340.0936 | 564.84313 |
| 8.0 | 7.95 | 245.15634 | 225.21745 | 151.59883 | 66.836831 | 6262.0271 | 2022.1835 | 1355.2535 | 571.52682 |
| 8.1 | 8.05 | 232.81827 | 223.87447 | 150.71419 | 66.522576 | 6285.309 | 2044.571 | 1370.3249 | 578.17907 |
| 8.2 | 8.15 | 220.60615 | 222.53137 | 149.82929 | 66.207405 | 6307.3696 | 2066.8241 | 1385.3079 | 584.79981 |
| 8.3 | 8.25 | 208.51772 | 221.18845 | 148.94433 | 65.891405 | 6328.2214 | 2088.943 | 1400.2023 | 591.38895 |
| 8.4 | 8.35 | 196.55058 | 219.84597 | 148.05948 | 65.574657 | 6347.8764 | 2110.9276 | 1415.0083 | 597.94642 |

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| 8.5 | 8.45 | 184.70212 | 218.50421 | 147.17493 | 65.257241 | 6366.3466 | 2132.778 | 1429.7258 | 604.47214 |
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| 8.6 | 8.55 | 172.96944 | 217.16341 | 146.29085 | 64.939231 | 6383.6436 | 2154.4943 | 1444.3548 | 610.96607 |
| 8.7 | 8.65 | 161.34932 | 215.82383 | 145.4074 | 64.620701 | 6399.7785 | 2176.0767 | 1458.8956 | 617.42814 |
| 8.8 | 8.75 | 149.8381 | 214.48569 | 144.52474 | 64.301721 | 6414.7623 | 2197.5253 | 1473.348 | 623.85831 |
| 8.9 | 8.85 | 138.43152 | 213.14923 | 143.64301 | 63.98236 | 6428.6055 | 2218.8402 | 1487.7123 | 630.25655 |
| 9.0 | 8.95 | 127.12454 | 211.81466 | 142.76237 | 63.662681 | 6441.3179 | 2240.0217 | 1501.9886 | 636.62281 |
| 9.1 | 9.05 | 115.91101 | 210.48217 | 141.88296 | 63.342747 | 6452.909 | 2261.0699 | 1516.1769 | 642.95709 |
| 9.2 | 9.15 | 104.78324 | 209.15198 | 141.00489 | 63.022619 | 6463.3873 | 2281.9851 | 1530.2774 | 649.25935 |
| 9.3 | 9.25 | 93.73124 | 207.82427 | 140.12831 | 62.702355 | 6472.7605 | 2302.7675 | 1544.2902 | 655.52959 |
| 9.4 | 9.35 | 82.741515 | 206.49921 | 139.25333 | 62.382012 | 6481.0346 | 2323.4174 | 1558.2155 | 661.76779 |
| 9.5 | 9.45 | 71.794898 | 205.17699 | 138.38007 | 62.061641 | 6488.2141 | 2343.9351 | 1572.0535 | 667.97395 |
| 9.6 | 9.55 | 60.862386 | 203.85777 | 137.50864 | 61.741297 | 6494.3003 | 2364.3209 | 1585.8044 | 674.14808 |
| 9.7 | 9.65 | 49.896233 | 202.54171 | 136.63915 | 61.421028 | 6499.29 | 2384.5751 | 1599.4683 | 680.29018 |
| 9.8 | 9.75 | 38.807645 | 201.22895 | 135.7717 | 61.100883 | 6503.1707 | 2404.698 | 1613.0455 | 686.40027 |
| 9.9 | 9.85 | 27.395076 | 199.91966 | 134.90639 | 60.780909 | 6505.9102 | 2424.6899 | 1626.5361 | 692.47836 |
| 10.0 | 9.95 | 11.766151 | 198.61396 | 134.04331 | 60.461149 | 6507.0869 | 2444.5513 | 1639.9405 | 698.52448 |
| 10.1 | 10.05 | 0.0234657 | 197.31199 | 133.18256 | 60.141648 | 6507.0892 | 2464.2825 | 1653.2587 | 704.53864 |
| 10.2 | 10.15 | 0.0233341 | 196.01389 | 132.32421 | 59.822447 | 6507.0915 | 2483.8839 | 1666.4911 | 710.52089 |
| 10.3 | 10.25 | 0.0232032 | 194.71976 | 131.46836 | 59.503586 | 6507.0939 | 2503.3559 | 1679.638 | 716.47125 |
| 10.4 | 10.35 | 0.023073 | 193.42973 | 130.61509 | 59.185103 | 6507.0962 | 2522.6989 | 1692.6995 | 722.38976 |
| 10.5 | 10.45 | 0.0229435 | 192.14391 | 129.76446 | 58.867035 | 6507.0985 | 2541.9133 | 1705.6759 | 728.27646 |
| 10.6 | 10.55 | 0.0228148 | 190.8624 | 128.91655 | 58.549419 | 6507.1007 | 2560.9995 | 1718.5676 | 734.1314 |
| 10.7 | 10.65 | 0.0226868 | 189.58532 | 128.07144 | 58.232289 | 6507.103 | 2579.958 | 1731.3747 | 739.95463 |
| 10.8 | 10.75 | 0.0225595 | 188.31275 | 127.22918 | 57.915679 | 6507.1053 | 2598.7893 | 1744.0976 | 745.7462 |
| 10.9 | 10.85 | 0.022433 | 187.0448 | 126.38984 | 57.599619 | 6507.1075 | 2617.4938 | 1756.7366 | 751.50616 |
| 11.0 | 10.95 | 0.0223071 | 185.78154 | 125.55348 | 57.284142 | 6507.1097 | 2636.0719 | 1769.292 | 757.23457 |
| 11.1 | 11.05 | 0.022182 | 184.52307 | 124.72016 | 56.969277 | 6507.112 | 2654.5243 | 1781.764 | 762.9315 |
| 11.2 | 11.15 | 0.0220575 | 183.26947 | 123.88994 | 56.655053 | 6507.1142 | 2672.8512 | 1794.153 | 768.59701 |
| 11.3 | 11.25 | 0.0219338 | 182.02081 | 123.06286 | 56.341496 | 6507.1164 | 2691.0533 | 1806.4593 | 774.23116 |
| 11.4 | 11.35 | 0.0218107 | 180.77717 | 122.23898 | 56.028635 | 6507.1185 | 2709.131 | 1818.6832 | 779.83402 |

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| 11.5 | 11.45 | 0.0216883 | 179.53861 | 121.41834 | 55.716494 | 6507.1207 | 2727.0849 | 1830.825 | 785.40567 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 11.6 | 11.55 | 0.0215667 | 178.30521 | 120.601 | 55.405099 | 6507.1229 | 2744.9154 | 1842.8851 | 790.94618 |
| 11.7 | 11.65 | 0.0214457 | 177.07703 | 119.78699 | 55.094472 | 6507.125 | 2762.6231 | 1854.8638 | 796.45563 |
| 11.8 | 11.75 | 0.0213253 | 175.85412 | 118.97636 | 54.784637 | 6507.1271 | 2780.2085 | 1866.7614 | 801.93409 |
| 11.9 | 11.85 | 0.0212057 | 174.63655 | 118.16915 | 54.475616 | 6507.1293 | 2797.6722 | 1878.5784 | 807.38165 |
| 12.0 | 11.95 | 0.0210867 | 173.42437 | 117.36538 | 54.16743 | 6507.1314 | 2815.0146 | 1890.3149 | 812.79839 |
| 12.1 | 12.05 | 0.0209684 | 172.21764 | 116.56511 | 53.860099 | 6507.1335 | 2832.2364 | 1901.9714 | 818.1844 |
| 12.2 | 12.15 | 0.0208508 | 171.01639 | 115.76836 | 53.553643 | 6507.1356 | 2849.338 | 1913.5482 | 823.53977 |
| 12.3 | 12.25 | 0.0207338 | 169.82068 | 114.97517 | 53.24808 | 6507.1376 | 2866.3201 | 1925.0458 | 828.86458 |
| 12.4 | 12.35 | 0.0206175 | 168.63055 | 114.18556 | 52.94343 | 6507.1397 | 2883.1831 | 1936.4643 | 834.15892 |
| 12.5 | 12.45 | 0.0205018 | 167.44603 | 113.39956 | 52.639708 | 6507.1417 | 2899.9277 | 1947.8043 | 839.42289 |
| 12.6 | 12.55 | 0.0203868 | 166.26718 | 112.61721 | 52.336933 | 6507.1438 | 2916.5544 | 1959.066 | 844.65658 |
| 12.7 | 12.65 | 0.0202724 | 165.09403 | 111.83852 | 52.035119 | 6507.1458 | 2933.0638 | 1970.2498 | 849.8601 |
| 12.8 | 12.75 | 0.0201587 | 163.9266 | 111.06352 | 51.734283 | 6507.1478 | 2949.4565 | 1981.3562 | 855.03352 |
| 12.9 | 12.85 | 0.0200456 | 162.76494 | 110.29223 | 51.434439 | 6507.1498 | 2965.733 | 1992.3854 | 860.17697 |
| 13.0 | 12.95 | 0.0199331 | 161.59256 | 109.52468 | 51.135602 | 6507.1518 | 2981.8922 | 2003.3379 | 865.29053 |
| 13.1 | 13.05 | 0.0198213 | 160.39341 | 108.76088 | 50.837784 | 6507.1538 | 2997.9316 | 2014.214 | 870.37431 |
| 13.2 | 13.15 | 0.0197101 | 159.20093 | 108.00085 | 50.540999 | 6507.1558 | 3013.8517 | 2025.0141 | 875.42841 |
| 13.3 | 13.25 | 0.0195995 | 158.01514 | 107.24462 | 50.24526 | 6507.1577 | 3029.6532 | 2035.7385 | 880.45293 |
| 13.4 | 13.35 | 0.0194895 | 156.83605 | 106.49219 | 49.950578 | 6507.1597 | 3045.3368 | 2046.3877 | 885.44799 |
| 13.5 | 13.45 | 0.0193802 | 155.66367 | 105.74358 | 49.656966 | 6507.1616 | 3060.9032 | 2056.9621 | 890.41369 |
| 13.6 | 13.55 | 0.0192714 | 154.498 | 104.9988 | 49.364433 | 6507.1635 | 3076.353 | 2067.462 | 895.35013 |
| 13.7 | 13.65 | 0.0191633 | 153.33905 | 104.25787 | 49.07299 | 6507.1655 | 3091.6869 | 2077.8878 | 900.25743 |
| 13.8 | 13.75 | 0.0190558 | 152.18682 | 103.5208 | 48.782648 | 6507.1674 | 3106.9056 | 2088.2398 | 905.13569 |
| 13.9 | 13.85 | 0.0189489 | 151.04133 | 102.7876 | 48.493415 | 6507.1693 | 3122.0097 | 2098.5186 | 909.98504 |
| 14.0 | 13.95 | 0.0188426 | 149.90257 | 102.05828 | 48.205302 | 6507.1711 | 3136.9999 | 2108.7244 | 914.80557 |
| 14.1 | 14.05 | 0.0187369 | 148.77053 | 101.33284 | 47.918316 | 6507.173 | 3151.877 | 2118.8577 | 919.5974 |
| 14.2 | 14.15 | 0.0186318 | 147.64524 | 100.61131 | 47.632466 | 6507.1749 | 3166.6415 | 2128.9188 | 924.36064 |
| 14.3 | 14.25 | 0.0185272 | 146.52667 | 99.893667 | 47.34776 | 6507.1767 | 3181.2942 | 2138.9082 | 929.09542 |
| 14.4 | 14.35 | 0.0184233 | 145.41483 | 99.179937 | 47.064205 | 6507.1786 | 3195.8357 | 2148.8262 | 933.80184 |

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| 14.5 | 14.45 | 0.0183199 | 144.30971 | 98.47012 | 46.781808 | 6507.1804 | 3210.2666 | 2158.6732 | 938.48002 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 14.6 | 14.55 | 0.0182171 | 143.21131 | 97.76422 | 46.500576 | 6507.1822 | 3224.5878 | 2168.4496 | 943.13008 |
| 14.7 | 14.65 | 0.0181149 | 142.11963 | 97.062241 | 46.220516 | 6507.184 | 3238.7997 | 2178.1559 | 947.75213 |
| 14.8 | 14.75 | 0.0180133 | 141.03465 | 96.364185 | 45.941633 | 6507.1858 | 3252.9032 | 2187.7923 | 952.34629 |
| 14.9 | 14.85 | 0.0179122 | 139.95637 | 95.670054 | 45.663934 | 6507.1876 | 3266.8988 | 2197.3593 | 956.91269 |
| 15.0 | 14.95 | 0.0178117 | 138.88478 | 94.97985 | 45.387422 | 6507.1894 | 3280.7873 | 2206.8573 | 961.45143 |
| 15.1 | 15.05 | 0.0177118 | 137.81987 | 94.293573 | 45.112105 | 6507.1912 | 3294.5693 | 2216.2866 | 965.96264 |
| 15.2 | 15.15 | 0.0176124 | 136.76162 | 93.611224 | 44.837985 | 6507.1929 | 3308.2455 | 2225.6478 | 970.44644 |
| 15.3 | 15.25 | 0.0175136 | 135.71004 | 92.9328 | 44.565068 | 6507.1947 | 3321.8165 | 2234.941 | 974.90295 |
| 15.4 | 15.35 | 0.0174154 | 134.6651 | 92.258302 | 44.293358 | 6507.1964 | 3335.283 | 2244.1669 | 979.33228 |
| 15.5 | 15.45 | 0.0173177 | 133.62679 | 91.587726 | 44.022859 | 6507.1982 | 3348.6457 | 2253.3256 | 983.73457 |
| 15.6 | 15.55 | 0.0172205 | 132.5951 | 90.921071 | 43.753574 | 6507.1999 | 3361.9052 | 2262.4177 | 988.10992 |
| 15.7 | 15.65 | 0.0171239 | 131.57002 | 90.258334 | 43.485506 | 6507.2016 | 3375.0622 | 2271.4436 | 992.45848 |
| 15.8 | 15.75 | 0.0170278 | 130.55152 | 89.59951 | 43.218659 | 6507.2033 | 3388.1173 | 2280.4035 | 996.78034 |
| 15.9 | 15.85 | 0.0169323 | 129.5396 | 88.944596 | 42.953035 | 6507.205 | 3401.0713 | 2289.298 | 1001.0756 |
| 16.0 | 15.95 | 0.0168373 | 128.53424 | 88.293587 | 42.688638 | 6507.2067 | 3413.9247 | 2298.1273 | 1005.3445 |
| 16.1 | 16.05 | 0.0167428 | 127.53541 | 87.646478 | 42.425469 | 6507.2084 | 3426.6783 | 2306.892 | 1009.5871 |
| 16.2 | 16.15 | 0.0166489 | 126.54311 | 87.003263 | 42.16353 | 6507.21 | 3439.3326 | 2315.5923 | 1013.8034 |
| 16.3 | 16.25 | 0.0165555 | 125.55731 | 86.363936 | 41.902823 | 6507.2117 | 3451.8883 | 2324.2287 | 1017.9937 |
| 16.4 | 16.35 | 0.0164626 | 124.57799 | 85.72849 | 41.643351 | 6507.2133 | 3464.3461 | 2332.8016 | 1022.158 |
| 16.5 | 16.45 | 0.0163702 | 123.60514 | 85.096919 | 41.385114 | 6507.215 | 3476.7066 | 2341.3113 | 1026.2965 |
| 16.6 | 16.55 | 0.0162784 | 122.63873 | 84.469215 | 41.128114 | 6507.2166 | 3488.9705 | 2349.7582 | 1030.4093 |
| 16.7 | 16.65 | 0.0161871 | 121.67875 | 83.84537 | 40.872351 | 6507.2182 | 3501.1384 | 2358.1427 | 1034.4966 |
| 16.8 | 16.75 | 0.0160962 | 120.72518 | 83.225377 | 40.617828 | 6507.2198 | 3513.2109 | 2366.4653 | 1038.5584 |
| 16.9 | 16.85 | 0.0160059 | 119.77799 | 82.609226 | 40.364543 | 6507.2214 | 3525.1887 | 2374.7262 | 1042.5948 |
| 17.0 | 16.95 | 0.0159161 | 118.83716 | 81.996909 | 40.112498 | 6507.223 | 3537.0724 | 2382.9259 | 1046.6061 |
| 17.1 | 17.05 | 0.0158268 | 117.90267 | 81.388416 | 39.861694 | 6507.2246 | 3548.8627 | 2391.0647 | 1050.5922 |
| 17.2 | 17.15 | 0.0157381 | 116.97449 | 80.783738 | 39.61213 | 6507.2262 | 3560.5601 | 2399.1431 | 1054.5535 |
| 17.3 | 17.25 | 0.0156498 | 116.05261 | 80.182865 | 39.363806 | 6507.2277 | 3572.1654 | 2407.1614 | 1058.4898 |
| 17.4 | 17.35 | 0.015562 | 115.137 | 79.585786 | 39.116722 | 6507.2293 | 3583.6791 | 2415.1199 | 1062.4015 |

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| 17.5 | 17.45 | 0.0154746 | 114.22763 | 78.992492 | 38.870878 | 6507.2308 | 3595.1018 | 2423.0192 | 1066.2886 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 17.6 | 17.55 | 0.0153878 | 113.32449 | 78.402971 | 38.626273 | 6507.2324 | 3606.4343 | 2430.8595 | 1070.1512 |
| 17.7 | 17.65 | 0.0153015 | 112.21742 | 77.817213 | 38.382907 | 6507.2339 | 3617.656 | 2438.6412 | 1073.9895 |
| 17.8 | 17.75 | 0.0152156 | 110.76917 | 77.235205 | 38.140779 | 6507.2354 | 3628.7329 | 2446.3647 | 1077.8036 |
| 17.9 | 17.85 | 0.0151303 | 109.33418 | 76.656936 | 37.899888 | 6507.2369 | 3639.6664 | 2454.0304 | 1081.5936 |
| 18.0 | 17.95 | 0.0150454 | 107.91233 | 76.082395 | 37.660232 | 6507.2384 | 3650.4576 | 2461.6387 | 1085.3596 |
| 18.1 | 18.05 | 0.014961 | 106.50353 | 75.511569 | 37.421812 | 6507.2399 | 3661.1079 | 2469.1898 | 1089.1018 |
| 18.2 | 18.15 | 0.014877 | 105.10766 | 74.944446 | 37.184625 | 6507.2414 | 3671.6187 | 2476.6843 | 1092.8202 |
| 18.3 | 18.25 | 0.0147936 | 103.72463 | 74.381013 | 36.94867 | 6507.2429 | 3681.9912 | 2484.1224 | 1096.5151 |
| 18.4 | 18.35 | 0.0147106 | 102.35431 | 73.821258 | 36.713945 | 6507.2444 | 3692.2266 | 2491.5045 | 1100.1865 |
| 18.5 | 18.45 | 0.0146281 | 100.99663 | 73.265167 | 36.48045 | 6507.2458 | 3702.3263 | 2498.831 | 1103.8346 |
| 18.6 | 18.55 | 0.014546 | 99.651454 | 72.712727 | 36.248181 | 6507.2473 | 3712.2914 | 2506.1023 | 1107.4594 |
| 18.7 | 18.65 | 0.0144644 | 98.318699 | 72.163926 | 36.017137 | 6507.2487 | 3722.1233 | 2513.3187 | 1111.0611 |
| 18.8 | 18.75 | 0.0143832 | 96.998257 | 71.618748 | 35.787317 | 6507.2502 | 3731.8231 | 2520.4806 | 1114.6398 |
| 18.9 | 18.85 | 0.0143025 | 95.690029 | 71.077182 | 35.558718 | 6507.2516 | 3741.3921 | 2527.5883 | 1118.1957 |
| 19.0 | 18.95 | 0.0142223 | 94.393915 | 70.539212 | 35.331338 | 6507.253 | 3750.8315 | 2534.6422 | 1121.7288 |
| 19.1 | 19.05 | 0.0141425 | 93.109814 | 70.004824 | 35.105174 | 6507.2545 | 3760.1425 | 2541.6427 | 1125.2393 |
| 19.2 | 19.15 | 0.0140631 | 91.837629 | 69.474005 | 34.880225 | 6507.2559 | 3769.3262 | 2548.5901 | 1128.7274 |
| 19.3 | 19.25 | 0.0139842 | 90.577261 | 68.94674 | 34.656487 | 6507.2573 | 3778.384 | 2555.4847 | 1132.193 |
| 19.4 | 19.35 | 0.0139058 | 89.328615 | 68.423014 | 34.433959 | 6507.2586 | 3787.3168 | 2562.327 | 1135.6364 |
| 19.5 | 19.45 | 0.0138278 | 88.091592 | 67.902814 | 34.212637 | 6507.26 | 3796.126 | 2569.1173 | 1139.0577 |
| 19.6 | 19.55 | 0.0137502 | 86.866099 | 67.386123 | 33.992519 | 6507.2614 | 3804.8126 | 2575.8559 | 1142.4569 |
| 19.7 | 19.65 | 0.013673 | 85.652039 | 66.872927 | 33.773602 | 6507.2628 | 3813.3778 | 2582.5432 | 1145.8343 |
| 19.8 | 19.75 | 0.0135963 | 84.44932 | 66.363212 | 33.555884 | 6507.2641 | 3821.8227 | 2589.1796 | 1149.1899 |
| 19.9 | 19.85 | 0.0135201 | 83.257847 | 65.856961 | 33.33936 | 6507.2655 | 3830.1485 | 2595.7653 | 1152.5238 |
| 20.0 | 19.95 | 0.0134442 | 82.077529 | 65.35416 | 33.124029 | 6507.2668 | 3838.3563 | 2602.3007 | 1155.8362 |
| 20.1 | 20.05 | 0.0133688 | 80.908273 | 64.854794 | 32.909887 | 6507.2682 | 3846.4471 | 2608.7861 | 1159.1272 |
| 20.2 | 20.15 | 0.0132938 | 79.749988 | 64.358846 | 32.696931 | 6507.2695 | 3854.4221 | 2615.222 | 1162.3969 |
| 20.3 | 20.25 | 0.0132192 | 78.602583 | 63.866302 | 32.485157 | 6507.2708 | 3862.2824 | 2621.6087 | 1165.6454 |
| 20.4 | 20.35 | 0.013145 | 77.46597 | 63.377146 | 32.274563 | 6507.2721 | 3870.029 | 2627.9464 | 1168.8729 |

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| 20.5 | 20.45 | 0.0130713 | 76.340058 | 62.891361 | 32.065146 | 6507.2734 | 3877.663 | 2634.2355 | 1172.0794 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 20.6 | 20.55 | 0.0129979 | 75.224759 | 62.408933 | 31.8569 | 6507.2747 | 3885.1854 | 2640.4764 | 1175.2651 |
| 20.7 | 20.65 | 0.012925 | 74.119986 | 61.929846 | 31.649824 | 6507.276 | 3892.5974 | 2646.6694 | 1178.43 |
| 20.8 | 20.75 | 0.0128525 | 73.025652 | 61.454082 | 31.443914 | 6507.2773 | 3899.9 | 2652.8148 | 1181.5744 |
| 20.9 | 20.85 | 0.0127804 | 71.94167 | 60.981628 | 31.239166 | 6507.2786 | 3907.0942 | 2658.913 | 1184.6984 |
| 21.0 | 20.95 | 0.0127087 | 70.867954 | 60.512466 | 31.035576 | 6507.2799 | 3914.181 | 2664.9642 | 1187.8019 |
| 21.1 | 21.05 | 0.0126374 | 69.80442 | 60.04658 | 30.833141 | 6507.2811 | 3921.1614 | 2670.9689 | 1190.8852 |
| 21.2 | 21.15 | 0.0125665 | 68.750983 | 59.583955 | 30.631857 | 6507.2824 | 3928.0365 | 2676.9273 | 1193.9484 |
| 21.3 | 21.25 | 0.012496 | 67.707559 | 59.124574 | 30.431721 | 6507.2836 | 3934.8073 | 2682.8397 | 1196.9916 |
| 21.4 | 21.35 | 0.0124259 | 66.674066 | 58.66842 | 30.232728 | 6507.2849 | 3941.4747 | 2688.7066 | 1200.0149 |
| 21.5 | 21.45 | 0.0123562 | 65.65042 | 58.215478 | 30.034874 | 6507.2861 | 3948.0397 | 2694.5281 | 1203.0183 |
| 21.6 | 21.55 | 0.0122868 | 64.63654 | 57.765731 | 29.838157 | 6507.2873 | 3954.5034 | 2700.3047 | 1206.0022 |
| 21.7 | 21.65 | 0.0122179 | 63.632345 | 57.319163 | 29.642571 | 6507.2886 | 3960.8666 | 2706.0366 | 1208.9664 |
| 21.8 | 21.75 | 0.0121494 | 62.637754 | 56.875758 | 29.448113 | 6507.2898 | 3967.1304 | 2711.7242 | 1211.9112 |
| 21.9 | 21.85 | 0.0120812 | 61.652688 | 56.435498 | 29.254778 | 6507.291 | 3973.2956 | 2717.3677 | 1214.8367 |
| 22.0 | 21.95 | 0.0120134 | 60.677066 | 55.998368 | 29.062564 | 6507.2922 | 3979.3633 | 2722.9676 | 1217.743 |
| 22.1 | 22.05 | 0.011946 | 59.710811 | 55.564352 | 28.871465 | 6507.2934 | 3985.3344 | 2728.524 | 1220.6301 |
| 22.2 | 22.15 | 0.011879 | 58.753844 | 55.133432 | 28.681478 | 6507.2946 | 3991.2098 | 2734.0373 | 1223.4983 |
| 22.3 | 22.25 | 0.0118123 | 57.806087 | 54.705592 | 28.492598 | 6507.2958 | 3996.9904 | 2739.5079 | 1226.3475 |
| 22.4 | 22.35 | 0.0117461 | 56.867464 | 54.280815 | 28.304821 | 6507.2969 | 4002.6772 | 2744.936 | 1229.178 |
| 22.5 | 22.45 | 0.0116802 | 55.937898 | 53.859086 | 28.118144 | 6507.2981 | 4008.271 | 2750.3219 | 1231.9898 |
| 22.6 | 22.55 | 0.0116146 | 55.017314 | 53.440387 | 27.932561 | 6507.2993 | 4013.7727 | 2755.6659 | 1234.7831 |
| 22.7 | 22.65 | 0.0115495 | 54.105636 | 53.024702 | 27.748069 | 6507.3004 | 4019.1832 | 2760.9684 | 1237.5579 |
| 22.8 | 22.75 | 0.0114847 | 53.20279 | 52.612015 | 27.564663 | 6507.3016 | 4024.5035 | 2766.2296 | 1240.3143 |
| 22.9 | 22.85 | 0.0114203 | 52.308702 | 52.202309 | 27.382339 | 6507.3027 | 4029.7344 | 2771.4498 | 1243.0526 |
| 23.0 | 22.95 | 0.0113562 | 51.423298 | 51.795567 | 27.201093 | 6507.3038 | 4034.8767 | 2776.6294 | 1245.7727 |
| 23.1 | 23.05 | 0.0112925 | 50.546505 | 51.391773 | 27.02092 | 6507.305 | 4039.9314 | 2781.7686 | 1248.4748 |
| 23.2 | 23.15 | 0.0112291 | 49.678252 | 50.99091 | 26.841816 | 6507.3061 | 4044.8992 | 2786.8677 | 1251.159 |
| 23.3 | 23.25 | 0.0111661 | 48.818465 | 50.592962 | 26.663776 | 6507.3072 | 4049.7811 | 2791.927 | 1253.8253 |
| 23.4 | 23.35 | 0.0111035 | 47.967075 | 50.197913 | 26.486797 | 6507.3083 | 4054.5778 | 2796.9467 | 1256.474 |

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| 23.5 | 23.45 | 0.0110412 | 47.12401 | 49.805745 | 26.310873 | 6507.3094 | 4059.2902 | 2801.9273 | 1259.1051 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 23.6 | 23.55 | 0.0109792 | 46.2892 | 49.416442 | 26.136001 | 6507.3105 | 4063.9191 | 2806.869 | 1261.7187 |
| 23.7 | 23.65 | 0.0109176 | 45.462575 | 49.029989 | 25.962175 | 6507.3116 | 4068.4653 | 2811.772 | 1264.3149 |
| 23.8 | 23.75 | 0.0108564 | 44.644066 | 48.646367 | 25.789392 | 6507.3127 | 4072.9297 | 2816.6366 | 1266.8939 |
| 23.9 | 23.85 | 0.0107955 | 43.833605 | 48.265562 | 25.617646 | 6507.3138 | 4077.3131 | 2821.4632 | 1269.4556 |
| 24.0 | 23.95 | 0.0107349 | 43.031124 | 47.887556 | 25.446934 | 6507.3148 | 4081.6162 | 2826.2519 | 1272.0003 |
| 24.1 | 24.05 | 0.0106747 | 42.236554 | 47.512333 | 25.277251 | 6507.3159 | 4085.8399 | 2831.0031 | 1274.528 |
| 24.2 | 24.15 | 0.0106148 | 41.449829 | 47.139877 | 25.108592 | 6507.317 | 4089.9849 | 2835.7171 | 1277.0389 |
| 24.3 | 24.25 | 0.0105552 | 40.670883 | 46.770172 | 24.940953 | 6507.318 | 4094.0519 | 2840.3941 | 1279.533 |
| 24.4 | 24.35 | 0.010496 | 39.899648 | 46.4032 | 24.774329 | 6507.3191 | 4098.0419 | 2845.0345 | 1282.0104 |
| 24.5 | 24.45 | 0.0104371 | 39.13606 | 46.038947 | 24.608716 | 6507.3201 | 4101.9555 | 2849.6384 | 1284.4713 |
| 24.6 | 24.55 | 0.0103786 | 38.380054 | 45.677395 | 24.444109 | 6507.3212 | 4105.7935 | 2854.2061 | 1286.9157 |
| 24.7 | 24.65 | 0.0103203 | 37.631564 | 45.318528 | 24.280503 | 6507.3222 | 4109.5567 | 2858.738 | 1289.3438 |
| 24.8 | 24.75 | 0.0102624 | 36.890527 | 44.96233 | 24.117895 | 6507.3232 | 4113.2457 | 2863.2342 | 1291.7556 |
| 24.9 | 24.85 | 0.0102049 | 36.156878 | 44.608786 | 23.956279 | 6507.3242 | 4116.8614 | 2867.6951 | 1294.1512 |
| 25.0 | 24.95 | 0.0101476 | 35.430556 | 44.257878 | 23.79565 | 6507.3253 | 4120.4045 | 2872.1209 | 1296.5307 |
| 25.1 | 25.05 | 0.0100907 | 34.711495 | 43.909591 | 23.636006 | 6507.3263 | 4123.8756 | 2876.5118 | 1298.8943 |
| 25.2 | 25.15 | 0.0100341 | 33.999636 | \#\#\#\#\#\#\#\#\# | 23.477339 | 6507.3273 | 4127.2756 | 2880.8682 | 1301.2421 |
| 25.3 | 25.25 | 0.0099778 | 33.294914 | 43.220816 | 23.319647 | 6507.3283 | 4130.6051 | 2885.1903 | 1303.574 |
| 25.4 | 25.35 | 0.0099218 | 32.59727 | 42.880295 | 23.162924 | 6507.3293 | 4133.8648 | 2889.4783 | 1305.8903 |
| 25.5 | 25.45 | 0.0098661 | 31.906641 | 42.542331 | 23.007167 | 6507.3302 | 4137.0555 | 2893.7325 | 1308.1911 |
| 25.6 | 25.55 | 0.0098108 | 31.222968 | 42.206909 | 22.852369 | 6507.3312 | 4140.1778 | 2897.9532 | 1310.4763 |
| 25.7 | 25.65 | 0.0097557 | 30.54619 | 41.874011 | 22.698527 | 6507.3322 | 4143.2324 | 2902.1406 | 1312.7461 |
| 25.8 | 25.75 | 0.009701 | 29.876247 | 41.543623 | 22.545637 | 6507.3332 | 4146.22 | 2906.295 | 1315.0007 |
| 25.9 | 25.85 | 0.0096466 | 29.213079 | 41.215728 | 22.393692 | 6507.3341 | 4149.1413 | 2910.4166 | 1317.2401 |
| 26.0 | 25.95 | 0.0095925 | 28.556629 | 40.890312 | 22.24269 | 6507.3351 | 4151.997 | 2914.5056 | 1319.4643 |
| 26.1 | 26.05 | 0.0095386 | 27.906836 | 40.567357 | 22.092625 | 6507.336 | 4154.7877 | 2918.5623 | 1321.6736 |
| 26.2 | 26.15 | 0.0094851 | 27.263644 | 40.24685 | 21.943492 | 6507.337 | 4157.514 | 2922.587 | 1323.868 |
| 26.3 | 26.25 | 0.0094319 | 26.626993 | 39.928773 | 21.795288 | 6507.3379 | 4160.1767 | 2926.5799 | 1326.0475 |
| 26.4 | 26.35 | 0.009379 | 25.996826 | 39.613112 | 21.648007 | 6507.3389 | 4162.7764 | 2930.5412 | 1328.2123 |

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| 26.5 | 26.45 | 0.0093264 | 25.373087 | 39.299851 | 21.501645 | 6507.3398 | 4165.3137 | 2934.4712 | 1330.3625 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 26.6 | 26.55 | 0.009274 | 24.755718 | 38.988975 | 21.356198 | 6507.3407 | 4167.7893 | 2938.3701 | 1332.4981 |
| 26.7 | 26.65 | 0.009222 | 24.144662 | 38.680469 | 21.21166 | 6507.3417 | 4170.2038 | 2942.2381 | 1334.6192 |
| 26.8 | 26.75 | 0.0091703 | 23.539864 | 38.374316 | 21.068027 | 6507.3426 | 4172.5577 | 2946.0756 | 1336.726 |
| 26.9 | 26.85 | 0.0091188 | 22.941268 | 38.070503 | 20.925295 | 6507.3435 | 4174.8519 | 2949.8826 | 1338.8186 |
| 27.0 | 26.95 | 0.0090677 | 22.348817 | 37.769013 | 20.783459 | 6507.3444 | 4177.0868 | 2953.6595 | 1340.8969 |
| 27.1 | 27.05 | 0.0090168 | 21.762456 | 37.469831 | 20.642514 | 6507.3453 | 4179.263 | 2957.4065 | 1342.9612 |
| 27.2 | 27.15 | 0.0089662 | 21.182131 | 37.172943 | 20.502457 | 6507.3462 | 4181.3812 | 2961.1238 | 1345.0114 |
| 27.3 | 27.25 | 0.0089159 | 20.607785 | 36.878334 | 20.363281 | 6507.3471 | 4183.442 | 2964.8116 | 1347.0477 |
| 27.4 | 27.35 | 0.0088659 | 20.039366 | 36.585988 | 20.224984 | 6507.348 | 4185.4459 | 2968.4702 | 1349.0702 |
| 27.5 | 27.45 | 0.0088161 | 19.476817 | 36.295891 | 20.087559 | 6507.3489 | 4187.3936 | 2972.0998 | 1351.079 |
| 27.6 | 27.55 | 0.0087667 | 18.920084 | 36.008027 | 19.951004 | 6507.3497 | 4189.2856 | 2975.7006 | 1353.0741 |
| 27.7 | 27.65 | 0.0087175 | 18.369114 | 35.722382 | 19.815312 | 6507.3506 | 4191.1225 | 2979.2729 | 1355.0556 |
| 27.8 | 27.75 | 0.0086686 | 17.823852 | 35.438941 | 19.680481 | 6507.3515 | 4192.9049 | 2982.8168 | 1357.0237 |
| 27.9 | 27.85 | 0.0086199 | 17.284244 | 35.157144 | 19.546504 | 6507.3523 | 4194.6333 | 2986.3325 | 1358.9783 |
| 28.0 | 27.95 | 0.0085716 | 16.750236 | 34.869175 | 19.413379 | 6507.3532 | 4196.3084 | 2989.8194 | 1360.9197 |
| 28.1 | 28.05 | 0.0085235 | 16.221774 | 34.583498 | 19.281099 | 6507.354 | 4197.9305 | 2993.2777 | 1362.8478 |
| 28.2 | 28.15 | 0.0084757 | 15.698803 | 34.300097 | 19.149661 | 6507.3549 | 4199.5004 | 2996.7078 | 1364.7627 |
| 28.3 | 28.25 | 0.0084281 | 15.18127 | 34.018955 | 19.019061 | 6507.3557 | 4201.0185 | 3000.1096 | 1366.6646 |
| 28.4 | 28.35 | 0.0083808 | 14.66912 | 33.740057 | 18.889293 | 6507.3566 | 4202.4855 | 3003.4837 | 1368.5536 |
| 28.5 | 28.45 | 0.0083338 | 14.162299 | 33.463388 | 18.760354 | 6507.3574 | 4203.9017 | 3006.83 | 1370.4296 |
| 28.6 | 28.55 | 0.0082871 | 13.66075 | 33.188931 | 18.632238 | 6507.3582 | 4205.2678 | 3010.1489 | 1372.2928 |
| 28.7 | 28.65 | 0.0082406 | 13.16442 | 32.91667 | 18.504942 | 6507.3591 | 4206.5842 | 3013.4406 | 1374.1433 |
| 28.8 | 28.75 | 0.0081943 | 12.673252 | 32.646592 | 18.378462 | 6507.3599 | 4207.8515 | 3016.7052 | 1375.9812 |
| 28.9 | 28.85 | 0.0081484 | 12.187189 | 32.378679 | 18.252791 | 6507.3607 | 4209.0702 | 3019.9431 | 1377.8065 |
| 29.0 | 28.95 | 0.0081026 | 11.706174 | 32.112916 | 18.127928 | 6507.3615 | 4210.2409 | 3023.1544 | 1379.6192 |
| 29.1 | 29.05 | 0.0080572 | 11.230148 | 31.849289 | 18.003866 | 6507.3623 | 4211.3639 | 3026.3393 | 1381.4196 |
| 29.2 | 29.15 | 0.008012 | 10.759052 | 31.587781 | 17.880601 | 6507.3631 | 4212.4398 | 3029.4981 | 1383.2077 |
| 29.3 | 29.25 | 0.007967 | 10.292825 | 31.328379 | 17.75813 | 6507.3639 | 4213.4691 | 3032.6309 | 1384.9835 |
| 29.4 | 29.35 | 0.0079223 | 9.8314032 | 31.071066 | 17.636447 | 6507.3647 | 4214.4522 | 3035.738 | 1386.7472 |

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| 29.5 | 29.45 | 0.0078779 | 9.3747222 | 30.815829 | 17.51555 | 6507.3655 | 4215.3897 | 3038.8196 | 1388.4987 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 29.6 | 29.55 | 0.0078337 | 8.922714 | 30.562651 | 17.395432 | 6507.3663 | 4216.282 | 3041.8759 | 1390.2383 |
| 29.7 | 29.65 | 0.0077897 | 8.4753078 | 30.311518 | 17.27609 | 6507.367 | 4217.1295 | 3044.907 | 1391.9659 |
| 29.8 | 29.75 | 0.007746 | 8.0324288 | 30.062415 | 17.157519 | 6507.3678 | 4217.9327 | 3047.9133 | 1393.6816 |
| 29.9 | 29.85 | 0.0077026 | 7.5939972 | 29.815328 | 17.039716 | 6507.3686 | 4218.6921 | 3050.8948 | 1395.3856 |
| 30.0 | 29.95 | 0.0076594 | 7.1599274 | 29.570242 | 16.922676 | 6507.3694 | 4219.4081 | 3053.8518 | 1397.0779 |
| 30.1 | 30.05 | 0.0076164 | 6.7301263 | 29.327143 | 16.806395 | 6507.3701 | 4220.0811 | 3056.7845 | 1398.7585 |
| 30.2 | 30.15 | 0.0075737 | 6.304491 | 29.086016 | 16.690868 | 6507.3709 | 4220.7116 | 3059.6931 | 1400.4276 |
| 30.3 | 30.25 | 0.0075312 | 5.8829067 | 28.846846 | 16.576091 | 6507.3716 | 4221.2999 | 3062.5778 | 1402.0852 |
| 30.4 | 30.35 | 0.0074889 | 5.4652427 | 28.60962 | 16.462061 | 6507.3724 | 4221.8464 | 3065.4388 | 1403.7314 |
| 30.5 | 30.45 | 0.0074469 | 5.0513471 | 28.374323 | 16.348772 | 6507.3731 | 4222.3515 | 3068.2762 | 1405.3663 |
| 30.6 | 30.55 | 0.0074051 | 4.6410401 | 28.140942 | 16.236221 | 6507.3739 | 4222.8156 | 3071.0903 | 1406.9899 |
| 30.7 | 30.65 | 0.0073636 | 4.2341029 | 27.909461 | 16.124404 | 6507.3746 | 4223.239 | 3073.8813 | 1408.6023 |
| 30.8 | 30.75 | 0.0073223 | 3.8302613 | 27.679867 | 16.013316 | 6507.3753 | 4223.6221 | 3076.6492 | 1410.2037 |
| 30.9 | 30.85 | 0.0072812 | 3.4291604 | 27.452147 | 15.902953 | 6507.3761 | 4223.965 | 3079.3945 | 1411.794 |
| 31.0 | 30.95 | 0.0072403 | 3.0303218 | 27.226286 | 15.793311 | 6507.3768 | 4224.268 | 3082.1171 | 1413.3733 |
| 31.1 | 31.05 | 0.0071997 | 2.6330678 | 27.002271 | 15.684386 | 6507.3775 | 4224.5313 | 3084.8173 | 1414.9417 |
| 31.2 | 31.15 | 0.0071593 | 2.2363781 | 26.780087 | 15.576173 | 6507.3782 | 4224.755 | 3087.4953 | 1416.4993 |
| 31.3 | 31.25 | 0.0071191 | 1.8385835 | 26.559722 | 15.46867 | 6507.3789 | 4224.9388 | 3090.1513 | 1418.0462 |
| 31.4 | 31.35 | 0.0070792 | 1.4366106 | 26.341162 | 15.361871 | 6507.3796 | 4225.0825 | 3092.7854 | 1419.5824 |
| 31.5 | 31.45 | 0.0070395 | 1.0236066 | 26.124393 | 15.255773 | 6507.3803 | 4225.1848 | 3095.3979 | 1421.108 |
| 31.6 | 31.55 | 0.007 | 0.4816943 | 25.909403 | 15.150372 | 6507.381 | 4225.233 | 3097.9888 | 1422.623 |
| 31.7 | 31.65 | 0.0069607 | 0.0007861 | 25.696177 | 15.045663 | 6507.3817 | 4225.2331 | 3100.5584 | 1424.1276 |
| 31.8 | 31.75 | 0.0069217 | 0.0007817 | 25.484703 | 14.941642 | 6507.3824 | 4225.2332 | 3103.1069 | 1425.6217 |
| 31.9 | 31.85 | 0.0068828 | 0.0007773 | 25.274967 | 14.838306 | 6507.3831 | 4225.2332 | 3105.6344 | 1427.1056 |
| 32.0 | 31.95 | 0.0068442 | 0.000773 | 25.066957 | 14.735651 | 6507.3838 | 4225.2333 | 3108.1411 | 1428.5791 |
| 32.1 | 32.05 | 0.0068058 | 0.0007686 | 24.860659 | 14.633672 | 6507.3845 | 4225.2334 | 3110.6271 | 1430.0425 |
| 32.2 | 32.15 | 0.0067676 | 0.0007643 | 24.656061 | 14.532366 | 6507.3852 | 4225.2335 | 3113.0927 | 1431.4957 |
| 32.3 | 32.25 | 0.0067297 | 0.00076 | 24.453149 | 14.431729 | 6507.3858 | 4225.2336 | 3115.5381 | 1432.9389 |
| 32.4 | 32.35 | 0.0066919 | 0.0007558 | 24.251912 | 14.331757 | 6507.3865 | 4225.2336 | 3117.9632 | 1434.3721 |

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| 32.5 | 32.45 | 0.0066544 | 0.0007515 | 24.052336 | 14.232445 | 6507.3872 | 4225.2337 | 3120.3685 | 1435.7953 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 32.6 | 32.55 | 0.006617 | 0.0007473 | 23.854408 | 14.13379 | 6507.3878 | 4225.2338 | 3122.7539 | 1437.2087 |
| 32.7 | 32.65 | 0.0065799 | 0.0007431 | 23.658117 | 14.035789 | 6507.3885 | 4225.2339 | 3125.1197 | 1438.6123 |
| 32.8 | 32.75 | 0.006543 | 0.000739 | 23.46345 | 13.938437 | 6507.3891 | 4225.2339 | 3127.4661 | 1440.0061 |
| 32.9 | 32.85 | 0.0065063 | 0.0007348 | 23.270394 | 13.84173 | 6507.3898 | 4225.234 | 3129.7931 | 1441.3903 |
| 33.0 | 32.95 | 0.0064698 | 0.0007307 | 23.078937 | 13.745665 | 6507.3904 | 4225.2341 | 3132.101 | 1442.7649 |
| 33.1 | 33.05 | 0.0064335 | 0.0007266 | 22.889067 | 13.650238 | 6507.3911 | 4225.2341 | 3134.3899 | 1444.1299 |
| 33.2 | 33.15 | 0.0063974 | 0.0007225 | 22.700772 | 13.555445 | 6507.3917 | 4225.2342 | 3136.66 | 1445.4854 |
| 33.3 | 33.25 | 0.0063615 | 0.0007185 | 22.51404 | 13.461282 | 6507.3924 | 4225.2343 | 3138.9114 | 1446.8316 |
| 33.4 | 33.35 | 0.0063258 | 0.0007144 | 22.328858 | 13.367746 | 6507.393 | 4225.2344 | 3141.1443 | 1448.1684 |
| 33.5 | 33.45 | 0.0062903 | 0.0007104 | 22.145215 | 13.274832 | 6507.3936 | 4225.2344 | 3143.3588 | 1449.4958 |
| 33.6 | 33.55 | 0.006255 | 0.0007064 | 21.963099 | 13.182537 | 6507.3942 | 4225.2345 | 3145.5551 | 1450.8141 |
| 33.7 | 33.65 | 0.0062199 | 0.0007025 | 21.782498 | 13.090858 | 6507.3949 | 4225.2346 | 3147.7334 | 1452.1232 |
| 33.8 | 33.75 | 0.006185 | 0.0006985 | 21.603401 | 12.999791 | 6507.3955 | 4225.2346 | 3149.8937 | 1453.4232 |
| 33.9 | 33.85 | 0.0061503 | 0.0006946 | 21.425795 | 12.909331 | 6507.3961 | 4225.2347 | 3152.0363 | 1454.7141 |
| 34.0 | 33.95 | 0.0061158 | 0.0006907 | 21.24967 | 12.819476 | 6507.3967 | 4225.2348 | 3154.1613 | 1455.996 |
| 34.1 | 34.05 | 0.0060815 | 0.0006868 | 21.075013 | 12.730222 | 6507.3973 | 4225.2348 | 3156.2688 | 1457.2691 |
| 34.2 | 34.15 | 0.0060474 | 0.000683 | 20.901814 | 12.641564 | 6507.3979 | 4225.2349 | 3158.3589 | 1458.5332 |
| 34.3 | 34.25 | 0.0060135 | 0.0006792 | 20.730061 | 12.5535 | 6507.3985 | 4225.235 | 3160.4319 | 1459.7886 |
| 34.4 | 34.35 | 0.0059797 | 0.0006754 | 20.559743 | 12.466026 | 6507.3991 | 4225.2351 | 3162.4879 | 1461.0352 |
| 34.5 | 34.45 | 0.0059462 | 0.0006716 | 20.390848 | 12.379138 | 6507.3997 | 4225.2351 | 3164.527 | 1462.2731 |
| 34.6 | 34.55 | 0.0059128 | 0.0006678 | 20.223365 | 12.292833 | 6507.4003 | 4225.2352 | 3166.5493 | 1463.5024 |
| 34.7 | 34.65 | 0.0058797 | 0.000664 | 20.057284 | 12.207107 | 6507.4009 | 4225.2353 | 3168.5551 | 1464.7231 |
| 34.8 | 34.75 | 0.0058467 | 0.0006603 | 19.892594 | 12.121957 | 6507.4015 | 4225.2353 | 3170.5443 | 1465.9353 |
| 34.9 | 34.85 | 0.0058139 | 0.0006566 | 19.729283 | 12.037378 | 6507.4021 | 4225.2354 | 3172.5173 | 1467.139 |
| 35.0 | 34.95 | 0.0057812 | 0.0006529 | 19.56734 | 11.953369 | 6507.4026 | 4225.2354 | 3174.474 | 1468.3343 |
| 35.1 | 35.05 | 0.0057488 | 0.0006493 | 19.406755 | 11.869924 | 6507.4032 | 4225.2355 | 3176.4147 | 1469.5213 |
| 35.2 | 35.15 | 0.0057166 | 0.0006456 | 19.247518 | 11.787042 | 6507.4038 | 4225.2356 | 3178.3394 | 1470.7 |
| 35.3 | 35.25 | 0.0056845 | 0.000642 | 19.089617 | 11.704717 | 6507.4044 | 4225.2356 | 3180.2484 | 1471.8705 |
| 35.4 | 35.35 | 0.0056526 | 0.0006384 | 18.933042 | 11.622948 | 6507.4049 | 4225.2357 | 3182.1417 | 1473.0328 |

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| 35.5 | 35.45 | 0.0056209 | 0.0006348 | 18.777782 | 11.54173 | 6507.4055 | 4225.2358 | 3184.0195 | 1474.187 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 35.6 | 35.55 | 0.0055893 | 0.0006313 | 18.623827 | 11.46106 | 6507.406 | 4225.2358 | 3185.8818 | 1475.3331 |
| 35.7 | 35.65 | 0.005558 | 0.0006277 | 18.471167 | 11.380934 | 6507.4066 | 4225.2359 | 3187.729 | 1476.4712 |
| 35.8 | 35.75 | 0.0055268 | 0.0006242 | 18.319792 | 11.30135 | 6507.4072 | 4225.236 | 3189.5609 | 1477.6013 |
| 35.9 | 35.85 | 0.0054958 | 0.0006207 | 18.16969 | 11.222304 | 6507.4077 | 4225.236 | 3191.3779 | 1478.7235 |
| 36.0 | 35.95 | 0.005465 | 0.0006172 | 18.020852 | 11.143792 | 6507.4083 | 4225.2361 | 3193.18 | 1479.8379 |
| 36.1 | 36.05 | 0.0054343 | 0.0006137 | 17.873269 | 11.065812 | 6507.4088 | 4225.2361 | 3194.9673 | 1480.9445 |
| 36.2 | 36.15 | 0.0054038 | 0.0006103 | 17.726929 | 10.98836 | 6507.4093 | 4225.2362 | 3196.74 | 1482.0433 |
| 36.3 | 36.25 | 0.0053735 | 0.0006069 | 17.581823 | 10.911432 | 6507.4099 | 4225.2363 | 3198.4982 | 1483.1345 |
| 36.4 | 36.35 | 0.0053433 | 0.0006035 | 17.437941 | 10.835026 | 6507.4104 | 4225.2363 | 3200.242 | 1484.218 |
| 36.5 | 36.45 | 0.0053134 | 0.0006001 | 17.295274 | 10.759139 | 6507.4109 | 4225.2364 | 3201.9715 | 1485.2939 |
| 36.6 | 36.55 | 0.0052836 | 0.0005967 | 17.15381 | 10.683766 | 6507.4115 | 4225.2364 | 3203.6869 | 1486.3623 |
| 36.7 | 36.65 | 0.0052539 | 0.0005934 | 17.013542 | 10.608905 | 6507.412 | 4225.2365 | 3205.3883 | 1487.4232 |
| 36.8 | 36.75 | 0.0052244 | 0.00059 | 16.874458 | 10.534552 | 6507.4125 | 4225.2366 | 3207.0757 | 1488.4766 |
| 36.9 | 36.85 | 0.0051951 | 0.0005867 | 16.736551 | 10.460705 | 6507.413 | 4225.2366 | 3208.7494 | 1489.5227 |
| 37.0 | 36.95 | 0.005166 | 0.0005834 | 16.599809 | 10.38736 | 6507.4136 | 4225.2367 | 3210.4093 | 1490.5614 |
| 37.1 | 37.05 | 0.005137 | 0.0005802 | 16.464224 | 10.314515 | 6507.4141 | 4225.2367 | 3212.0558 | 1491.5929 |
| 37.2 | 37.15 | 0.0051082 | 0.0005769 | 16.329786 | 10.242165 | 6507.4146 | 4225.2368 | 3213.6887 | 1492.6171 |
| 37.3 | 37.25 | 0.0050795 | 0.0005737 | 16.196486 | 10.170308 | 6507.4151 | 4225.2369 | 3215.3084 | 1493.6341 |
| 37.4 | 37.35 | 0.005051 | 0.0005705 | 15.965248 | 10.098941 | 6507.4156 | 4225.2369 | 3216.9049 | 1494.644 |
| 37.5 | 37.45 | 0.0050227 | 0.0005673 | 15.704295 | 10.02806 | 6507.4161 | 4225.237 | 3218.4753 | 1495.6468 |
| 37.6 | 37.55 | 0.0049945 | 0.0005641 | 15.445853 | 9.9576633 | 6507.4166 | 4225.237 | 3220.0199 | 1496.6426 |
| 37.7 | 37.65 | 0.0049665 | 0.0005609 | 15.1899 | 9.8877468 | 6507.4171 | 4225.2371 | 3221.5389 | 1497.6314 |
| 37.8 | 37.75 | 0.0049386 | 0.0005578 | 14.936416 | 9.8183079 | 6507.4176 | 4225.2371 | 3223.0326 | 1498.6132 |
| 37.9 | 37.85 | 0.0049109 | 0.0005546 | 14.685381 | 9.7493434 | 6507.4181 | 4225.2372 | 3224.5011 | 1499.5881 |
| 38.0 | 37.95 | 0.0048834 | 0.0005515 | 14.436774 | 9.6808504 | 6507.4186 | 4225.2372 | 3225.9448 | 1500.5562 |
| 38.1 | 38.05 | 0.004856 | 0.0005484 | 14.190575 | 9.6128259 | 6507.419 | 4225.2373 | 3227.3638 | 1501.5175 |
| 38.2 | 38.15 | 0.0048287 | 0.0005454 | 13.946763 | 9.5452668 | 6507.4195 | 4225.2374 | 3228.7585 | 1502.472 |
| 38.3 | 38.25 | 0.0048016 | 0.0005423 | 13.705319 | 9.4781704 | 6507.42 | 4225.2374 | 3230.129 | 1503.4198 |
| 38.4 | 38.35 | 0.0047747 | 0.0005393 | 13.466223 | 9.4115335 | 6507.4205 | 4225.2375 | 3231.4757 | 1504.361 |

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| 38.5 | 38.45 | 0.0047479 | 0.0005362 | 13.229454 | 9.3453533 | 6507.421 | 4225.2375 | 3232.7986 | 1505.2955 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 38.6 | 38.55 | 0.0047213 | 0.0005332 | 12.994995 | 9.2796268 | 6507.4214 | 4225.2376 | 3234.0981 | 1506.2235 |
| 38.7 | 38.65 | 0.0046948 | 0.0005302 | 12.762825 | 9.2143513 | 6507.4219 | 4225.2376 | 3235.3744 | 1507.1449 |
| 38.8 | 38.75 | 0.0046684 | 0.0005273 | 12.532924 | 9.1495237 | 6507.4224 | 4225.2377 | 3236.6277 | 1508.0599 |
| 38.9 | 38.85 | 0.0046422 | 0.0005243 | 12.305275 | 9.0851413 | 6507.4228 | 4225.2377 | 3237.8582 | 1508.9684 |
| 39.0 | 38.95 | 0.0046162 | 0.0005214 | 12.079857 | 9.0212011 | 6507.4233 | 4225.2378 | 3239.0662 | 1509.8705 |
| 39.1 | 39.05 | 0.0045903 | 0.0005184 | 11.856653 | 8.9577004 | 6507.4238 | 4225.2378 | 3240.2519 | 1510.7663 |
| 39.2 | 39.15 | 0.0045645 | 0.0005155 | 11.635643 | 8.8946363 | 6507.4242 | 4225.2379 | 3241.4154 | 1511.6558 |
| 39.3 | 39.25 | 0.0045389 | 0.0005126 | 11.416809 | 8.832006 | 6507.4247 | 4225.2379 | 3242.5571 | 1512.539 |
| 39.4 | 39.35 | 0.0045135 | 0.0005098 | 11.200132 | 8.7698068 | 6507.4251 | 4225.238 | 3243.6771 | 1513.4159 |
| 39.5 | 39.45 | 0.0044881 | 0.0005069 | 10.985595 | 8.7080359 | 6507.4256 | 4225.238 | 3244.7757 | 1514.2867 |
| 39.6 | 39.55 | 0.004463 | 0.000504 | 10.773179 | 8.6466905 | 6507.426 | 4225.2381 | 3245.853 | 1515.1514 |
| 39.7 | 39.65 | 0.0044379 | 0.0005012 | 10.562866 | 8.5857678 | 6507.4265 | 4225.2381 | 3246.9093 | 1516.01 |
| 39.8 | 39.75 | 0.004413 | 0.0004984 | 10.354638 | 8.5252652 | 6507.4269 | 4225.2382 | 3247.9447 | 1516.8625 |
| 39.9 | 39.85 | 0.0043883 | 0.0004956 | 10.148477 | 8.4651799 | 6507.4273 | 4225.2382 | 3248.9596 | 1517.709 |
| 40.0 | 39.95 | 0.0043637 | 0.0004928 | 9.9443666 | 8.4055092 | 6507.4278 | 4225.2383 | 3249.954 | 1518.5496 |
| 40.1 | 40.05 | 0.0043392 | 0.0004901 | 9.7422884 | 8.3462506 | 6507.4282 | 4225.2383 | 3250.9283 | 1519.3842 |
| 40.2 | 40.15 | 0.0043148 | 0.0004873 | 9.5422251 | 8.2874012 | 6507.4286 | 4225.2384 | 3251.8825 | 1520.2129 |
| 40.3 | 40.25 | 0.0042906 | 0.0004846 | 9.3441595 | 8.2289584 | 6507.4291 | 4225.2384 | 3252.8169 | 1521.0358 |
| 40.4 | 40.35 | 0.0042665 | 0.0004819 | 9.1480745 | 8.1709197 | 6507.4295 | 4225.2385 | 3253.7317 | 1521.8529 |
| 40.5 | 40.45 | 0.0042426 | 0.0004792 | 8.953953 | 8.1132823 | 6507.4299 | 4225.2385 | 3254.6271 | 1522.6643 |
| 40.6 | 40.55 | 0.0042188 | 0.0004765 | 8.7617783 | 8.0560437 | 6507.4303 | 4225.2386 | 3255.5033 | 1523.4699 |
| 40.7 | 40.65 | 0.0041951 | 0.0004738 | 8.5715334 | 7.9992013 | 6507.4308 | 4225.2386 | 3256.3604 | 1524.2698 |
| 40.8 | 40.75 | 0.0041716 | 0.0004711 | 8.3832017 | 7.9427524 | 6507.4312 | 4225.2387 | 3257.1987 | 1525.0641 |
| 40.9 | 40.85 | 0.0041482 | 0.0004685 | 8.1967666 | 7.8866947 | 6507.4316 | 4225.2387 | 3258.0184 | 1525.8527 |
| 41.0 | 40.95 | 0.0041249 | 0.0004659 | 8.0122118 | 7.8310254 | 6507.432 | 4225.2388 | 3258.8196 | 1526.6358 |
| 41.1 | 41.05 | 0.0041018 | 0.0004633 | 7.8295207 | 7.7757421 | 6507.4324 | 4225.2388 | 3259.6026 | 1527.4134 |
| 41.2 | 41.15 | 0.0040788 | 0.0004607 | 7.6486773 | 7.7208422 | 6507.4328 | 4225.2389 | 3260.3675 | 1528.1855 |
| 41.3 | 41.25 | 0.0040559 | 0.0004581 | 7.4696652 | 7.6663232 | 6507.4332 | 4225.2389 | 3261.1144 | 1528.9521 |
| 41.4 | 41.35 | 0.0040331 | 0.0004555 | 7.2924685 | 7.6121827 | 6507.4336 | 4225.2389 | 3261.8437 | 1529.7133 |

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| 41.5 | 41.45 | 0.0040105 | 0.0004529 | 7.1170713 | 7.5584181 | 6507.434 | 4225.239 | 3262.5554 | 1530.4692 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 41.6 | 41.55 | 0.003988 | 0.0004504 | 6.9434575 | 7.5050271 | 6507.4344 | 4225.239 | 3263.2497 | 1531.2197 |
| 41.7 | 41.65 | 0.0039656 | 0.0004479 | 6.7716115 | 7.4520071 | 6507.4348 | 4225.2391 | 3263.9269 | 1531.9649 |
| 41.8 | 41.75 | 0.0039434 | 0.0004454 | 6.6015175 | 7.3993557 | 6507.4352 | 4225.2391 | 3264.587 | 1532.7048 |
| 41.9 | 41.85 | 0.0039213 | 0.0004429 | 6.43316 | 7.3470705 | 6507.4356 | 4225.2392 | 3265.2304 | 1533.4395 |
| 42.0 | 41.95 | 0.0038993 | 0.0004404 | 6.2665233 | 7.2951491 | 6507.436 | 4225.2392 | 3265.857 | 1534.169 |
| 42.1 | 42.05 | 0.0038774 | 0.0004379 | 6.1015921 | 7.2435891 | 6507.4364 | 4225.2393 | 3266.4672 | 1534.8934 |
| 42.2 | 42.15 | 0.0038556 | 0.0004355 | 5.9383508 | 7.1923881 | 6507.4368 | 4225.2393 | 3267.061 | 1535.6126 |
| 42.3 | 42.25 | 0.003834 | 0.000433 | 5.7767842 | 7.1415438 | 6507.4372 | 4225.2393 | 3267.6387 | 1536.3268 |
| 42.4 | 42.35 | 0.0038125 | 0.0004306 | 5.616877 | 7.0910537 | 6507.4375 | 4225.2394 | 3268.2004 | 1537.0359 |
| 42.5 | 42.45 | 0.0037911 | 0.0004282 | 5.4586138 | 7.0409157 | 6507.4379 | 4225.2394 | 3268.7462 | 1537.74 |
| 42.6 | 42.55 | 0.0037698 | 0.0004258 | 5.3019796 | 6.9911272 | 6507.4383 | 4225.2395 | 3269.2764 | 1538.4391 |
| 42.7 | 42.65 | 0.0037487 | 0.0004234 | 5.1469591 | 6.9416861 | 6507.4387 | 4225.2395 | 3269.7911 | 1539.1333 |
| 42.8 | 42.75 | 0.0037276 | 0.000421 | 4.9935371 | 6.8925901 | 6507.439 | 4225.2396 | 3270.2905 | 1539.8225 |
| 42.9 | 42.85 | 0.0037067 | 0.0004186 | 4.8416987 | 6.8438367 | 6507.4394 | 4225.2396 | 3270.7747 | 1540.5069 |
| 43.0 | 42.95 | 0.0036859 | 0.0004163 | 4.6914286 | 6.7954239 | 6507.4398 | 4225.2396 | 3271.2438 | 1541.1865 |
| 43.1 | 43.05 | 0.0036653 | 0.000414 | 4.5427116 | 6.7473493 | 6507.4401 | 4225.2397 | 3271.6981 | 1541.8612 |
| 43.2 | 43.15 | 0.0036447 | 0.0004116 | 4.3955327 | 6.6996106 | 6507.4405 | 4225.2397 | 3272.1376 | 1542.5312 |
| 43.3 | 43.25 | 0.0036242 | 0.0004093 | 4.2498766 | 6.6522057 | 6507.4409 | 4225.2398 | 3272.5626 | 1543.1964 |
| 43.4 | 43.35 | 0.0036039 | 0.000407 | 4.1057281 | 6.6051324 | 6507.4412 | 4225.2398 | 3272.9732 | 1543.8569 |
| 43.5 | 43.45 | 0.0035837 | 0.0004047 | 3.9630719 | 6.5583883 | 6507.4416 | 4225.2398 | 3273.3695 | 1544.5127 |
| 43.6 | 43.55 | 0.0035636 | 0.0004025 | 3.8218924 | 6.5119714 | 6507.442 | 4225.2399 | 3273.7517 | 1545.1639 |
| 43.7 | 43.65 | 0.0035436 | 0.0004002 | 3.6821742 | 6.4658795 | 6507.4423 | 4225.2399 | 3274.1199 | 1545.8105 |
| 43.8 | 43.75 | 0.0035237 | 0.000398 | 3.5439014 | 6.4201103 | 6507.4427 | 4225.24 | 3274.4743 | 1546.4525 |
| 43.9 | 43.85 | 0.0035039 | 0.0003957 | 3.4070583 | 6.3746618 | 6507.443 | 4225.24 | 3274.815 | 1547.09 |
| 44.0 | 43.95 | 0.0034843 | 0.0003935 | 3.2716285 | 6.3295318 | 6507.4434 | 4225.24 | 3275.1422 | 1547.7229 |
| 44.1 | 44.05 | 0.0034647 | 0.0003913 | 3.1375956 | 6.2847182 | 6507.4437 | 4225.2401 | 3275.4559 | 1548.3514 |
| 44.2 | 44.15 | 0.0034453 | 0.0003891 | 3.0049427 | 6.2402188 | 6507.444 | 4225.2401 | 3275.7564 | 1548.9754 |
| 44.3 | 44.25 | 0.003426 | 0.0003869 | 2.8736527 | 6.1960316 | 6507.4444 | 4225.2402 | 3276.0438 | 1549.595 |
| 44.4 | 44.35 | 0.0034067 | 0.0003848 | 2.7437076 | 6.1521544 | 6507.4447 | 4225.2402 | 3276.3181 | 1550.2103 |

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| 44.5 | 44.45 | 0.0033876 | 0.0003826 | 2.6150889 | 6.1085853 | 6507.4451 | 4225.2402 | 3276.5797 | 1550.8211 |
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| 44.6 | 44.55 | 0.0033686 | 0.0003805 | 2.4877776 | 6.065322 | 6507.4454 | 4225.2403 | 3276.8284 | 1551.4276 |
| 44.7 | 44.65 | 0.0033497 | 0.0003783 | 2.3617532 | 6.0223627 | 6507.4457 | 4225.2403 | 3277.0646 | 1552.0299 |
| 44.8 | 44.75 | 0.0033309 | 0.0003762 | 2.2369946 | 5.9797052 | 6507.4461 | 4225.2404 | 3277.2883 | 1552.6279 |
| 44.9 | 44.85 | 0.0033122 | 0.0003741 | 2.1134787 | 5.9373475 | 6507.4464 | 4225.2404 | 3277.4997 | 1553.2216 |
| 45.0 | 44.95 | 0.0032937 | 0.000372 | 1.9911811 | 5.8952877 | 6507.4467 | 4225.2404 | 3277.6988 | 1553.8111 |
| 45.1 | 45.05 | 0.0032752 | 0.0003699 | 1.8700748 | 5.8535236 | 6507.4471 | 4225.2405 | 3277.8858 | 1554.3965 |
| 45.2 | 45.15 | 0.0032568 | 0.0003678 | 1.75013 | 5.8120533 | 6507.4474 | 4225.2405 | 3278.0608 | 1554.9777 |
| 45.3 | 45.25 | 0.0032385 | 0.0003658 | 1.6313133 | 5.7708749 | 6507.4477 | 4225.2405 | 3278.2239 | 1555.5548 |
| 45.4 | 45.35 | 0.0032204 | 0.0003637 | 1.5135864 | 5.7299863 | 6507.448 | 4225.2406 | 3278.3753 | 1556.1278 |
| 45.5 | 45.45 | 0.0032023 | 0.0003617 | 1.3969045 | 5.6893856 | 6507.4484 | 4225.2406 | 3278.515 | 1556.6967 |
| 45.6 | 45.55 | 0.0031843 | 0.0003596 | 1.2812143 | 5.6490709 | 6507.4487 | 4225.2406 | 3278.6431 | 1557.2616 |
| 45.7 | 45.65 | 0.0031665 | 0.0003576 | 1.1664504 | 5.6090403 | 6507.449 | 4225.2407 | 3278.7597 | 1557.8225 |
| 45.8 | 45.75 | 0.0031487 | 0.0003556 | 1.05253 | 5.5692918 | 6507.4493 | 4225.2407 | 3278.865 | 1558.3794 |
| 45.9 | 45.85 | 0.003131 | 0.0003536 | 0.9393452 | 5.5298234 | 6507.4496 | 4225.2408 | 3278.9589 | 1558.9324 |
| 46.0 | 45.95 | 0.0031135 | 0.0003516 | 0.8267481 | 5.4906335 | 6507.4499 | 4225.2408 | 3279.0416 | 1559.4815 |
| 46.1 | 46.05 | 0.003096 | 0.0003497 | 0.7145265 | 5.4517199 | 6507.4502 | 4225.2408 | 3279.1131 | 1560.0267 |
| 46.2 | 46.15 | 0.0030786 | 0.0003477 | 0.6023545 | 5.4130809 | 6507.4505 | 4225.2409 | 3279.1733 | 1560.568 |
| 46.3 | 46.25 | 0.0030614 | 0.0003457 | 0.489684 | 5.3747146 | 6507.4509 | 4225.2409 | 3279.2223 | 1561.1054 |
| 46.4 | 46.35 | 0.0030442 | 0.0003438 | 0.3754631 | 5.3366192 | 6507.4512 | 4225.2409 | 3279.2598 | 1561.6391 |
| 46.5 | 46.45 | 0.0030271 | 0.0003419 | 0.2571653 | 5.2987928 | 6507.4515 | 4225.241 | 3279.2855 | 1562.169 |
| 46.6 | 46.55 | 0.0030101 | 0.00034 | 0.0795803 | 5.2612336 | 6507.4518 | 4225.241 | 3279.2935 | 1562.6951 |
| 46.7 | 46.65 | 0.0029932 | 0.0003381 | 0.000161 | 5.2239398 | 6507.4521 | 4225.241 | 3279.2935 | 1563.2175 |
| 46.8 | 46.75 | 0.0029764 | 0.0003362 | 0.0001601 | 5.1869096 | 6507.4524 | 4225.2411 | 3279.2935 | 1563.7362 |
| 46.9 | 46.85 | 0.0029597 | 0.0003343 | 0.0001592 | 5.1501411 | 6507.4527 | 4225.2411 | 3279.2935 | 1564.2512 |
| 47.0 | 46.95 | 0.0029431 | 0.0003324 | 0.0001583 | 5.1136327 | 6507.4529 | 4225.2411 | 3279.2935 | 1564.7626 |
| 47.1 | 47.05 | 0.0029266 | 0.0003305 | 0.0001574 | 5.0773824 | 6507.4532 | 4225.2412 | 3279.2936 | 1565.2703 |
| 47.2 | 47.15 | 0.0029102 | 0.0003287 | 0.0001565 | 5.0413887 | 6507.4535 | 4225.2412 | 3279.2936 | 1565.7744 |
| 47.3 | 47.25 | 0.0028939 | 0.0003268 | 0.0001556 | 5.0056497 | 6507.4538 | 4225.2412 | 3279.2936 | 1566.275 |
| 47.4 | 47.35 | 0.0028776 | 0.000325 | 0.0001548 | 4.9701636 | 6507.4541 | 4225.2413 | 3279.2936 | 1566.772 |

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| 47.5 | 47.45 | 0.0028615 | 0.0003232 | 0.0001539 | 4.9349289 | 6507.4544 | 4225.2413 | 3279.2936 | 1567.2655 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| 47.6 | 47.55 | 0.0028454 | 0.0003214 | 0.000153 | 4.8999437 | 6507.4547 | 4225.2413 | 3279.2936 | 1567.7555 |
| 47.7 | 47.65 | 0.0028295 | 0.0003196 | 0.0001522 | 4.8652063 | 6507.455 | 4225.2414 | 3279.2937 | 1568.242 |
| 47.8 | 47.75 | 0.0028136 | 0.0003178 | 0.0001513 | 4.8307151 | 6507.4552 | 4225.2414 | 3279.2937 | 1568.7251 |
| 47.9 | 47.85 | 0.0027978 | 0.000316 | 0.0001505 | 4.7964683 | 6507.4555 | 4225.2414 | 3279.2937 | 1569.2047 |
| 48.0 | 47.95 | 0.0027821 | 0.0003142 | 0.0001496 | 4.7624644 | 6507.4558 | 4225.2415 | 3279.2937 | 1569.681 |
| 48.1 | 48.05 | 0.0027665 | 0.0003124 | 0.0001488 | 4.7287015 | 6507.4561 | 4225.2415 | 3279.2937 | 1570.1539 |
| 48.2 | 48.15 | 0.002751 | 0.0003107 | 0.0001479 | 4.6951782 | 6507.4564 | 4225.2415 | 3279.2937 | 1570.6234 |
| 48.3 | 48.25 | 0.0027356 | 0.000309 | 0.0001471 | 4.6618927 | 6507.4566 | 4225.2415 | 3279.2937 | 1571.0896 |
| 48.4 | 48.35 | 0.0027202 | 0.0003072 | 0.0001463 | 4.6288434 | 6507.4569 | 4225.2416 | 3279.2938 | 1571.5525 |
| 48.5 | 48.45 | 0.0027049 | 0.0003055 | 0.0001455 | 4.5960286 | 6507.4572 | 4225.2416 | 3279.2938 | 1572.0121 |
| 48.6 | 48.55 | 0.0026898 | 0.0003038 | 0.0001446 | 4.5634469 | 6507.4574 | 4225.2416 | 3279.2938 | 1572.4684 |
| 48.7 | 48.65 | 0.0026747 | 0.0003021 | 0.0001438 | 4.5310965 | 6507.4577 | 4225.2417 | 3279.2938 | 1572.9215 |
| 48.8 | 48.75 | 0.0026597 | 0.0003004 | 0.000143 | 4.4989759 | 6507.458 | 4225.2417 | 3279.2938 | 1573.3714 |
| 48.9 | 48.85 | 0.0026448 | 0.0002987 | 0.0001422 | 4.4670835 | 6507.4582 | 4225.2417 | 3279.2938 | 1573.8181 |
| 49.0 | 48.95 | 0.0026299 | 0.000297 | 0.0001414 | 4.4354178 | 6507.4585 | 4225.2418 | 3279.2938 | 1574.2617 |
| 49.1 | 49.05 | 0.0026152 | 0.0002954 | 0.0001406 | 4.4039771 | 6507.4588 | 4225.2418 | 3279.2939 | 1574.7021 |
| 49.2 | 49.15 | 0.0026005 | 0.0002937 | 0.0001398 | 4.37276 | 6507.459 | 4225.2418 | 3279.2939 | 1575.1393 |
| 49.3 | 49.25 | 0.0025859 | 0.0002921 | 0.0001391 | 4.3417648 | 6507.4593 | 4225.2418 | 3279.2939 | 1575.5735 |
| 49.4 | 49.35 | 0.0025714 | 0.0002904 | 0.0001383 | 4.3109901 | 6507.4595 | 4225.2419 | 3279.2939 | 1576.0046 |
| 49.5 | 49.45 | 0.002557 | 0.0002888 | 0.0001375 | 4.2804343 | 6507.4598 | 4225.2419 | 3279.2939 | 1576.4327 |
| 49.6 | 49.55 | 0.0025426 | 0.0002872 | 0.0001367 | 4.2500959 | 6507.46 | 4225.2419 | 3279.2939 | 1576.8577 |
| 49.7 | 49.65 | 0.0025284 | 0.0002856 | 0.000136 | 4.2199735 | 6507.4603 | 4225.242 | 3279.2939 | 1577.2797 |
| 49.8 | 49.75 | 0.0025142 | 0.0002839 | 0.0001352 | 4.1900654 | 6507.4606 | 4225.242 | 3279.294 | 1577.6987 |
| 49.9 | 49.85 | 0.0025001 | 0.0002824 | 0.0001344 | 4.1603703 | 6507.4608 | 4225.242 | 3279.294 | 1578.1147 |
| 50.0 | 49.95 | 0.002486 | 0.0002808 | 0.0001337 | 4.1308867 | 6507.4611 | 4225.242 | 3279.294 | 1578.5278 |

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[^0]:    * Actual units for this $\boldsymbol{k}_{\boldsymbol{S}}^{\boldsymbol{o}}$ entry are atom fraction- $\mathrm{Pa} 1 / 2$, consistent with source.
    ${ }^{\dagger}$ Original source could not be located, values are those cited by Yamanaka et al.

