RAI Volume 3, Chapter 2.2.1.3.4, Second Set, Number 7:

Describe and provide quantitative information on the movement of key radionuclides through the various components of the engineered barrier system. Quantitative information should include radionuclide mass in and flux between the physical domains. In particular, quantitatively describe the movement of isotopes of neptunium, plutonium and a highly mobile element such as technetium for the nominal and igneous modeling cases. For each combination of radionuclide and modeling case, identify one realization that contributes significantly to mean dose for that combination and one realization that represents typical EBS releases and provide the following:

- Radionuclide flux (dissolved and, for plutonium, irreversibly associated with each colloid type) from the waste form domain, corrosion product domain, and invert as functions of time.

- Sorbed, precipitated, and dissolved mass in the waste form domain, corrosion product domain, and invert as functions of time.

Basis: Information on radionuclide retention in individual components of the EBS abstraction is needed to verify that the TSPA results are consistent with the process abstractions. This information is needed to verify compliance with 10 CFR 63.21(c)(11) and (12), and 63.114(a) and (b).

1. RESPONSE

This response provides information extracted from existing single realizations of the total system performance assessment (TSPA) model, supplementing previously documented results. The specific single realizations selected are:

- The 1,000,000-year igneous intrusion modeling case, with a single igneous intrusion event at 10,000 years and epistemic uncertainty vector 286 (realization 2855). This single realization is described in Section 7.7.1.3[a] of *Total System Performance Assessment Model/Analysis for the License Application* (TSPA-LA) (SNL 2008).

- The 1,000,000-year nominal modeling case for epistemic uncertainty vector 286. This single realization is described in SAR Section 2.4.2.2.3.1 and Section 7.7.1.5[a] of *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008).

For each realization, information is presented for the following:

- Five radionuclide types: ^{129}I dissolved (representative of a highly mobile element), ^{237}Np dissolved and reversibly sorbed to colloids, ^{242}Pu dissolved and reversibly sorbed to colloids, ^{242}Pu irreversibly attached to waste form colloids, and ^{242}Pu irreversibly attached to corrosion product (iron oxyhydroxide) colloids

- Two waste package types: commercial spent nuclear fuel (SNF) and codisposal

- Two waste package environments: percolation bin 3 seeping and non-seeping

- Seven Engineered Barrier System (EBS) model domains: 3 domains for commercial SNF waste packages (commercial SNF waste form (cell 1), commercial SNF corrosion products/waste package (cell 2), and invert) and 4 domains for codisposal waste packages (high-level waste (HLW) waste form (cell 1a), DOE SNF waste form (cell 1b), codisposal corrosion products/waste package (cell 2), and invert)

- Two transport processes: advective and diffusive

- Seven types of radionuclide mass in place: unexposed (i.e., immobile mass within the non-degraded waste form), dissolved, precipitated, reversibly sorbed onto mobile colloids, reversibly sorbed onto stationary material (stationary corrosion products or invert tuff), irreversibly attached to suspended (i.e., stable, mobile) colloids (only for plutonium), and irreversibly attached to settled (i.e., unstable, temporarily immobile) colloids (only for plutonium).

A general description of the movement and retention of radionuclide mass, supported by plots of time histories of radionuclide mass flux between EBS model domains and radionuclide mass in place in EBS model domains, is provided in Section 1.1 for the igneous intrusion modeling case single realization and in Section 1.2 for the nominal modeling case single realization. The information supplements the related information in the SAR and in *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008), however, where appropriate, references to SAR Section 2.4.2.2.3.1 and to Sections 7.7.1.3[a] and 7.7.1.5[a] of the latter report (SNL 2008) are made to describe specific details of the radionuclide behavior.

The two selected single realizations are representative of typical EBS releases and illustrate the movement and retention of key radionuclides in the EBS model domains for the two modeling cases. Results from additional outlier realizations that contribute significantly to mean dose are documented in Section 7.7.1[a] of *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008). The outlier results were contrasted with the results presented for the typical realizations in the TSPA-LA report (SNL 2008) and are therefore not presented in this response. The selection of a different realization for each combination of radionuclide and modeling case would complicate the analysis because the different epistemic parameters selected for each radionuclide would preclude comparison of results across radionuclides (e.g., there would be different in-package environments for each radionuclide). Therefore, all radionuclides were analyzed for the same realization in a specific modeling case, resulting in the two selected realizations that focus the analyses on key EBS processes.

1.1 SINGLE REALIZATION OF THE IGNEOUS INTRUSION MODELING CASE FOR 1,000,000 YEARS

The realization selected to represent the 1,000,000-year igneous intrusion modeling case is epistemic uncertainty vector 286 with an igneous intrusion event at 10,000 years (realization 2855). This single realization is described in *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008, Section 7.7.1.3[a]).

Expected annual dose for each of the 300 epistemic uncertainty vectors for the 1,000,000-year igneous intrusion modeling case is shown in Figure 1.1-1. The figure also shows how the expected annual dose for the selected realization, epistemic uncertainty vector 286, closely resembles the mean annual dose behavior. Expected annual dose for epistemic uncertainty vector 286 is calculated from ten aleatory uncertainty vectors, corresponding to ten different igneous intrusion event times ranging from 250 years to 800,000 years (Figure 1.1-2), using the techniques outlined in *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008, Appendix J, Section J7.2). For this analysis, realization 2855, corresponding to the combination of epistemic uncertainty vector 286 and an igneous intrusion event time of 10,000 years, was selected to best isolate key EBS behavior subsequent to an igneous intrusion event. The slow decrease in late-time annual dose for realization 2855 differs from the late-time trend of expected annual dose for vector 286 because the expected annual dose includes contributions from additional aleatory realizations with later igneous intrusion events (SNL 2008, Section 7.7.1.3[a], p. 7-55[a]).

The contribution from each major radionuclide to mean annual dose from all realizations is shown in Figure 1.1-3. The mean annual dose at early time (up to about 200,000 years) is dominated by contributions from ^{239}Pu, and the late time dose is dominated by contributions from ^{242}Pu, ^{237}Np, and ^{226}Ra. Figure 1.1-4 shows the contribution from certain radionuclides to the annual dose in realization 2855. For a short time (a few thousand years) immediately after the intrusion, annual dose in this realization is dominated by contributions from highly soluble and highly mobile radionuclides such as ^{99}Tc and ^{129}I (which are not shown on Figure 1.1-4); at later times, annual dose is dominated by contributions from ^{239}Pu, ^{242}Pu, and ^{237}Np. This single realization analysis focuses on the movement and retention of ^{129}I, ^{237}Np, and ^{242}Pu in the EBS in the seeping environment of percolation subregion 3. Percolation subregion 3 contains 40% of the total number of waste packages in the repository (3,285 commercial SNF waste packages and 1,366 codisposal waste packages), and locations in percolation subregion 3 are associated with the middle 40% of the expected range of percolation values.

The TSPA model segregates the waste packages in a percolation subregion into seeping and non-seeping environments. Waste packages in a seeping environment may experience dripping from seepage and condensation, whereas waste packages in a non-seeping environment may experience dripping from condensation only or may be in a non-dripping location. In the selected single realization, the seepage fraction for percolation subregion 3 is approximately 0.72, resulting in 2,369 commercial SNF waste packages and 984 codisposal waste packages in the seeping environment of percolation subregion 3. In the igneous intrusion modeling case, the drip shields and waste packages are assumed to be completely failed by the igneous intrusion event (at 10,000 years in this realization), and thereafter present no barrier to water flow. After the igneous intrusion event, percolation flux is applied to all waste package locations, including those previously identified as non-seeping, and the seepage model is no longer used. Thus, after the event, advective flux occurs in all locations, and the EBS behavior in the seeping and non-seeping environments is similar. Therefore, mass fluxes and masses in place are reported only for waste packages in the seeping environment.

In addition, all waste forms are assumed to be instantaneously degraded (i.e., all of the mass is exposed) at the time of the event. Immediately following the event, there is a short (100 years or less) thermal perturbation caused by the magma intrusion that prevents radionuclide releases (for as long as the waste package temperature is greater than 100°C). However, because the duration of the perturbation is short relative to the time-step size, it is not evident in the plots and it is not significant to the results.

The in-package chemistry (pH and P_{CO_2} over time) for realization 2855 is shown in Figure 1.1-5 for the commercial SNF waste form domain. The solubility limits and dissolved concentrations for radionuclides of interest are shown in Figure 1.1-6 for the commercial SNF waste form domain and Figure 1.1-7 for the commercial SNF corrosion products domain. After an igneous intrusion event, solubility limits in the invert are equal to those computed for the corrosion products domain. ^{129}I is not shown on these figures because the TSPA model applies no solubility limit to this radionuclide.

The following three subsections provide general descriptions and plots of the movement and retention of ^{129}I, ^{237}Np, and ^{242}Pu mass in the EBS, respectively, for epistemic uncertainty vector 286, realization 2855 of the 1,000,000-year igneous intrusion modeling case. The general descriptions are based on the commercial SNF waste package results, but differences in behavior and results associated with codisposal waste packages are identified. The results are from waste packages in a seeping environment of percolation subregion 3. In some of the plots, some data curves may be difficult to distinguish because they overlay each other. In these cases, the affected curves are identified in the figure. Data curves that are below the lower limit of the plot are not significant to the descriptions, and are not explicitly identified.

1.1.1 Iodine

The movement and retention of ^{129}I in the EBS model domains for the 1,000,000-year single realization of the igneous intrusion modeling case are described using the following plots:

- Time histories of radionuclide flux (both advective and diffusive) out of each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages)

- Time histories of mass in place (unexposed mass and/or dissolved mass) in each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages).

Because ^{129}I is highly soluble and non-sorbing, and no solubility-controlling solid is expected to form under repository conditions (SNL 2008, Section 6.3.7.5), there are no precipitated and sorbed ^{129}I masses in the EBS model domains to show on the mass in place plots for ^{129}I.

For this realization, the commercial SNF waste packages contain about 97% of the total initial ^{129}I inventory (4.63×10^6 g in commercial SNF waste packages in the seeping environment of percolation subregion 3 and 1.43×10^5 g in codisposal waste packages in the seeping environment of percolation subregion 3). Decay is not a significant factor; ^{129}I has a half-life of about 15,700,000 years, and thus only 4% of the initial ^{129}I mass decays within 1,000,000 years.

Figures 1.1-8 and 1.1-9 show the movement and retention of ^{129}I mass in the EBS from commercial SNF waste packages in the seeping environment. Figure 1.1-8 shows that there are no releases of ^{129}I from commercial SNF waste packages prior to the igneous intrusion event at 10,000 years. Prior to the event, all of the mass is unexposed mass (Figure 1.1-9). In the 500-year time step immediately following the igneous intrusion event at 10,000 years, 99.96% of the initial ^{129}I mass inventory is transported out of the EBS (through the waste form domain, the corrosion products domain, and the invert) (average rates are 9223.1 g/yr by advection from the invert plus 35.6 g/yr by diffusion from the invert, for a cumulative release of 4.63×10^6 g in 500 years). This rapid movement occurs because the instantaneous degradation of the waste form and the lack of a solubility limit for ^{129}I combine to dissolve all the initial ^{129}I inventory within a single time step. The advective release rates are orders of magnitude greater than diffusive release rates (Figure 1.1-8).

Figures 1.1-8 and 1.1-9 indicate that a small amount of residual ^{129}I remains in the EBS for several thousand years after the event. This residual mass is due to backward diffusion between domains in the EBS transport model. As indicated in *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008, Figure 6.3.8-4), the EBS transport model permits bidirectional diffusive flux between model domains. As noted above, 99.96% of ^{129}I mass moves through the EBS in the first time step after the igneous intrusion. Because of this large mass flux and the discretization employed in the numerical solution of the transport equations, the dissolved concentrations of ^{129}I become larger in the downstream model domains than in the upstream model domains, resulting in an upstream diffusive gradient (i.e., from the invert to the corrosion products domain and from the corrosion products domain to the waste form domain). The backward diffusion returns small amounts of ^{129}I from the invert to the corrosion products domain and from the corrosion products domain to the waste form domain, which is subsequently advected out of these model domains in the next time step. This "cycle" of backward diffusion and advection results in the declining release rates shown in Figure 1.1-8. The back diffusion cycle involves only a small fraction of the total ^{129}I mass (about 0.1%) and therefore does not have a significant impact on the mass release from the EBS. Additional discussion on backward diffusion is presented in the response to RAI 3.2.2.1.3.4-2-011.

Figures 1.1-10 and 1.1-11 show the movement and retention of ^{129}I mass in the EBS from codisposal waste packages in the seeping environment. The behavior for codisposal waste packages is similar to the behavior described for the commercial SNF waste packages. The time histories of release rates (Figure 1.1-10) and mass in place (Figure 1.1-11) are nearly identical to those for commercial SNF waste packages; the only significant difference is that magnitudes of the codisposal release rates and mass in place are lower due to the lower initial inventory in the codisposal waste packages.

1.1.2 Neptunium

The movement and retention of ^{237}Np in the EBS model domains for the 1,000,000-year single realization of the igneous intrusion modeling case are described using the following plots:

- Time histories of radionuclide flux (both advective and diffusive) out of each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages)

- Time histories of mass in place (unexposed mass and/or dissolved, precipitated, and sorbed mass) in each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages).

Sorbed mass is divided into mass reversibly sorbed onto stationary materials (corrosion products in the corrosion products domain, crushed tuff in the invert) and mass reversibly sorbed onto mobile colloids.

For this realization, the commercial SNF waste packages contain about 98% of the total initial ^{237}Np inventory. In addition, there is significant early-time ingrowth from the decay of ^{245}Cm (half-life = 8,500 years), ^{241}Pu (half-life = 14.4 years), and ^{241}Am (half-life = 432.7 years). These three short-lived radionuclides, when completely decayed to ^{237}Np, produce about 1.9 times the initial mass of ^{237}Np in commercial SNF waste packages and about 1.5 times the initial mass of ^{237}Np in codisposal waste packages. (The total initial inventory plus ingrowth is about 4.12×10^7 g in commercial SNF waste packages in a seeping environment of percolation subregion 3 and about 8.67×10^5 g in codisposal waste packages in a seeping environment of percolation subregion 3.) ^{237}Np has a half-life of 2,140,000 years; about 28% of the initial ^{237}Np mass (including ingrowth) decays within 1,000,000 years. The general decay and ingrowth behavior of ^{237}Np is presented in SAR Figure 2.1-18.

Figures 1.1-12 through 1.1-15 show the movement and retention of ^{237}Np mass in the EBS from commercial SNF waste packages in the seeping environment. Figure 1.1-12 shows advective and diffusive release rates of ^{237}Np from commercial SNF waste packages from each of the three EBS model domains. As with ^{129}I, advective release rates are seen to be orders of magnitude greater than diffusive release rates for this realization.

The in-package chemical conditions (see Figure 1.1-5), initial ^{237}Np inventory, and computed neptunium solubility for this realization result in a dissolved ^{237}Np concentration in the waste form domain at the solubility limit for the first 50,500 years (Figure 1.1-6). Prior to the igneous intrusion event, all of the ^{237}Np is unexposed mass in the waste form. Immediately following the event at 10,000 years, the waste form completely degrades, exposing the radionuclide mass, which becomes precipitated mass in the waste form domain (Figure 1.1-13). Because of the limited solubility, the dissolution of the precipitated mass in the waste form domain is a gradual process occurring from the time of the event at 10,000 years to about 50,500 years

(Figure 1.1-13). Due to increasing pore space resulting from corrosion of steel in the corrosion products domain, the volume of water in contact with the precipitated mass increases, leading to increasing dissolved mass and mass sorbed reversibly to mobile colloids (Figure 1.1-13), even though the solubility limit for ^{237}Np decreases (Figure 1.1-6). By 50,500 years, almost all of the precipitated ^{237}Np has been dissolved and transported (predominantly by advection) out of the waste form domain (over this time, release rates decrease from 1,123 to 543 g/yr for advection and from 117 to 43 g/yr for diffusion for a cumulative mass release of 4.12×10^7 g in 40,500 years), and the mass in the waste form domain (Figure 1.1-13) and the release rate from the waste form domain (Figure 1.1-12) both decrease significantly thereafter.

During this time (10,000 to 50,500 years), about 14% of the ^{237}Np mass transported out of the waste form domain moves through the corrosion products domain and through the invert and is released from the EBS (release rates decrease from 184 to 119 g/yr for advection with minimal diffusion from the invert for total mass release of 5.63×10^6 g in 40,500 years). The release rates from the corrosion products domain and from the invert are nearly identical (Figure 1.1-12), indicating that the mass retained in the invert (5.47×10^3 g at 50,500 years) (Figure 1.1-15) is not significant relative to the total mass of ^{237}Np in the EBS.

Also during this time (10,000 to 50,500 years), about 85% of the ^{237}Np mass transported out of the waste form domain is retained in the corrosion products domain as either precipitated mass (1.96×10^7 g at 50,500 years) or mass sorbed onto stationary corrosion products (1.55×10^7 g at 50,500 years) (Figure 1.1-14). In the corrosion products domain, the in-package chemical conditions result in a lower ^{237}Np solubility than in the waste form domain (which is why some ^{237}Np precipitates in the corrosion products domain) and the dissolved ^{237}Np concentration is maintained at the solubility limit until about 92,500 years (Figure 1.1-7). Therefore, between 50,500 and 92,500 years, the ^{237}Np mass sorbed onto corrosion products in the corrosion products domain continues to increase, even though the influx of ^{237}Np from the waste form domain is no longer significant. The increase is due to the precipitated mass in the corrosion products domain re-dissolving and sorbing on the stationary corrosion products, which continue to be produced as the steel corrodes (Figure 1.1-14). The mass of ^{237}Np dissolved and sorbed onto mobile colloids in the corrosion products domain is several orders of magnitude less than the mass sorbed onto stationary corrosion products.

After 50,500 years, the dissolved concentration of ^{237}Np in the corrosion products domain is higher than in the waste form domain, and there is backward diffusion from the corrosion products domain to the waste form domain. As discussed previously for iodine, the backward-diffused mass is subsequently transported back into the corrosion products domain by advection (Figure 1.1-12), reducing the concentrations in the waste form domain and perpetuating the cycle. This condition persists for the remainder of the realization and results in a steady state cycle of a minimal amount of mass (10.8 g/yr at 50,500 years and declining to 0.4 g/yr by 1,000,000 years) between the waste form domain and the corrosion products domain. The rate of cycling is about 8% of the rate of release of ^{237}Np from the EBS (Figure 1.1-12).

From 50,500 to 92,500 years, the ^{237}Np precipitate in the corrosion products domain re-dissolves. Most of the re-dissolved mass sorbs on the stationary corrosion products (Figure 1.1-14), while the remaining mass either remains dissolved or sorbs to mobile colloids. The mass of ^{237}Np sorbed onto the stationary corrosion products increases during this time because the dissolution rate is greater than the rate of desorption from the corrosion products. After all of the precipitate re-dissolves (at 92,500 years), there is no source of additional ^{237}Np to sorb onto the corrosion products. Continuing desorption of ^{237}Np from the corrosion products, along with radioactive decay, results in a declining mass of ^{237}Np sorbed onto stationary corrosion products in the corrosion products domain (Figure 1.1-14). The dissolved mass of the ^{237}Np is significantly greater than the mass of the ^{237}Np reversibly sorbed onto mobile colloids in all three EBS model domains. By 1,000,000 years, only about 3% of the initial (including ingrowth) inventory of ^{237}Np remains in the corrosion products domain, sorbed onto stationary corrosion products. Even though it is only 3% of the initial mass, the ^{237}Np mass sorbed onto stationary corrosion products still represents the majority of the mass remaining in the EBS. The mass of ^{237}Np dissolved and sorbed onto mobile colloids is significantly lower.

Most of the desorbed ^{237}Np mass is transported out of the corrosion products domain by advection, through the invert and released from the EBS, with the release rates declining from 112 g/yr at 92,500 years to 5 g/yr at 1,000,000 years (Figure 1.1-12). Over 1,000,000 years, the cumulative mass of ^{237}Np released from the invert (3.61×10^7 g) is about 88% of the total mass (including ingrowth).

At about 176,000 years, there is a change in slope in the release rate curves, resulting in slightly increased release rates (Figure 1.1-12). The change in slope corresponds to the complete corrosion of the stainless steel in the waste package and the corresponding change in the solubility-controlling solid phase from NpO_2 to Np_2O_5 (SAR Section 2.4.2.3.2.1.7, p. 2.4-164). Beyond this time, corrosion product production ceases, and there are no new sites available for sorption.

Figures 1.1-16 through 1.1-20 show the movement and retention of ^{237}Np mass in the EBS from codisposal waste packages in the seeping environment. The behavior for codisposal waste packages is qualitatively similar to the behavior described for the commercial SNF waste packages, but differs in a few aspects. The magnitudes of the codisposal release rates and mass in place are lower due to the lower initial inventory in codisposal waste packages, but the general time histories are similar. For the commercial SNF waste packages, the large exposed ^{237}Np mass (4.12×10^7 g) takes about 40,500 years to dissolve (Figure 1.1-13). For the codisposal waste packages, the exposed mass is much smaller (8.67×10^5 g) and takes only about 2,000 years to dissolve. As a result, there is no precipitated mass after 12,000 years in either of two codisposal waste form domains, the HLW domain (cell 1a) (Figure 1.1-17) or the DOE SNF domain (cell 1b) (Figure 1.1-18). Most of the mass present in these two waste form domains after 12,500 years is dissolved ^{237}Np, with a very minor amount of mass reversibly sorbed to colloids.

The greater mass of ^{237}Np in the commercial SNF waste packages results in a 40,500-year plateau in the release rate curve (Figure 1.1-12). In contrast, for codisposal waste packages, because the precipitated mass of ^{237}Np in the waste form domains is rapidly re-dissolved, the release rate curve (Figure 1.1-16) shows a very short duration advective pulse that transports a significant mass of ^{237}Np from the waste form domains into the corrosion products domain. As with the commercial SNF waste packages, a significant mass of ^{237}Np is sorbed onto stationary corrosion products in the corrosion products domain immediately after the event, which then slowly desorbs and decays over time (Figure 1.1-19).

1.1.3 Plutonium

Plutonium transport is different from iodine and neptunium because the transport of ^{242}Pu includes mass irreversibly attached to waste form colloids (designated Ic) and to iron oxyhydroxide colloids (designated If or FeO_x). The movement and retention of ^{242}Pu in the EBS model domains for the 1,000,000-year single realization of the igneous intrusion modeling case are described using the following plots:

- Time histories of radionuclide flux (both advective and diffusive) out of each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages)

- Time histories of mass in place (unexposed mass and/or dissolved, precipitated, sorbed, and irreversibly attached colloidal mass) in each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages).

Sorbed mass is divided into mass reversibly sorbed onto stationary materials (corrosion products in the corrosion products domain, crushed tuff in the invert) and mass reversibly sorbed onto mobile colloids. Mass irreversibly attached to colloids is divided into suspended mass (i.e., mobile) and settled mass (i.e., immobile) for each of the two types of colloids (waste form and FeO_x).

Where the general behavior of ^{242}Pu in the EBS is similar to that of ^{237}Np, references are made to the preceding neptunium discussion (Section 1.1.2), rather than repeating prior text. The focus of the descriptions in this subsection is on behavior that is unique to plutonium.

For this realization, the commercial SNF waste packages contain about 99.5% of the total initial ^{242}Pu inventory (1.44×10^7 g in commercial SNF waste packages in a seeping environment of percolation subregion 3 and 7.49×10^4 g in codisposal waste packages in a seeping environment of percolation subregion 3). ^{242}Pu has a half-life of 375,000 years; about 84% of the total mass of ^{242}Pu decays within 1,000,000 years. The general decay behavior of ^{242}Pu is presented in SAR Figure 2.1-18.

Figures 1.1-21 through 1.1-27 show the movement and retention of ^{242}Pu mass in the EBS from commercial SNF waste packages in the seeping environment. Key similarities with ^{237}Np behavior (Figures 1.1-12 through 1.1-15) are as follows:

- Advective release rates are orders of magnitude greater than diffusive release rates for this realization, a behavior that is expected for all igneous intrusion modeling case realizations due to the complete failure of all drip shields and waste packages at the time of the event and the application of percolation flux to all waste package locations after the event.

- In the waste form domain, following the igneous intrusion event at 10,000 years, the advective release rate is relatively high until all of the precipitated mass is dissolved. For ^{242}Pu, this occurs at about 204,000 years (Figure 1.1-25), corresponding to the time during which the dissolved ^{242}Pu concentration in the waste form domain is at the solubility limit (Figure 1.1-6). For comparison, all of the precipitated mass of ^{237}Np in the waste form domain was dissolved by 50,500 years. During this time (10,000 to 204,000 years), some of the ^{242}Pu mass transported out of the waste form domain moves through the corrosion products domain and through the invert and is released from the EBS (Figure 1.1-21). However, a portion of the ^{242}Pu mass transported out of the waste form domain is retained in the corrosion products domain as mass sorbed onto stationary corrosion products (Figure 1.1-26).

- In the corrosion products domain, a lower ^{242}Pu solubility than in the waste form domain results in re-precipitation of ^{242}Pu and the dissolved ^{242}Pu concentration being maintained at the solubility limit for about 260,000 years (Figure 1.1-7). For comparison, all of the precipitated mass of ^{237}Np in the corrosion products domain was dissolved by 92,500 years. The corresponding depletion of precipitated ^{242}Pu in the corrosion products domain at 260,000 years (Figure 1.1-26) results in a decrease in the advective release rates from all three EBS model domains.

- Once all of the precipitated ^{242}Pu mass is dissolved in the waste form domain, there is a cycle of back diffusion from the corrosion products domain to the waste form domain and subsequent advection from the waste form domain back into the corrosion products domain (Figure 1.1-21). The rate of cycling is about 16% of the rate of release of ^{242}Pu from the EBS (Figure 1.1-21) until the release rate is negligibly small.

- In all domains, the mass of ^{242}Pu sorbed onto mobile colloids is several orders of magnitude less than the dissolved mass and the mass sorbed onto stationary materials (Figures 1.1-25, 1.1-26, and 1.1-27).

By about 204,000 years, there are only about 64 g of ^{242}Pu left in the waste form domain (Figure 1.1-25). Most of the initial inventory of ^{242}Pu enters into the corrosion products domain (Figure 1.1-21), and some is lost to decay. The transport of ^{242}Pu into the corrosion products domain is predominantly by advection (Figure 1.1-21) and is about 76% irreversibly attached to waste form colloids (Figure 1.1-23) and about 24% dissolved and reversibly sorbed (Figure 1.1-22). During this time, about 11% of the ^{242}Pu that enters the corrosion products domain is subsequently transported into the invert and is released from the EBS (Figure 1.2-21). The transport of ^{242}Pu into the invert and out of the EBS is nearly 100% dissolved and reversibly sorbed ^{242}Pu (compare Figure 1.1-22 to Figure 1.1-21). The remainder of the ^{242}Pu that enters the corrosion products domain remains in the corrosion products domain irreversibly attached to settled waste form colloids or reversibly sorbed onto stationary corrosion products (Figure 1.1-26). In the corrosion products domain, the pH renders stable suspensions of waste form colloids from the waste form domain unstable, and the colloids settle. The mass of ^{242}Pu in the invert is not significant relative to the total mass of ^{242}Pu in the EBS (Figure 1.1-27). Also, the mass of ^{242}Pu irreversibly attached to FeO_x colloids is not significant (Figure 1.1-26).

After about 260,000 years, when there is no longer any precipitated ^{242}Pu mass in either the waste form domain or the corrosion products domain, the release rates and masses in place decline significantly. Most of the ^{242}Pu that is transported out of the corrosion products domain and subsequently out of the invert after 260,000 years is dissolved and reversibly sorbed mass (Figure 1.1-22) that derives from desorption of ^{242}Pu that was reversibly sorbed onto stationary corrosion products (Figure 1.1-26). Most of the mass of ^{242}Pu that remains in the corrosion products domain is irreversibly attached to settled waste form colloids. These colloids do not become stable in the corrosion products domain in this realization, so the remaining mass slowly declines due to decay and as minimal concentrations of colloids are transported out of the corrosion products domain (Figure 1.1-26). In addition, a relatively small mass (less than 4 g) of ^{242}Pu irreversibly attached to waste form colloids settles in the invert (Figure 1.1-27). An additional small mass (less than 10 g) of ^{242}Pu irreversibly attached to FeO_x colloids accumulates in the invert due to approximations made for the colloid concentrations in the invert in the solution to the transport equations. This mass is shown as settled irreversible FeO_x colloids on Figure 1.1-27, although the mass re-dissolves and is transported from the invert at later time steps.

Figure 1.1-21 shows that backward diffusion rates of ^{242}Pu are not significant relative to the total cumulative release from the EBS. Unlike ^{237}Np, the backward diffusion of ^{242}Pu to the waste form domain includes some ^{242}Pu mass irreversibly attached to FeO_x colloids (Figure 1.1-24) in addition to the ^{242}Pu mass dissolved and reversibly sorbed to colloids (Figure 1.1-22). Also, the ^{242}Pu mass that is subsequently advected out of the waste form domain is primarily mass that is irreversibly attached to waste form colloids (Figure 1.1-23), rather than mass dissolved and reversibly sorbed to colloids, as it was for ^{237}Np. The small amount of backward-diffused ^{242}Pu mass irreversibly attached to FeO_x colloids settles from solution and remains in the waste form domain. However, this settled mass comprises a negligible fraction of the total mass of ^{242}Pu (Figure 1.1-25). After about 600,000 years, the residual mass releases from the invert (Figure 1.1-21) result from backward diffusion from the EBS-unsaturated zone interface to the invert, as is further discussed in the response to RAI 3.2.2.1.3.4-2-011.

Figures 1.1-28 through 1.1-35 show the movement and retention of ^{242}Pu mass in the EBS from codisposal waste packages in the seeping environment. The behavior for codisposal waste packages is qualitatively similar to the behavior described for the commercial SNF waste packages, but differs in a few aspects. The magnitudes of the codisposal release rates and masses in place are lower due to the lower initial inventory in codisposal packages. For the codisposal waste packages, the exposed mass is much smaller (7.49×10^4 g) and thus the initially precipitated mass in the HLW waste form domain (cell 1a) and in the DOE SNF waste form domain (cell 1b) are more rapidly dissolved (Figures 1.1-32 and 1.1-33). Total release rates from the waste form (i.e., from cell 1b) (Figure 1.1-28) show two peaks, corresponding to the times of re-dissolution in the HLW waste form domain (Figure 1.1-32) and the DOE SNF waste form domain (Figure 1.1-33).

Similar to release rates for commercial SNF waste packages, most of the transport from the waste form domains in codisposal waste packages is by advection (Figure 1.1-28). Most of the ^{242}Pu that enters the corrosion products domain sorbs to the stationary corrosion products in the corrosion products domain (Figure 1.1-34), where slow desorption leads to slowly decreasing release rates from the corrosion products domain over time (Figure 1.1-28). However, unlike in commercial SNF waste packages, waste form colloid suspensions are stable in the corrosion products domain of the codisposal waste packages, resulting in transport of ^{242}Pu mass irreversibly attached to waste form colloids to the invert (Figure 1.1-30). The release rates for ^{242}Pu irreversibly attached to waste form colloids are small (roughly 5% of the release rates for ^{242}Pu dissolved and reversibly sorbed to colloids). The release rates for ^{242}Pu irreversibly attached to FeO_x colloids (Figure 1.1-31) are even smaller and are not significant. Also, waste form colloid suspensions in the invert are unstable, resulting in a relatively small amount (less than 100 g) of mass of ^{242}Pu irreversibly attached to settled waste form colloids in the invert (Figure 1.1-35). A smaller mass (less than 0.1 g) of ^{242}Pu irreversibly attached to FeO_x colloids accumulates in the invert due to approximations made for the colloid concentrations in the invert in the solution to the transport equations.

1.2 NOMINAL MODELING CASE 1,000,000-YEAR SINGLE REALIZATION

The realization selected to represent the 1,000,000-year nominal modeling case is epistemic uncertainty vector 286. This single realization is described in SAR Section 2.4.2.2.3.1 and in Section 7.7.1.5[a] of *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008).

Expected annual dose for each of the 300 epistemic uncertainty vectors for the 1,000,000-year nominal modeling case is shown in Figure 1.2-1. The figure also shows the expected annual dose for the selected realization, epistemic uncertainty vector 286. In contrast to the igneous intrusion modeling case, there is no aleatory uncertainty in the nominal modeling case. Because waste package failures are not coincident in all epistemic uncertainty vectors, the mean annual dose is determined by an increasing number of realizations as time increases. Thus, it is not possible to select a realization for which the expected annual dose closely resembles the mean annual dose through all time. The expected annual dose for epistemic uncertainty vector 286 is greater than the mean annual dose at late times, where the mean annual dose is largest, and exhibits similar features as are observed in the mean annual dose.

The contribution of individual radionuclides to the expected annual dose from epistemic uncertainty vector 286 is shown in Figure 1.2-2. Over the entire 1,000,000-year simulation, the dose is dominated by contributions from the highly soluble and highly mobile radionuclides, ^{129}I and ^{99}Tc. At later times, minor contributions from ^{135}Cs, ^{126}Sn, ^{79}Se, ^{242}Pu, ^{36}Cl, and ^{237}Np can be seen. This single realization analysis focuses on the movement and retention of ^{129}I, ^{237}Np, and ^{242}Pu in the EBS. The analysis presents results for percolation subregion 3 as representative of the behavior of the EBS. Percolation subregion 3 contains 40% of the total number of waste packages in the repository, and waste packages in percolation subregion 3 are associated with the middle 40% of the expected range of percolation values.

Because the epistemic uncertainty vector is the same for this nominal modeling case single realization as it was for the igneous modeling case single realization described in Section 1.1, the seepage fraction for percolation subregion 3 is the same, approximately 0.72. There are 2,369 commercial SNF waste packages and 984 codisposal waste packages in the seeping environment of percolation subregion 3, and 916 commercial SNF waste packages and 382 codisposal waste packages in the non-seeping environment. The initial mass inventories of ^{129}I, ^{237}Np, and ^{242}Pu for this nominal modeling case single realization are also the same as reported in Section 1.1.

In this single realization of the nominal modeling case, all drip shields fail by general corrosion at about 304,000 years. Waste packages fail intermittently in percolation subregion 3, also beginning at about 304,000 years (Figure 1.2-3). At the end of 1,000,000 years postclosure, 96% of codisposal waste packages and 94% of commercial SNF waste packages have failed. All of the waste package failures in percolation subregion 3 consist of stress corrosion cracks; none of the waste packages in percolation subregion 3 experience a general corrosion failure in this realization. In this single realization, only one general corrosion failure is observed in percolation subregion 1; thus, the results from percolation subregion 3 are representative of the EBS as a whole in this realization. General corrosion failures are not typical of realizations in the nominal modeling case, as demonstrated by SAR Figure 2.1-10(b). The steep increases in the number of failed waste packages at 500,000 years and 700,000 years result from the coarse timestep discretization used in the multiscale thermohydrologic model and the use of these timesteps to calculate stress corrosion crack failures; additional information about these timesteps and their effects is provided in *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008, Sections 7.7.1.5[a] and 7.3.3.7[a]). These effects are evident in most of the radionuclide flux and mass in place plots presented in the following subsections.

The following three subsections provide general descriptions and plots of the movement and retention of ^{129}I, ^{237}Np, and ^{242}Pu mass in the EBS, respectively, for epistemic uncertainty vector 286 of the 1,000,000-year nominal modeling case. The general descriptions are based on the commercial SNF waste package results, but differences in behavior and results associated with codisposal waste packages are identified. The results are from (a) waste packages in a seeping environment of percolation subregion 3, and (b) waste packages in a non-seeping environment of percolation subregion 3.

The primary differences between the igneous intrusion and nominal modeling cases that affect the results presented in this RAI response are:

- In the nominal modeling case, waste package failures are spread out over time rather than occurring at the time of a single event.
- In the nominal modeling case, waste form degradation may extend over tens of thousands of years, rather than occurring nearly instantaneously.
- In the nominal modeling case, there is no advective flux from seepage through waste packages in the non-seeping environment.

1.2.1 Iodine

The movement and retention of ^{129}I in the EBS model domains for the 1,000,000-year single realization of the nominal modeling case are described using the following plots:

- Time histories of radionuclide flux (both advective and diffusive) out of each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages)

- Time histories of mass in place (unexposed mass and/or dissolved mass) in each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages).

Because ^{129}I is highly soluble and non-sorbing, and no solubility-controlling solid is expected to form under repository conditions (SNL 2008, Section 6.3.7.5), there are no precipitated and sorbed ^{129}I masses in the EBS model domains to show on the mass in place plots for ^{129}I.

Figures 1.2-4 and 1.2-5 show the movement and retention of ^{129}I mass in the EBS from commercial SNF waste packages in the seeping environment. Figure 1.2-4 shows that there are no releases of ^{129}I from commercial SNF waste packages prior to the first waste package failure at 304,000 years. Prior to waste package failure, all of the ^{129}I mass is unexposed mass (Figure 1.2-5). After waste package failure, the immobile mass within the waste form begins to degrade, gradually releasing ^{129}I mass from the commercial SNF waste form (Figure 1.2-4). The releases from the waste form domain exhibit a series of peaks and valleys resulting from the failure of additional waste packages. The largest peaks at 500,000 years and 700,000 years correspond to the steep increases in the number of failed waste packages at these times (Figure 1.2-3). Because waste package failures are only due to stress corrosion cracking, radionuclide transport within the waste package (in the waste form domain and the corrosion products domain) is only by diffusion. As additional waste packages fail (Figure 1.2-3), more ^{129}I mass is subject to exposure and the unexposed mass decreases (Figure 1.2-5). At 1,000,000 years, approximately 6% of the initial ^{129}I mass inventory from commercial SNF waste packages remains in undegraded waste forms.

Figure 1.2-4 shows that steady-state diffusive transport conditions are readily established between the waste form domain through the corrosion products domain and into the invert (the release rates from each model domain are roughly equal). However, Figure 1.2-5 shows that the mass present in the corrosion products domain is much greater than the mass present in the invert, due to the relatively small diffusive area offered by the stress corrosion cracks. Once in the invert, most of the ^{129}I mass is transported out of the EBS. At 1,000,000 years, the cumulative release of ^{129}I from the EBS is approximately 83% of the initial ^{129}I mass inventory from commercial SNF waste packages in a seeping environment. Small masses of ^{129}I, relative to the initial inventory, remain in the EBS (Figure 1.2-5). Of the ^{129}I mass transported out of the EBS in seeping environment, 98.5% is transported by advection and 1.5% by diffusion (Figure 1.2-4).

Figures 1.2-6 and 1.2-7 show the movement and retention of ^{129}I mass in the EBS from commercial SNF waste packages in the non-seeping environment. The magnitudes of release rates (g/yr) and mass in place (g) are less than in Figures 1.2-4 and 1.2-5 because there are fewer commercial SNF waste packages in the non-seeping environment. The movement of ^{129}I in the non-seeping environment is qualitatively similar to movement in the seeping environment. At 1,000,000 years, the cumulative release of ^{129}I from the EBS is approximately 82% of the initial ^{129}I mass inventory from commercial SNF waste packages in a non-seeping environment, and small masses of ^{129}I, relative to the initial inventory, remain in the EBS (Figure 1.2-7). The main difference, due to the absence of seepage in the non-seeping environment, is that of the ^{129}I mass transported out of the EBS, 87% is released from the EBS by diffusion and 13% is released from the EBS by advection (from imbibition).

Figures 1.2-8 through 1.2-11 show the movement and retention of ^{129}I mass in the EBS from codisposal waste packages in seeping and non-seeping environments. There are no releases of ^{129}I from codisposal waste packages prior to the first waste package failure at 304,000 years. Due to the relatively slower rate of degradation of HLW (compared to commercial SNF), approximately 20% of the ^{129}I mass from the initial inventory in codisposal waste packages remains in undegraded waste forms. There is also a small amount of backward diffusion from the DOE SNF waste form domain (cell 1b) to the HLW waste form domain (cell 1a) due to the instantaneous degradation of DOE SNF in the DOE SNF waste form domain (Figure 1.2-8). Release rates and mass in place of ^{129}I in codisposal waste packages are qualitatively similar to commercial SNF waste packages, other than the additional detail of release rates from the two separate waste form domains (cell 1a and cell 1b) in codisposal waste packages. As for releases from the commercial SNF waste packages, releases from the waste form domains exhibit a series of peaks and valleys resulting from the ongoing failure of additional waste packages.

1.2.2 Neptunium

The movement and retention of ^{237}Np in the EBS model domains for the 1,000,000-year single realization of the nominal modeling case are described using the following plots:

- Time histories of radionuclide flux (both advective and diffusive) out of each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages)

- Time histories of mass in place (unexposed mass and/or dissolved, precipitated, and sorbed mass) in each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages).

Sorbed mass is divided into mass reversibly sorbed onto stationary materials (corrosion products in the corrosion products domain, crushed tuff in the invert) and mass reversibly sorbed onto mobile colloids.

Figures 1.2-12 through 1.2-15 show the movement and retention of ^{237}Np mass in the EBS from commercial SNF waste packages in the seeping environment. As for ^{129}I, releases of ^{237}Np from the waste form domain exhibit a series of peaks and valleys resulting from the failure of additional waste packages (Figure 1.2-12), with the largest peaks at 500,000 years and 700,000 years corresponding to the steep increases in the number of failed waste packages at these times (Figure 1.2-3). When the first waste packages fail at 304,000 years, and at the times when the number of failed waste packages increases sharply (500,000 years and 700,000 years), the rapid exposure of additional ^{237}Np mass from the commercial SNF waste form results in precipitated mass in the waste form domain (Figure 1.2-13). Due to different chemical conditions in the corrosion products domain, the solubility of ^{237}Np is lower than in the waste form domain. As a result, mass that diffuses from the waste form domain may also precipitate in the corrosion products domain (Figure 1.2-14). In both model domains, the precipitated mass re-dissolves relatively quickly. At 1,000,000 years, approximately 4% of the initial ^{237}Np mass inventory (either from the initial inventory or produced by radioactive decay) remains in undegraded waste forms. Additionally, as noted in Section 1.1, about 28% of the initial inventory decays over 1,000,000 years.

Because waste package failures are only due to stress corrosion cracking, transport is by diffusion from the waste form domain through the corrosion products domain to the invert (Figure 1.2-12). As in the igneous intrusion modeling case, most of the ^{237}Np mass that enters the corrosion products domain sorbs to the stationary corrosion products (Figure 1.2-14). At 1,000,000 years, ^{237}Np sorbed to the stationary corrosion products is the most significant ^{237}Np mass remaining in the EBS (about 68% of the initial inventory including ingrowth). Diffusion from the corrosion products domain to the invert is constrained by the small diffusive area presented by the stress corrosion cracks. Consequently, dissolved concentrations in the invert (Figure 1.2-15) are small compared to the dissolved concentrations in the waste form domain (Figure 1.2-13) or in the corrosion products domain (Figure 1.2-14). The release rates from the corrosion products domain and from the invert are nearly identical (Figure 1.2-12), indicating that most of the ^{237}Np mass that reaches the invert is transported out of the EBS and that the mass retained in the invert, predominantly sorbed to the crushed tuff (Figure 1.2-15), is not significant relative to the total mass of ^{237}Np in the EBS. Over 1,000,000 years, the cumulative release of ^{237}Np from the EBS from commercial SNF waste packages in the seeping environment is about 120 g; 99.5% moves out of the EBS by advection and 0.5% moves out of the EBS by diffusion (Figure 1.2-12).

Figures 1.2-16 through 1.2-19 show the movement and retention of ^{237}Np mass in the EBS from commercial SNF waste packages in the non-seeping environment. The magnitudes of release rates (g/yr) and mass in place (g) are less than in Figures 1.2-12 through 1.2-15 because there are fewer waste packages in the non-seeping environment. Except for releases from the invert (Figure 1.2-16), movement of ^{237}Np in the non-seeping environment is qualitatively similar to movement in the seeping environment. Because of the absence of seepage, approximately 70% of the ^{237}Np mass that moves through the invert is released from the EBS by diffusion (Figure 1.2-16) and about 30% of ^{237}Np is released from the EBS by advection (from imbibition). As in the seeping environment, the cumulative release of ^{237}Np from the EBS over 1,000,000 years is minimal; most of the remaining ^{237}Np mass is sorbed to the stationary corrosion products (Figure 1.2-23).

Figures 1.2-20 through 1.2-24 show the movement and retention of ^{237}Np mass in the EBS from codisposal waste packages in seeping environments. There are no releases of ^{237}Np from codisposal waste packages prior to the first waste package failure at 304,000 years. Due to the relatively slower rate of degradation of HLW (compared to commercial SNF), at 1,000,000 years, approximately 8% of the ^{237}Np mass from the initial inventory in codisposal waste packages or produced by radioactive decay is still within undegraded waste forms. Figures 1.2-21 and 1.2-22 provide the additional detail of release rates from each waste form domain (cell 1a and cell 1b) in the codisposal waste packages. Qualitatively, the only differences between releases and masses in place for codisposal waste packages as compared to commercial SNF waste packages are (1) the small amount of backward diffusion from the DOE SNF waste form domain (cell 1b) to the HLW waste form domain (cell 1a) due to the instantaneous degradation of DOE SNF (Figure 1.2-20), and (2) the very small mass of ^{237}Np that is present in codisposal waste packages as reversibly sorbed to mobile colloids (Figures 1.2-21 through 1.2-24).

Figures 1.2-25 through 1.2-29 show the movement and retention of ^{237}Np mass in the EBS from codisposal waste packages in the non-seeping environment. The magnitudes of release rates (g/yr) and mass in place (g) are less than in Figures 1.2-20 through 1.2-24 because there are fewer waste packages in the non-seeping environment. Except for releases from the invert (Figure 1.2-25), movement of ^{237}Np in the non-seeping environment is qualitatively similar to movement in the seeping environment.

1.2.3 Plutonium

The movement and retention of ^{242}Pu in the EBS model domains for the 1,000,000-year single realization of the nominal modeling case are described using the following plots:

- Time histories of radionuclide flux (both advective and diffusive) out of each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages)

- Time histories of mass in place (unexposed mass and/or dissolved, precipitated, sorbed, and irreversibly attached colloidal mass) in each of the EBS domains (3 domains for commercial SNF waste packages, 4 domains for codisposal waste packages).

Sorbed mass is divided into mass reversibly sorbed onto stationary materials (corrosion products in the corrosion products domain, crushed tuff in the invert) and mass reversibly sorbed onto mobile colloids. Mass irreversibly attached to colloids is divided into suspended mass (i.e., mobile) and settled mass (i.e., immobile) for each of the two types of colloids (waste form and FeO_x).

Figures 1.2-30 through 1.2-36 show the movement and retention of ^{242}Pu mass in the EBS from commercial SNF waste packages in the seeping environment. After failure of the first waste package in percolation subregion 3 (at 304,000 years), precipitated ^{242}Pu is present in the waste form domain until 800,000 years (Figure 1.2-34) and in the corrosion products domain out to 1,000,000 years (Figure 1.2-35). The lack of advective flow into the failed waste packages results in relatively low volumes of adsorbed water inside the failed waste packages. Within each failed waste package, the precipitated ^{242}Pu mass re-dissolves, maintaining dissolved concentrations at the solubility limit for some period of time after waste package failure. However, the rate of waste package failure outpaces the re-dissolution of precipitated ^{242}Pu until about 800,000 years in the waste form domain and out to 1,000,000 years in the corrosion products domain, resulting in the prolonged precipitated ^{242}Pu mass curves in Figures 1.2-34 and 1.2-35. This behavior is different than for ^{237}Np because ^{242}Pu has a lower solubility limit than ^{237}Np in this realization. At 1,000,000 years, approximately 1% of the initial ^{242}Pu mass inventory remains in undegraded waste forms. Additionally, as noted in Section 1.1, about 84% of the initial inventory decays over 1,000,000 years.

After failure of the first waste package in percolation subregion 3, transport is by diffusion from the waste form domain through the corrosion products domain to the invert (Figure 1.2-30). As in the igneous intrusion modeling case, most of the ^{242}Pu mass that enters the corrosion products domain sorbs to the stationary corrosion products (Figure 1.2-35). At 1,000,000 years, ^{242}Pu sorbed to the stationary corrosion products is the most significant ^{242}Pu mass remaining in the EBS (about 15% of the initial inventory). Diffusion from the corrosion products domain to the invert is constrained by the small diffusive area presented by the stress corrosion cracks. Consequently, dissolved concentrations in the invert (Figure 1.2-36) are small compared to the dissolved concentrations in the waste form domain (Figure 1.2-34) or in the corrosion products domain (Figure 1.2-35). The release rates from the corrosion products domain and from the invert are nearly identical (Figure 1.2-30), indicating that most of the ^{242}Pu mass that reaches the invert is transported out of the EBS and that the mass retained in the invert, predominantly sorbed to the crushed tuff (Figure 1.2-36), is not significant relative to the total mass of ^{242}Pu in the EBS. Over 1,000,000 years, the cumulative release of ^{242}Pu from the EBS from commercial SNF waste packages in the seeping environment is about 79 g; 99% is released from the EBS by advection and 1% is released from the EBS by diffusion.

Due to the lack of advective flow through the failed waste packages, colloid suspensions (waste form and FeO_x) remain unstable within the waste form and corrosion products domains. Consequently, release rates of ^{242}Pu mass irreversibly attached to either waste form or FeO_x colloids remain less than 10^{-7} g/yr (Figures 1.2-32 and 1.2-33). Due to the use of minimum concentrations of colloids when colloids are unstable (SAR Section 2.3.7.11.3, p. 2.3.7-65) and numerical methods used to solve the transport equations, a relatively small mass (less than 0.04 g) of ^{242}Pu irreversibly attached to either waste form or FeO_x colloids is present in the corrosion products domain (Figure 1.2-35) and, due to backward diffusion, in the waste form domain (Figure 1.2-34).

Figures 1.2-37 through 1.2-43 show the movement and retention of ^{242}Pu mass in the EBS from commercial SNF waste packages in the non-seeping environment. The magnitudes of release rates (g/yr) and mass in place (g) are less than in Figures 1.2-30 through 1.2-36 because there are fewer waste packages in the non-seeping environment. Except for releases from the invert (Figure 1.2-37), movement of ^{242}Pu in the non-seeping environment is qualitatively similar to movement in the seeping environment. Because of the absence of seepage, approximately 85% of the ^{242}Pu mass that moves through the invert is released from the EBS by diffusion (Figure 1.2-37) and about 15% of ^{242}Pu is released from the EBS by advection (from imbibition).

As in the seeping environment, the cumulative release of ^{242}Pu from the EBS over 1,000,000 years is minimal; most of the remaining ^{242}Pu mass is sorbed to the stationary corrosion products (Figure 1.2-42).

Figures 1.2-44 through 1.2-51 show the movement and retention of ^{242}Pu mass in the EBS from codisposal waste packages in seeping environments. There are no releases of ^{242}Pu from codisposal waste packages prior to the first waste package failure at 304,000 years. Due to the relatively slower rate of degradation of the HLW waste form, release rates from the HLW waste form domain (cell 1a) increase smoothly as additional waste packages fail and additional waste forms are subject to degradation (Figure 1.2-44). In contrast, the assumption of instantaneous degradation of DOE SNF results in a sequence of spikes in the release rates from the DOE SNF waste form domain (cell 1b) as additional waste packages fail (Figure 1.2-44). Releases are primarily by diffusion from the waste form domains through the corrosion products domain to the invert. As with commercial SNF waste packages, most of the ^{242}Pu mass that enters the corrosion products domain sorbs to the stationary corrosion products (Figure 1.2-50) and most of the ^{242}Pu mass that reaches the invert is transported out of the EBS by advection (Figure 1.2-44).

In the codisposal waste packages, waste form colloid suspensions are stable within the waste form domains (cells 1a and 1b) and corrosion products domain, with concentrations of ^{242}Pu mass irreversibly attached to waste form colloids equaling or exceeding dissolved concentrations. However, the much slower rate of diffusion of colloids through the stress corrosion cracks in the waste package outer barrier leads to relatively little ^{242}Pu mass (less than 10^{-6} g) irreversibly attached to waste form colloids in the invert. When large numbers of waste packages fail (at 304,000 years, 500,000 years, and 700,000 years), quantities of waste form colloids may be rapidly formed during degradation of the HLW. In this single realization, the colloid masses exceed the concentration limit for such colloids, and thus are modeled as precipitating from solution (shown on Figure 1.2-48 as settled irreversible waste form colloids). These colloid masses re-dissolve as the adsorbed water volumes increase.

In contrast, FeO_x colloids are unstable throughout the EBS model domains and thus maintain minimum concentrations (SAR Section 2.3.7.11.3, p. 2.3.7-65). However, due to the numerical methods used to solve the transport equations, a relatively small mass of ^{242}Pu irreversibly attached to FeO_x colloids appears in the corrosion products domain (Figure 1.2-50) and, due to backward diffusion, in the HLW waste form domain (Figure 1.2-48).

Figures 1.2-52 through 1.2-59 show the movement and retention of ^{242}Pu mass in the EBS from codisposal waste packages in the non-seeping environment. The magnitudes of release rates (g/yr) and mass in place (g) are less than in Figures 1.2-44 through 1.2-51 because there are fewer waste packages in the non-seeping environment. Except for releases from the invert (Figure 1.2-52), movement of ^{242}Pu in the non-seeping environment is qualitatively similar to movement in the seeping environment.

1.3 SUMMARY

This response provides additional information for (1) a single realization of the 1,000,000-year igneous intrusion modeling case, with a single igneous intrusion event at 10,000 years, and (2) a single realization of the 1,000,000-year nominal modeling case. The information supplements related information in the SAR Section 2.4.2.2.3.1 and *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008, Sections 7.7.1.3[a] and 7.7.1.5[a]).

For each single realization, a general description of the movement and retention of three radionuclides (^{129}I, ^{237}Np, and ^{242}Pu, including ^{242}Pu irreversibly attached to colloids) is supported by plots of time histories of radionuclide mass flux between EBS model domains and radionuclide mass in place in EBS model domains.

The two single realizations are representative of typical EBS releases for the respective modeling cases and illustrate the key processes affecting the movement and retention of key radionuclides in the EBS.

2. COMMITMENTS TO NRC

None.

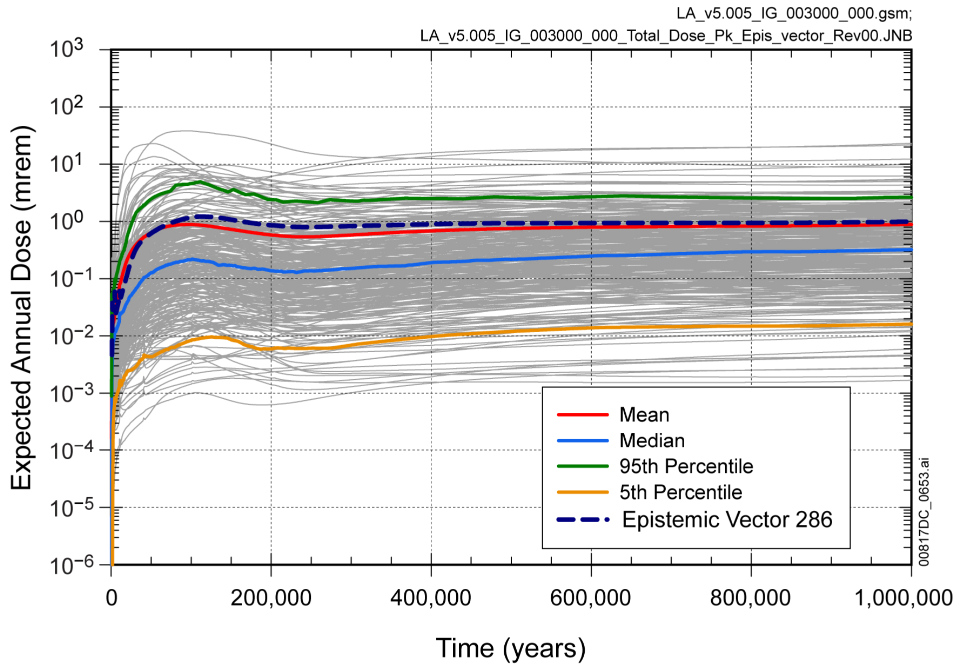
3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

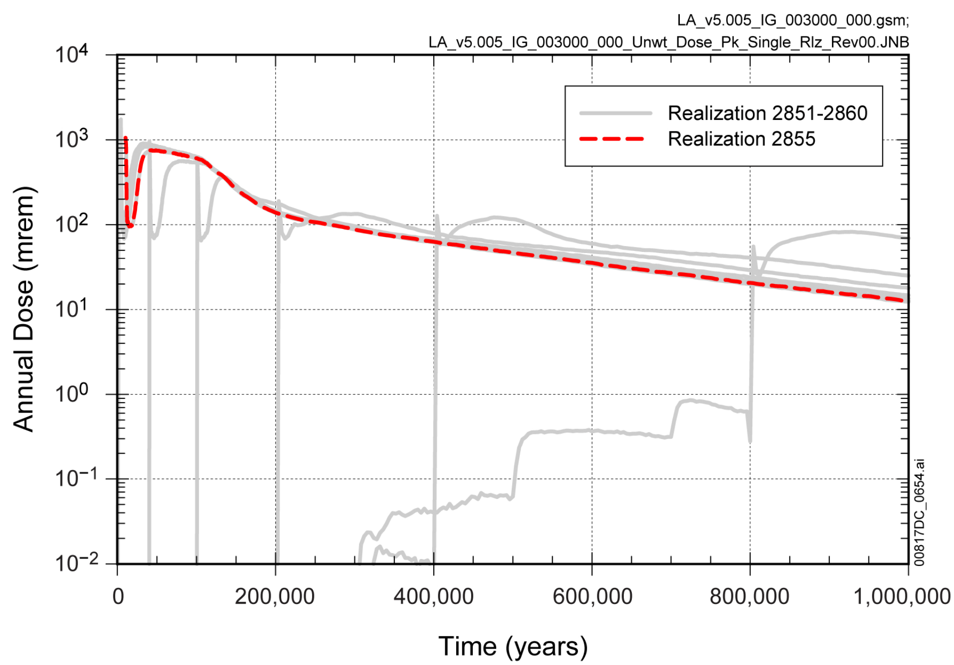
SNL (Sandia National Laboratories) 2008. *Total System Performance Assessment Model /Analysis for the License Application.* MDL-WIS-PA-000005 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080312.0001.

NOTE: In the series of figures presented below, the following abbreviations are sometimes used for convenience: CDSP = codisposal; CP = corrosion products; CSNF = commercial SNF; DSNF = DOE SNF; Irrev = irreversibly (sorbed); Susp = suspended; and WF = waste form.



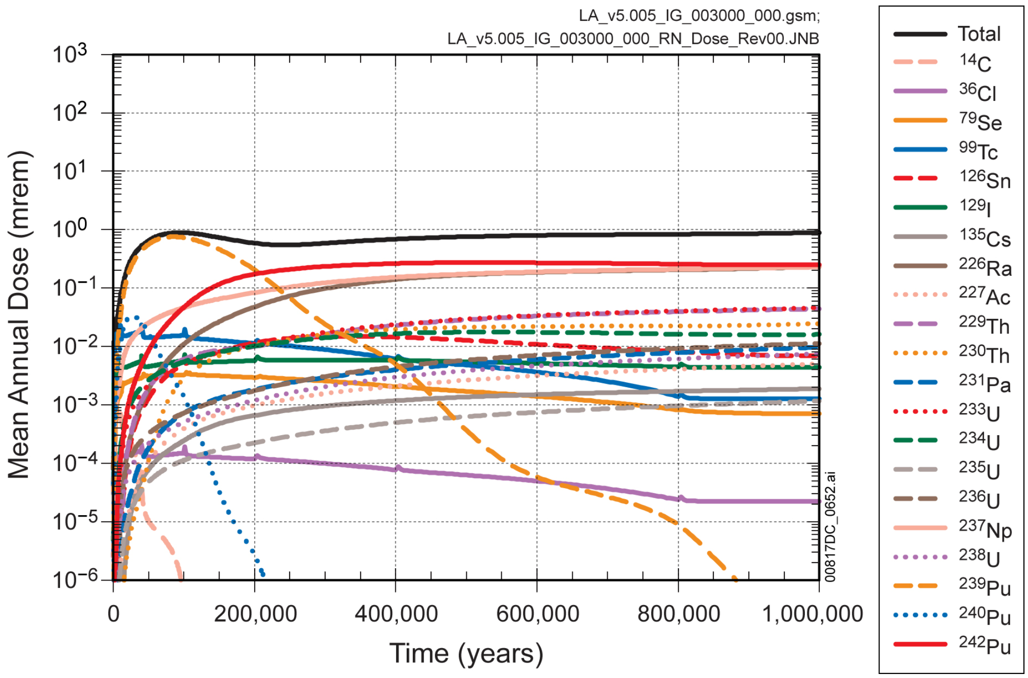
Source: SNL 2008, Figure 7.71-37[a].

Figure 1.1-1. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 286 for the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



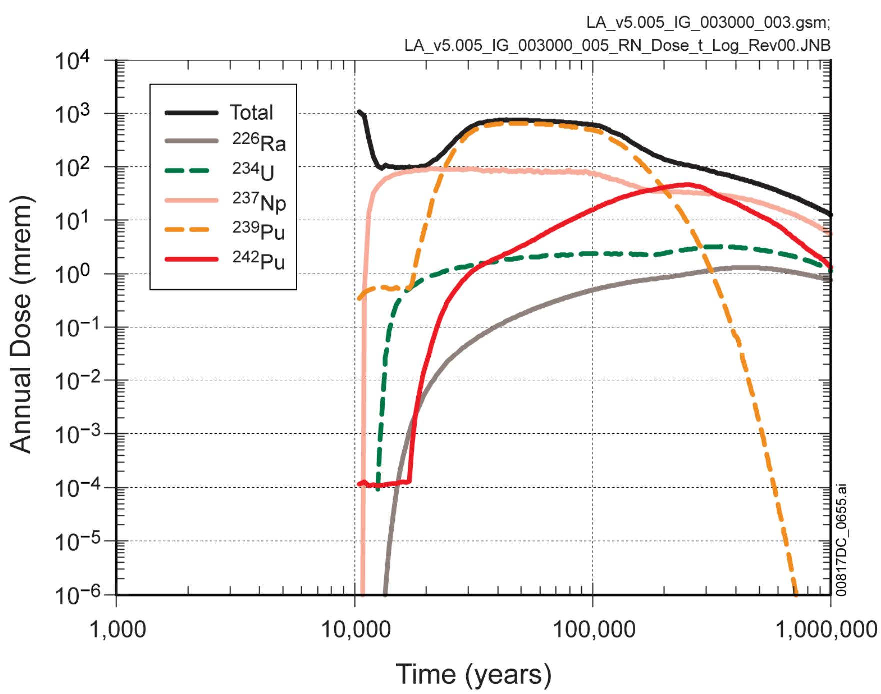
Source: SNL 2008, Figure 7.71-38[a].

Figure 1.1-2. Annual Dose for Realizations 2851 to 2860 (representing Epistemic Uncertainty Vector 286) along with Selected Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



Source: SNL 2008, Figure 7.71-36[a].

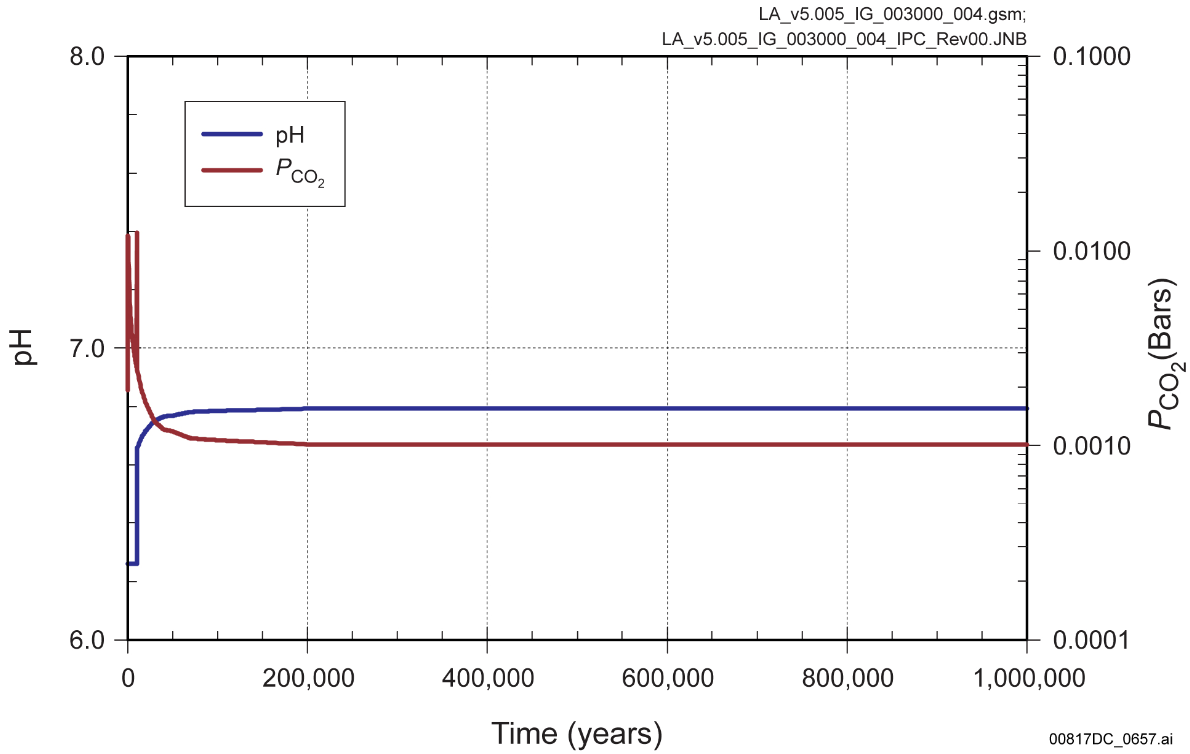
Figure 1.1-3. Major Radionuclide Contributors to Mean Annual Dose for the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



NOTE: Contributions to the total from ^{99}Tc and ^{129}I are not shown.

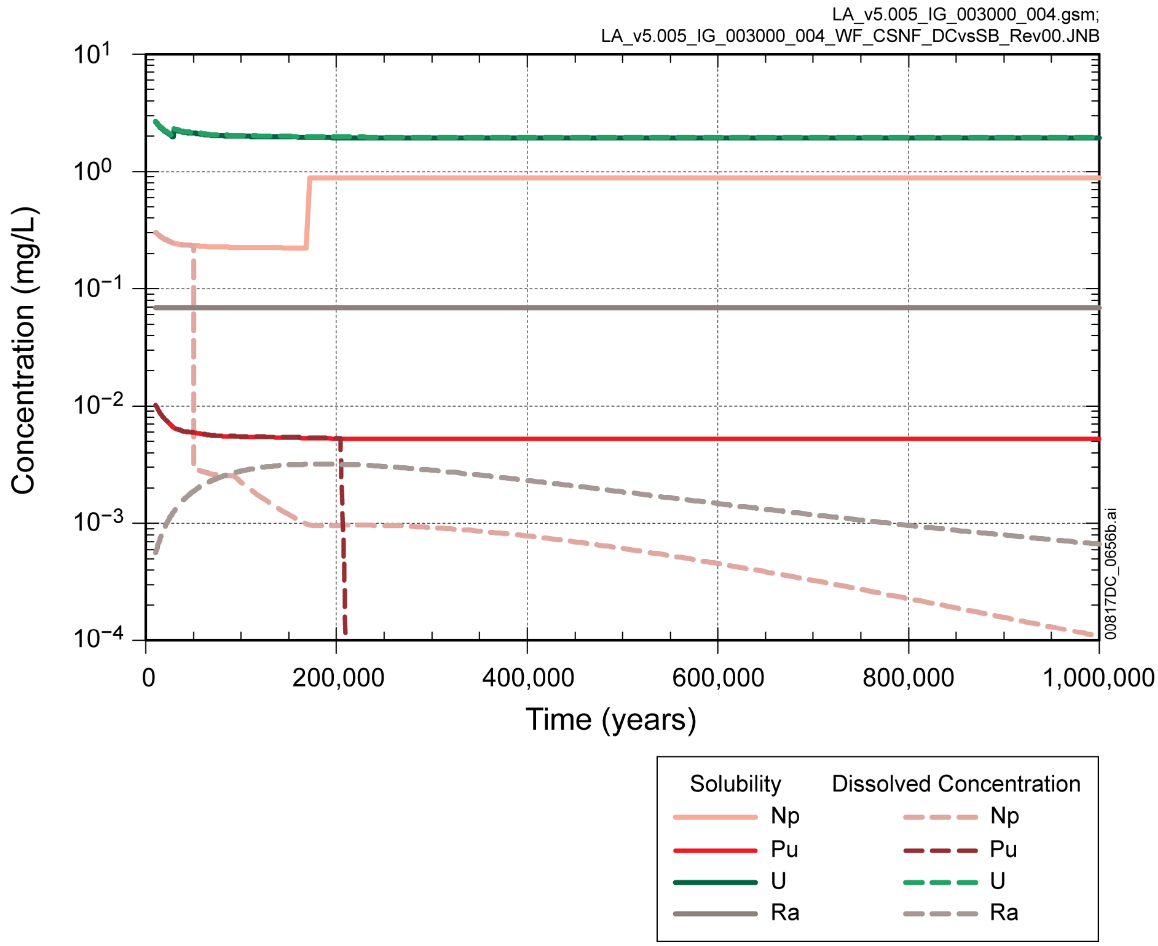
Source: SNL 2008, Figure 7.71-39[a].

Figure 1.1-4. Major Radionuclide Dose Contributors to Annual Dose for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



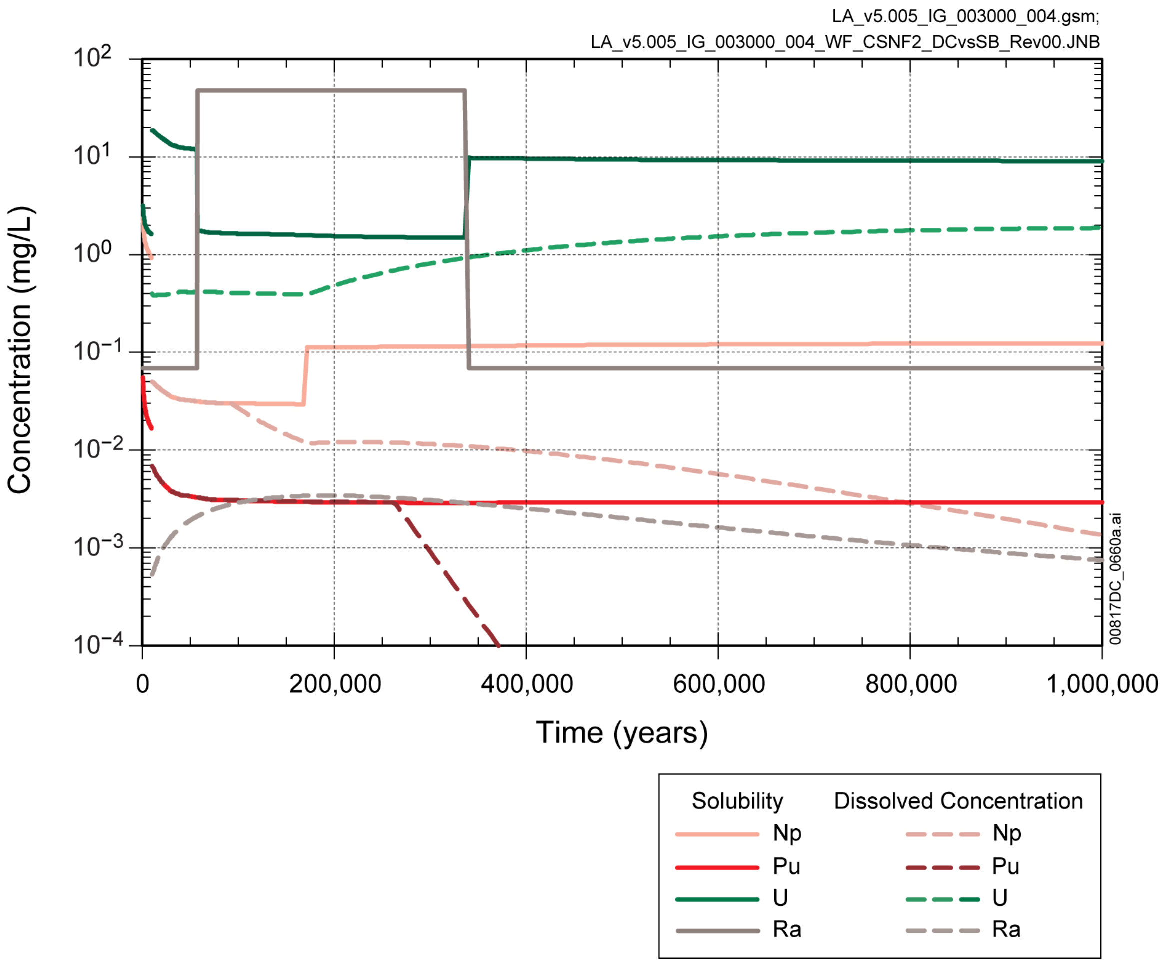
Source: SNL 2008, Figure 7.71-41[a].

Figure 1.1-5. In-Package pH and P_{CO_2} in the Commercial SNF Waste Form Domain in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



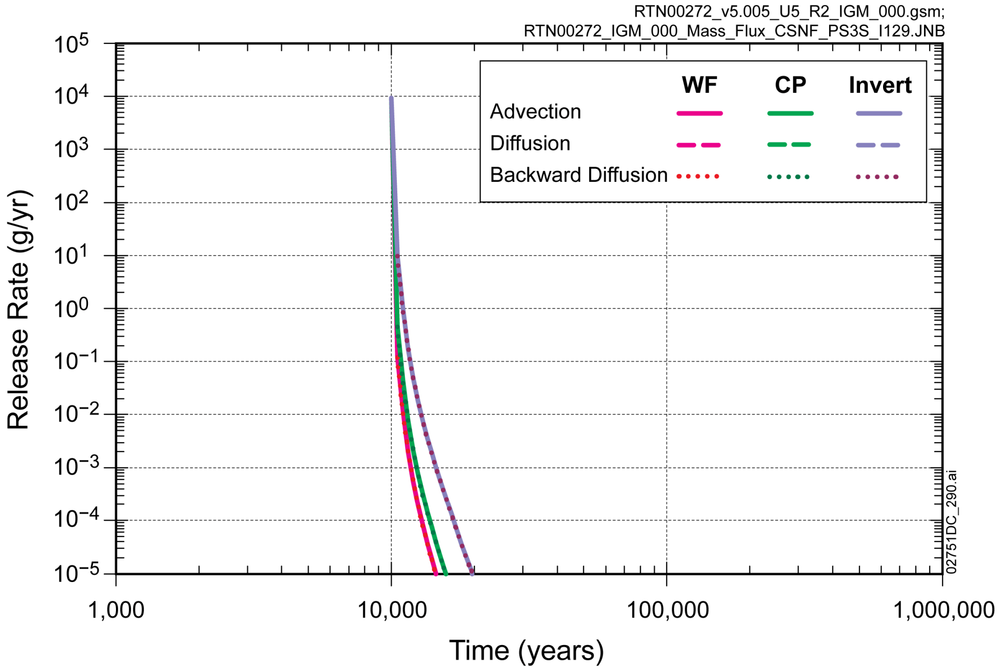
Source: SNL 2008, Figure 7.71-40[a].

Figure 1.1-6. Dissolved Concentrations and Solubility Limits of Neptunium, Plutonium, Uranium, and Radium in the Commercial SNF Waste Form Domain in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



Source: SNL 2008, Figure 7.71-44[a].

Figure 1.1-7. Total Dissolved Concentrations and Solubility Limits of Neptunium, Plutonium, Uranium, and Radium in the Corrosion Products Domain of Commercial SNF Waste Packages Located in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



NOTE: WF Advection overlays WF Backward Diffusion, CP Advection overlays CP Backward Diffusion, Invert Advection overlays Invert Backward Diffusion.

Figure 1.1-8. Release Rate of ^{129}I from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

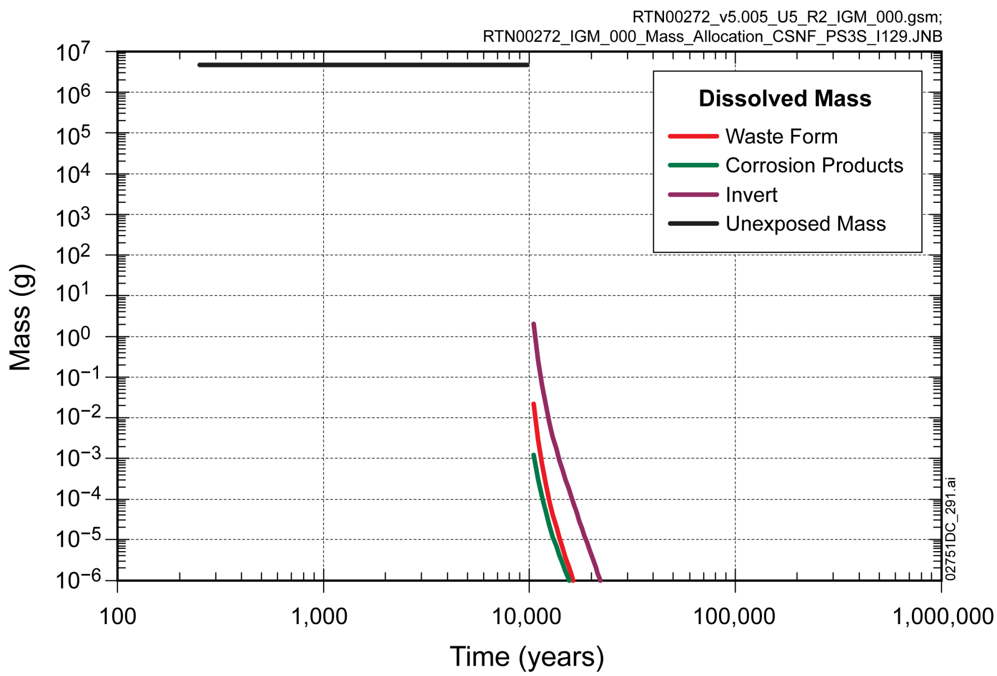
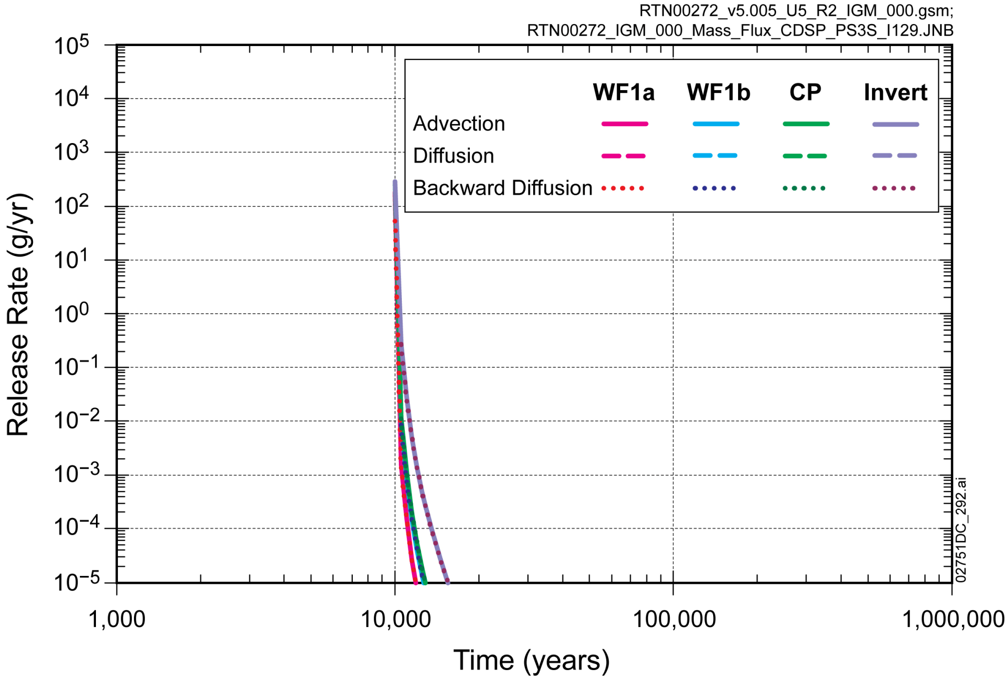


Figure 1.1-9. Mass of ^{129}I in Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



NOTE: WF1a Advection overlays WF1a Backward Diffusion, WF1b Advection overlays WF1b Backward Diffusion, CP Advection overlays CP Backward Diffusion, Invert Advection overlays Invert Backward Diffusion.

Figure 1.1-10. Release Rate of ^{129}I from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

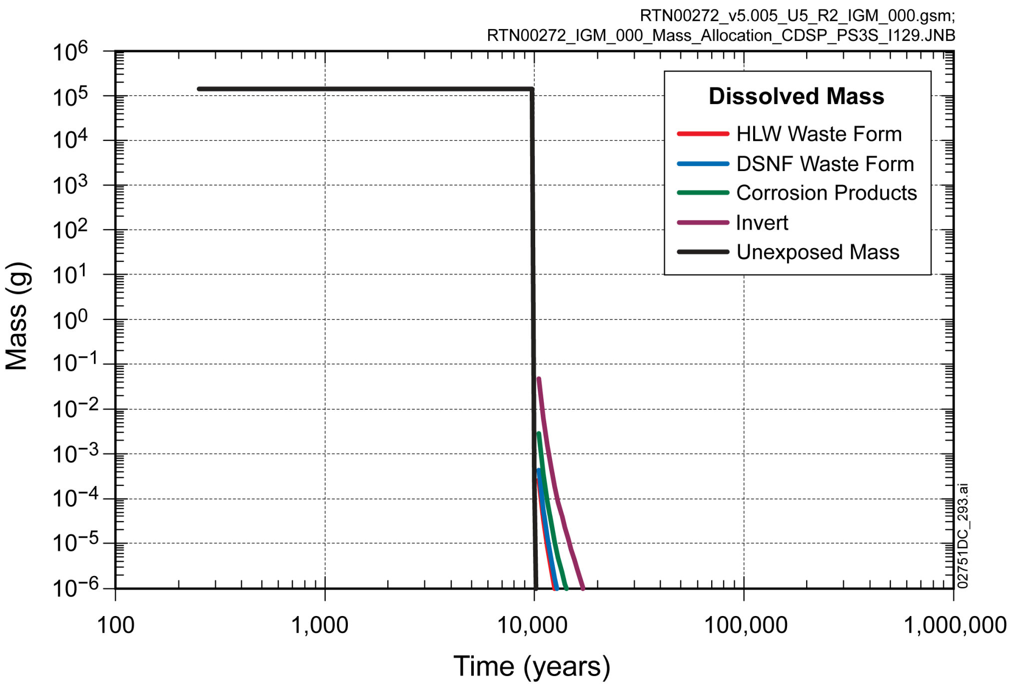
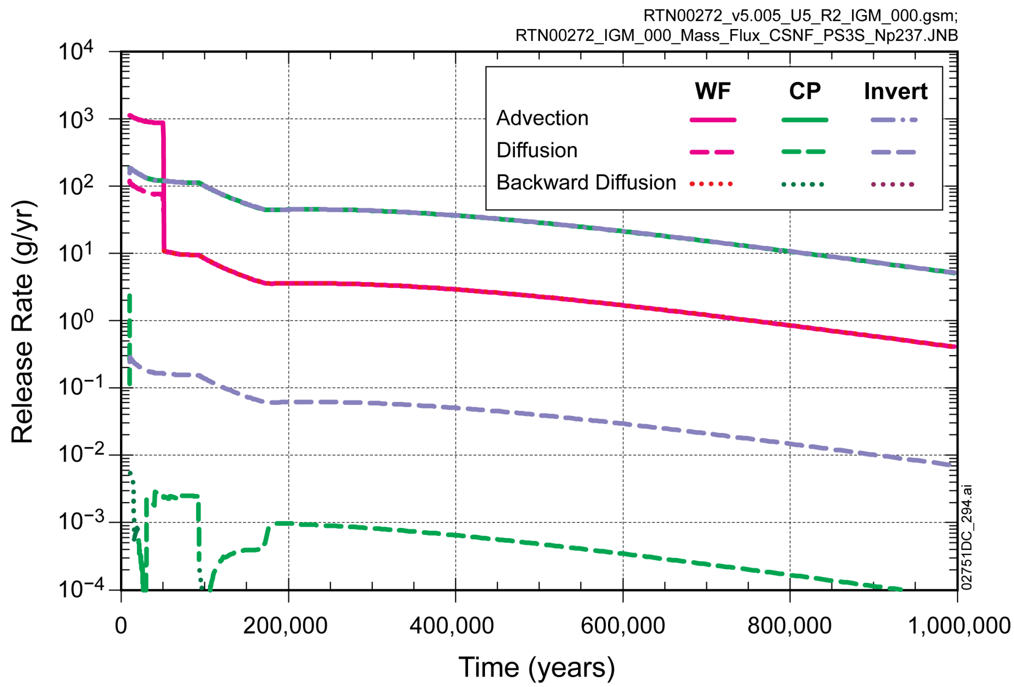


Figure 1.1-11. Mass of ^{129}I in Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



NOTE: WF Advection overlays WF1 Backward Diffusion (after 50,500 years), Invert Advection overlays CP Advection.

Figure 1.1-12. Release Rate of ^{237}Np from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

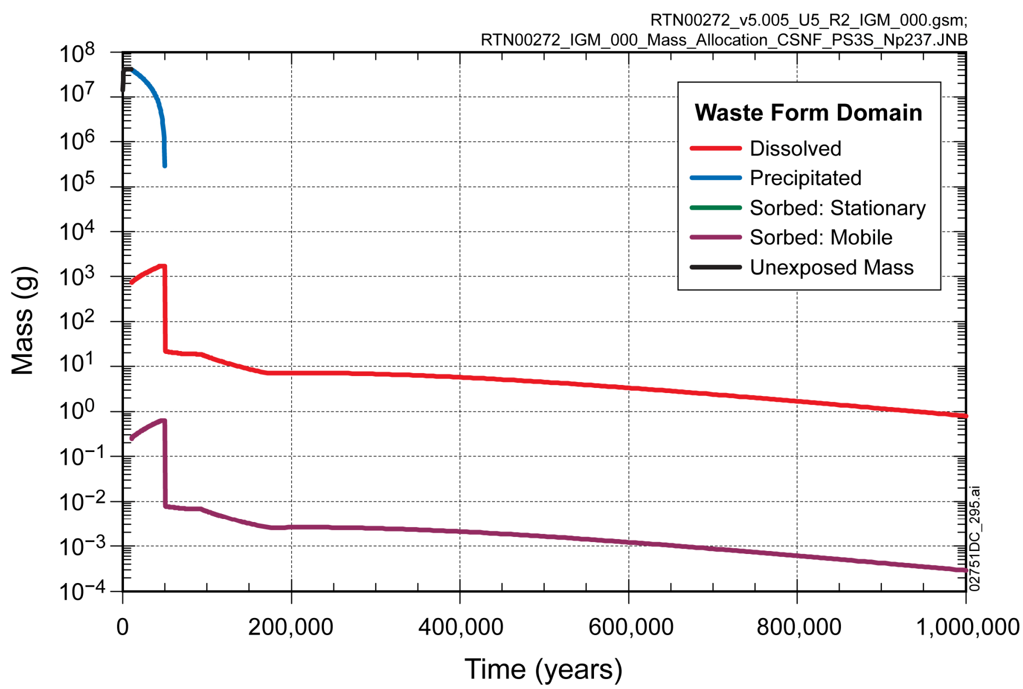


Figure 1.1-13. Mass of ^{237}Np in the Commercial SNF Waste Form Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

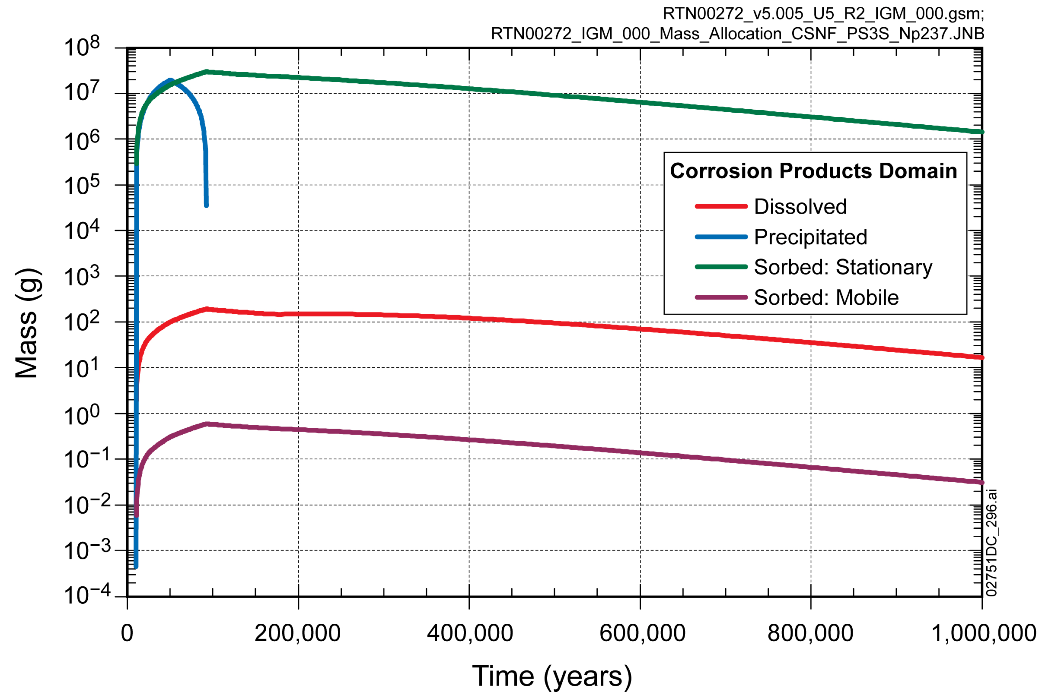


Figure 1.1-14. Mass of ^{237}Np in the Corrosion Products Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

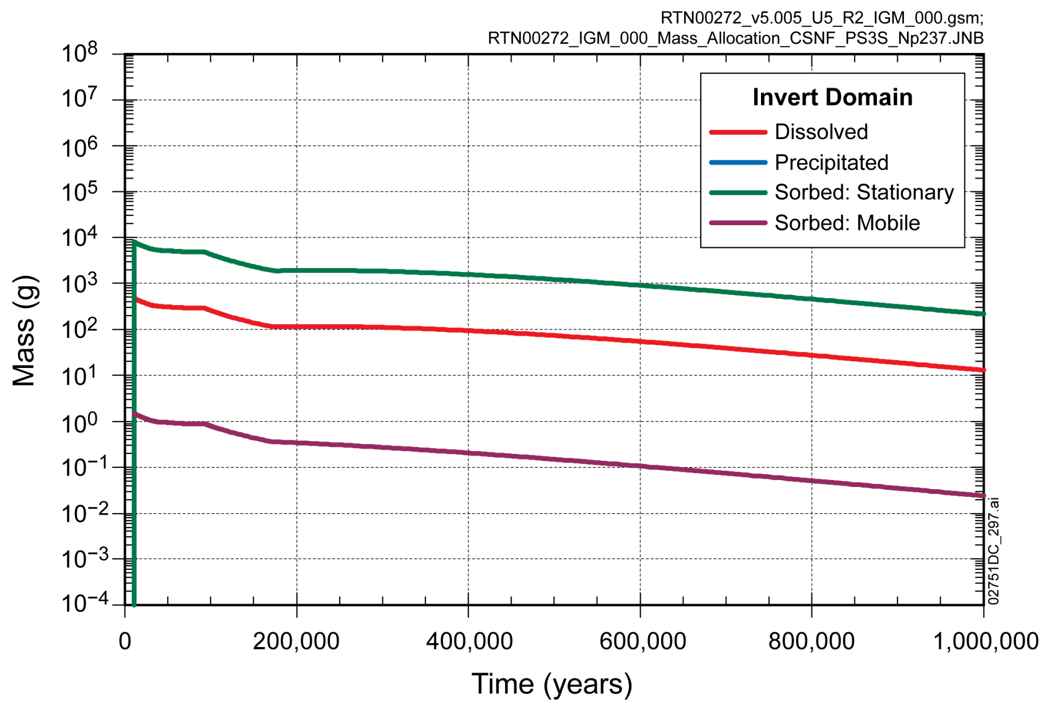
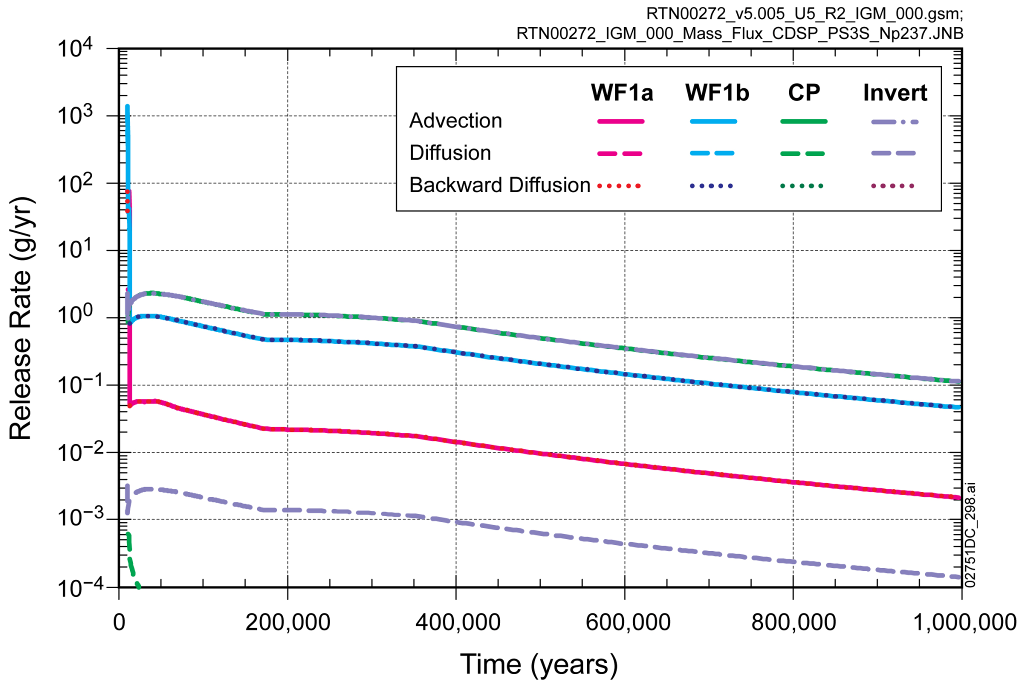


Figure 1.1-15. Mass of ^{237}Np in the Invert from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



NOTE: WF1a Advection overlays WF1a Backward Diffusion, WF1b Advection overlays WF1b Backward Diffusion, Invert Advection overlays CP Advection.

Figure 1.1-16. Release Rate of ^{237}Np from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

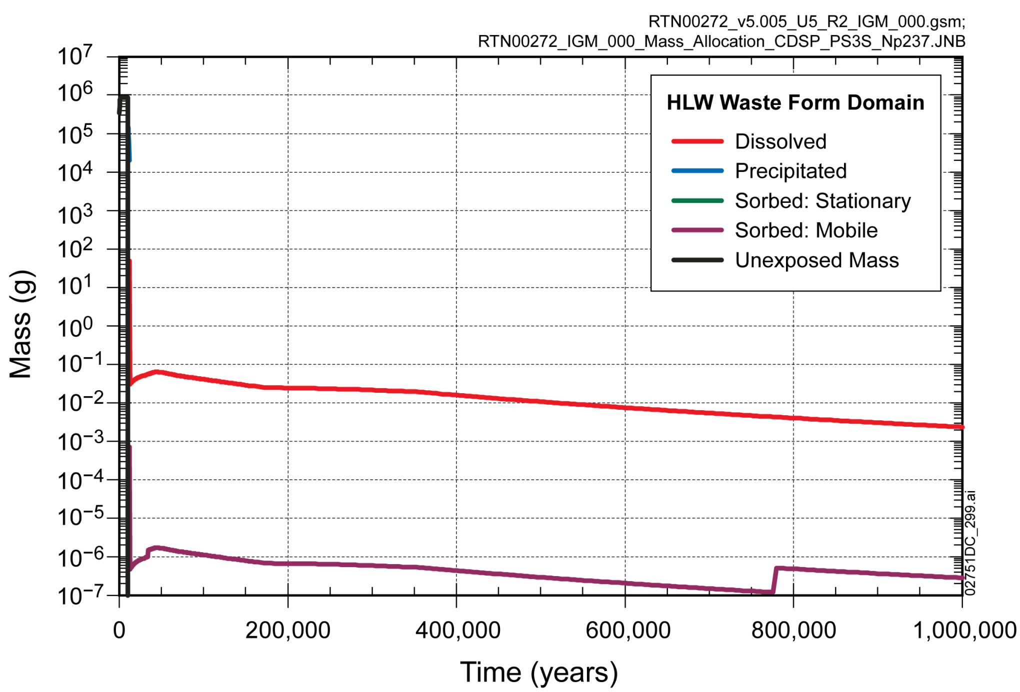


Figure 1.1-17. Mass of ^{237}Np in the HLW Waste Form Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

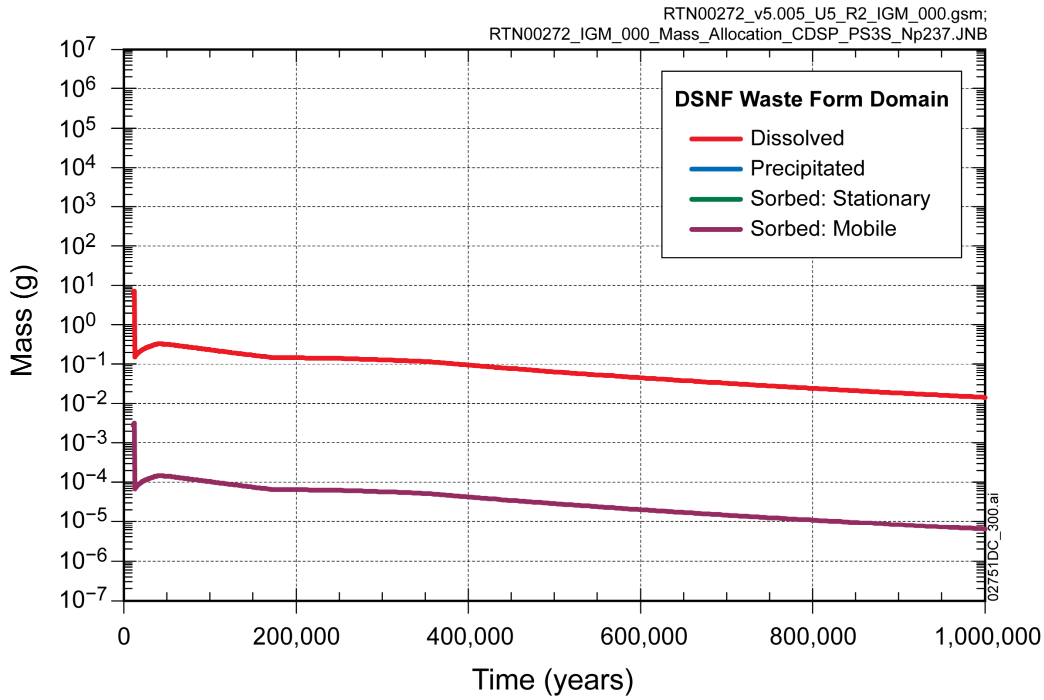


Figure 1.1-18. Mass of ^{237}Np in the DOE SNF Waste Form Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

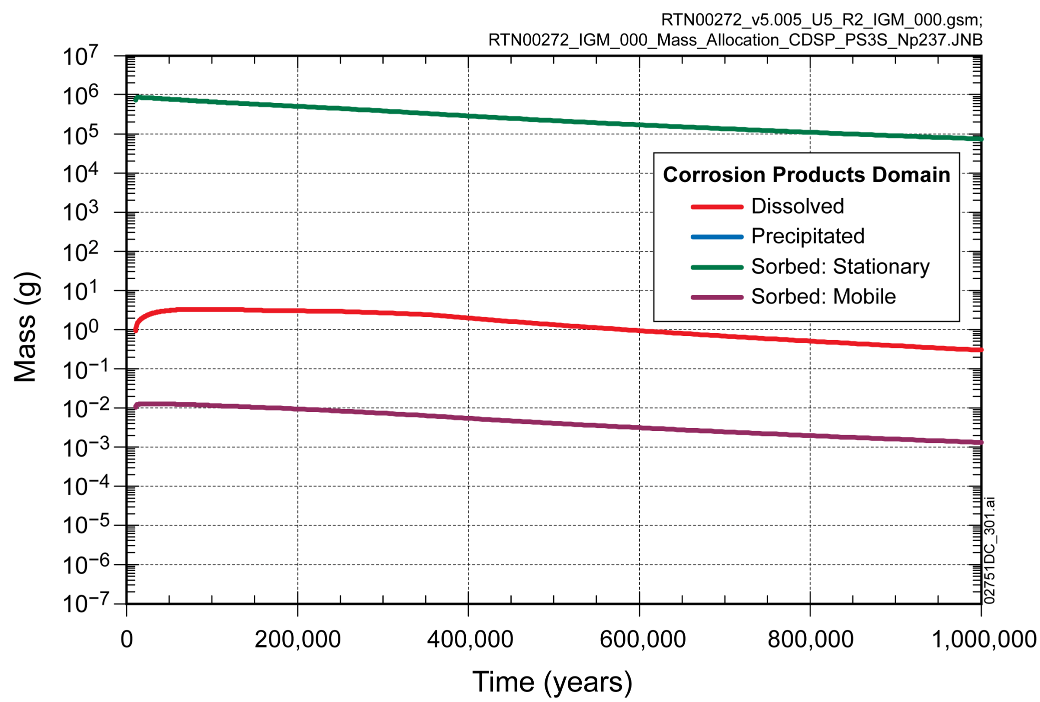


Figure 1.1-19. Mass of ^{237}Np in the Corrosion Products Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

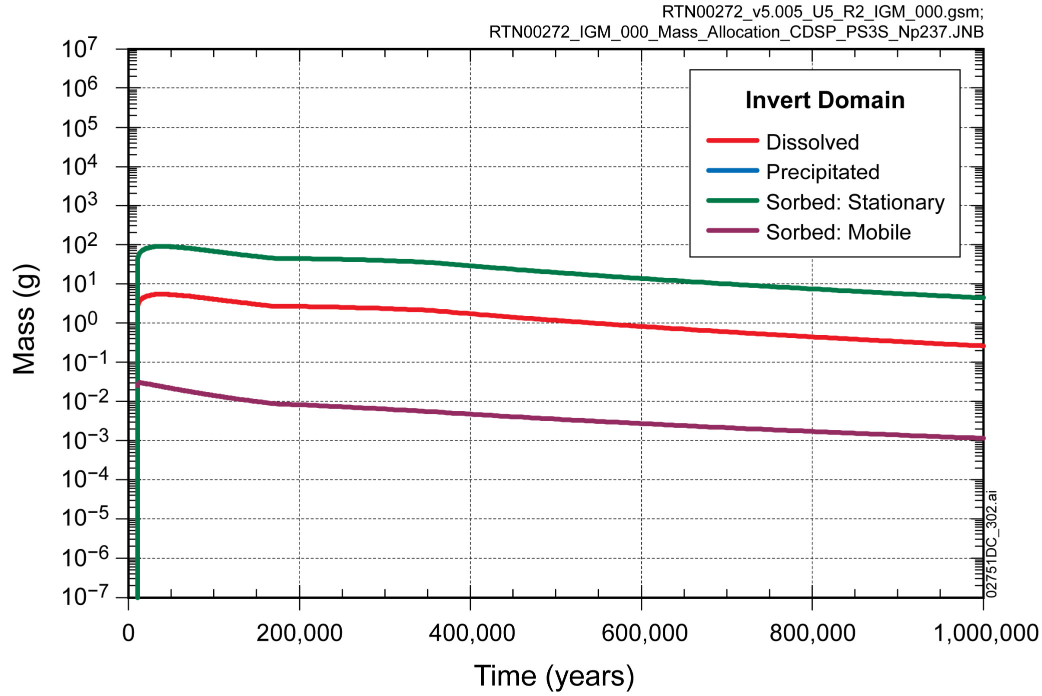
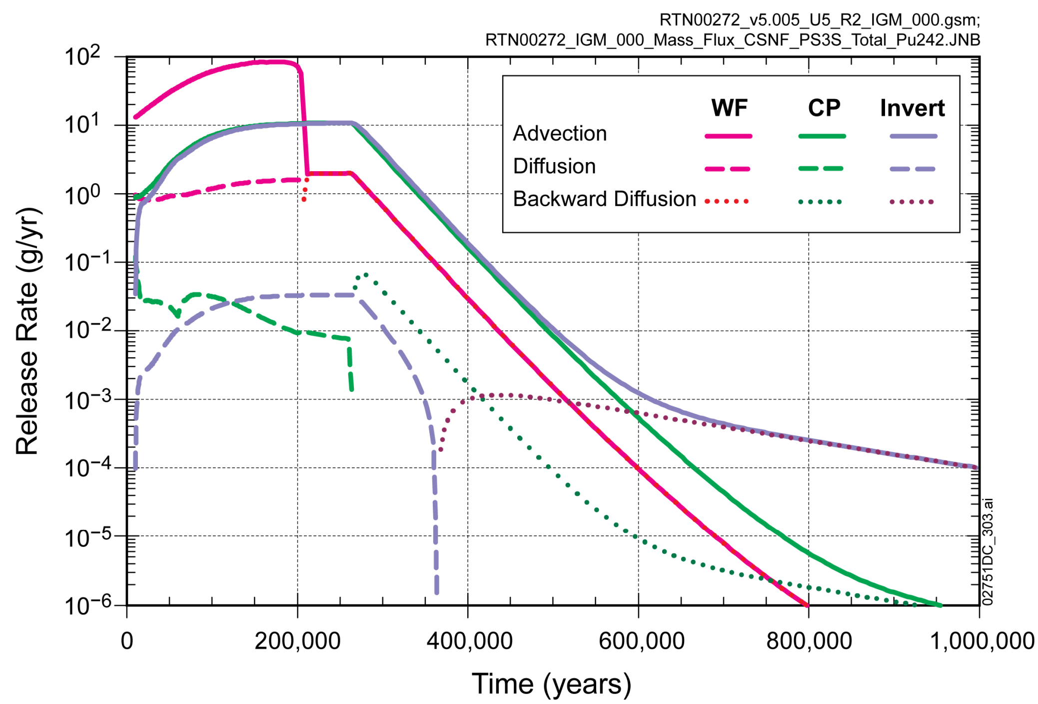


Figure 1.1-20. Mass of ^{237}Np in the Invert from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



NOTE: WF Advection overlays WF Backward Diffusion (after 204,000 years).

Figure 1.1-21. Release Rate of Total ^{242}Pu from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

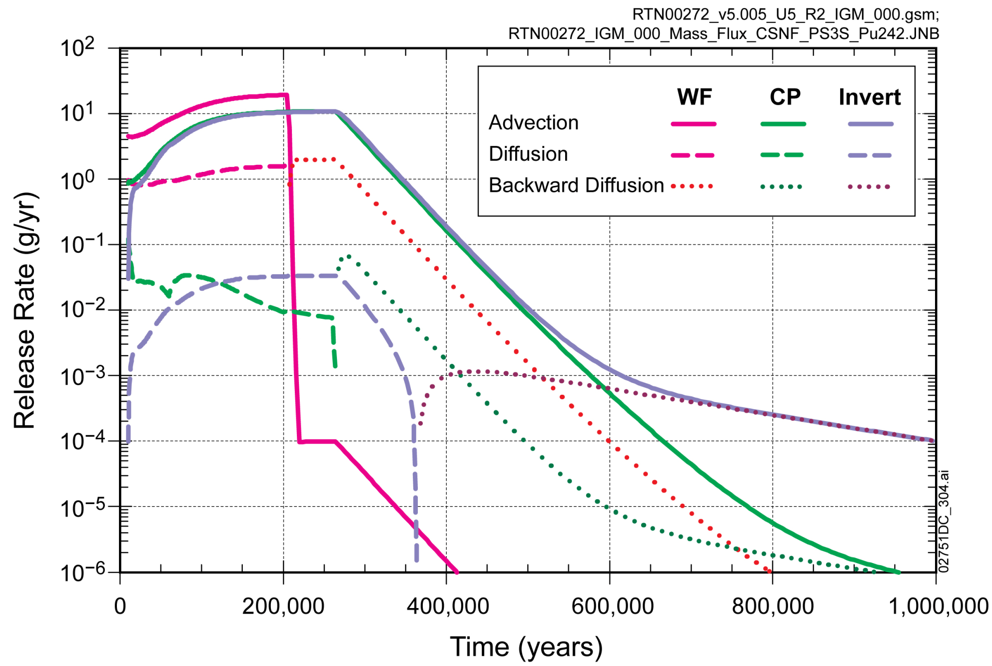
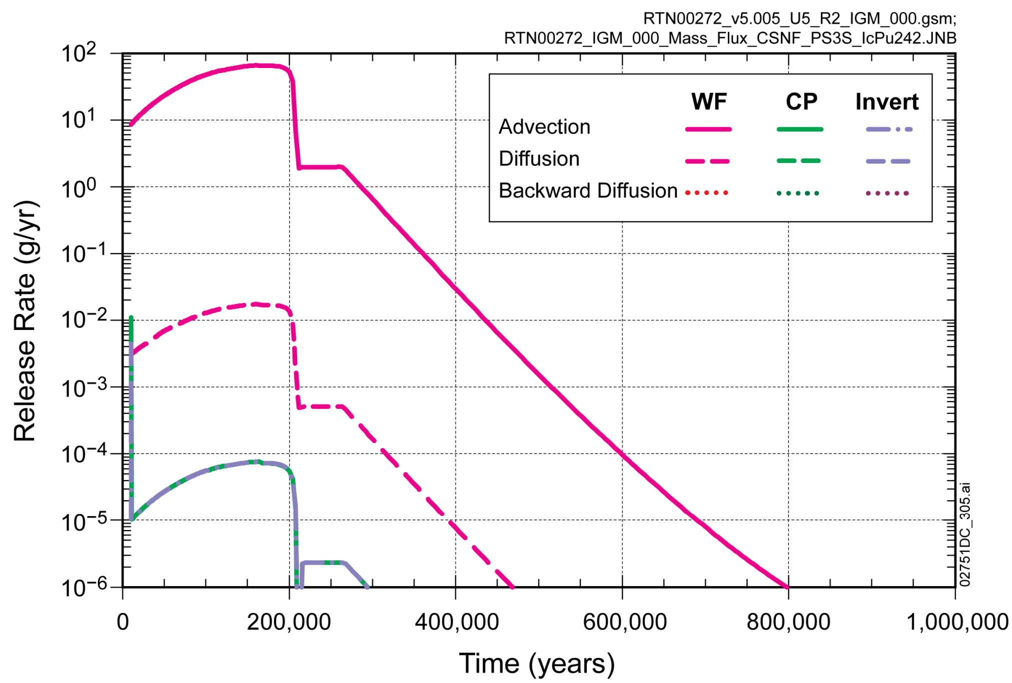
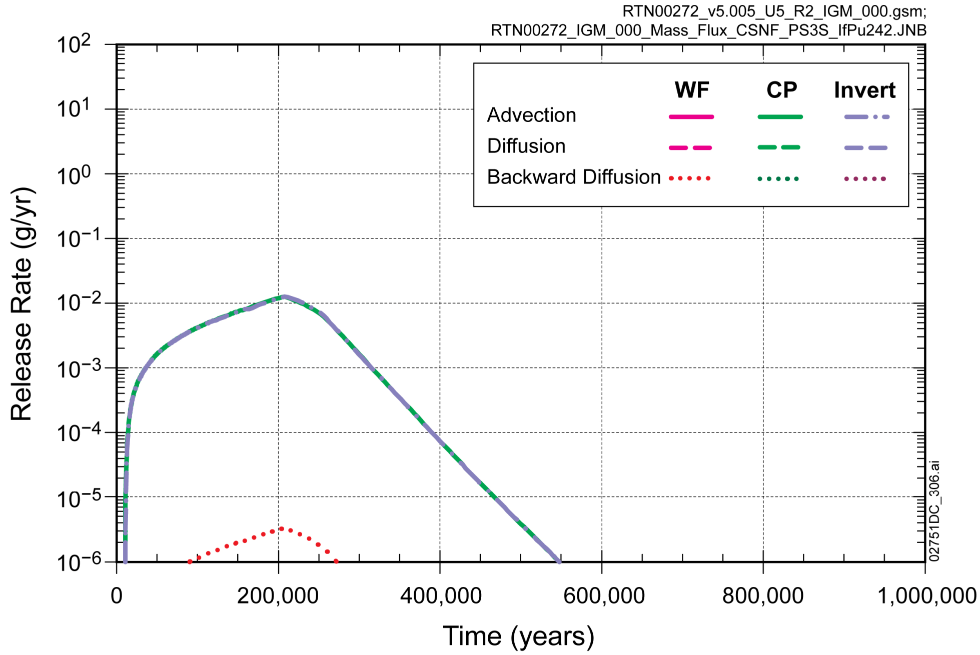


Figure 1.1-22. Release Rate of ^{242}Pu Dissolved and Reversibly Sorbed from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



NOTE: Invert Advection overlays CP Advection.

Figure 1.1-23. Release Rate of ^{242}Pu Irreversibly Attached to Waste Form (Ic) Colloids from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



NOTE: Invert Advection overlays CP Advection.

Figure 1.1-24. Release Rate of ^{242}Pu Irreversibly Attached to Iron Oxyhydroxide (If) Colloids from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

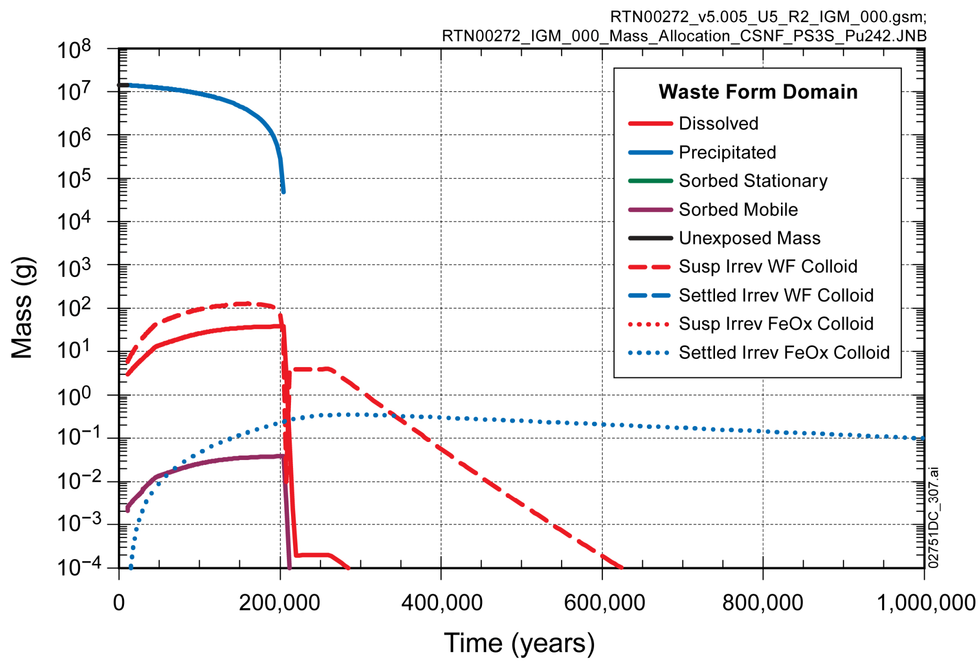


Figure 1.1-25. Mass of ^{242}Pu in the Commercial SNF Waste Form Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

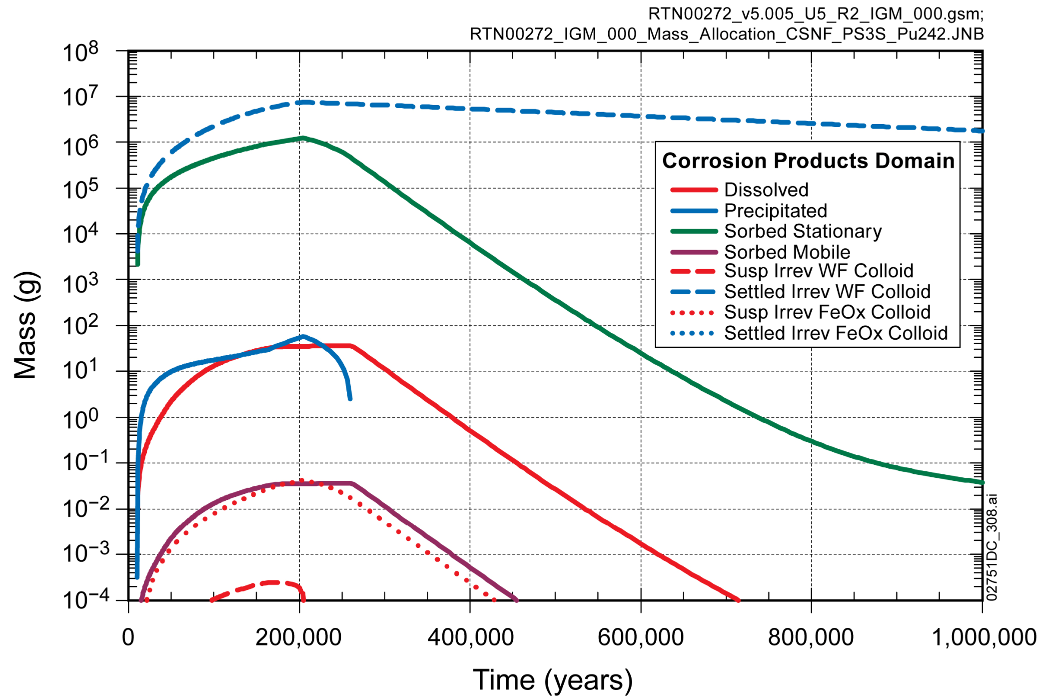


Figure 1.1-26. Mass of ^{242}Pu in the Corrosion Products Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

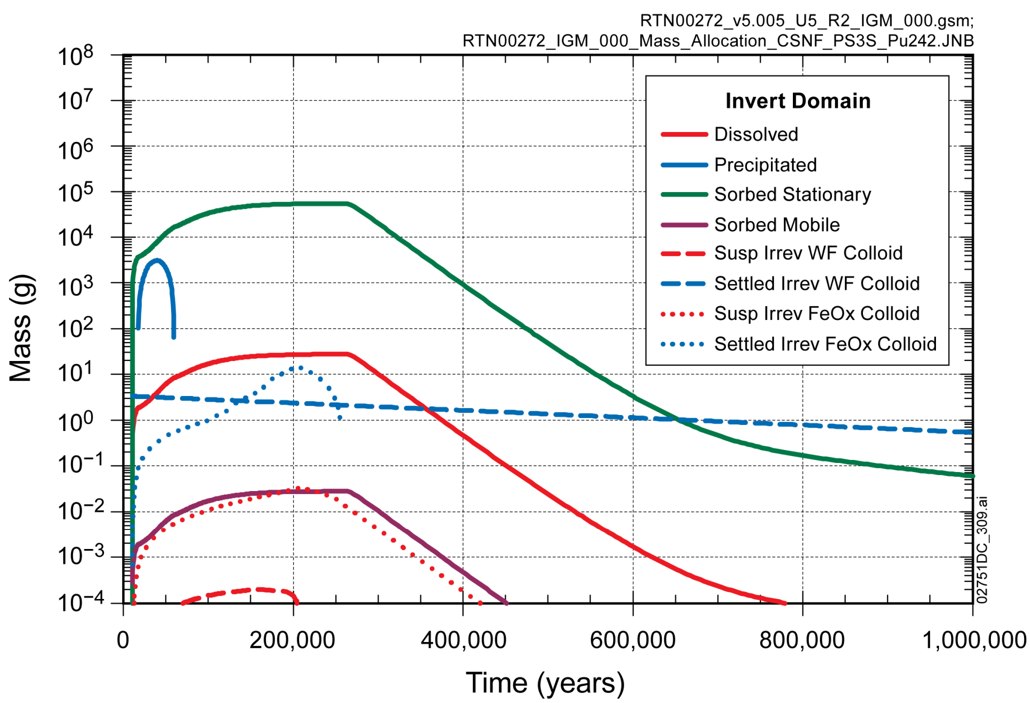
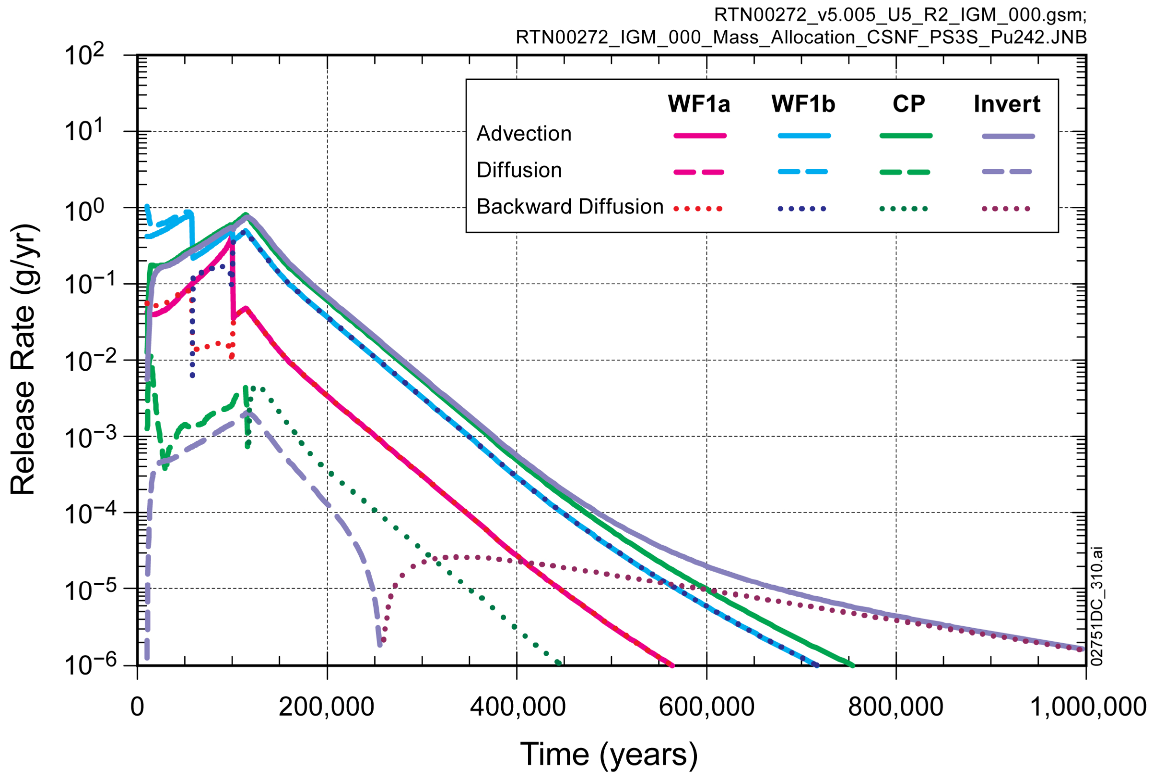
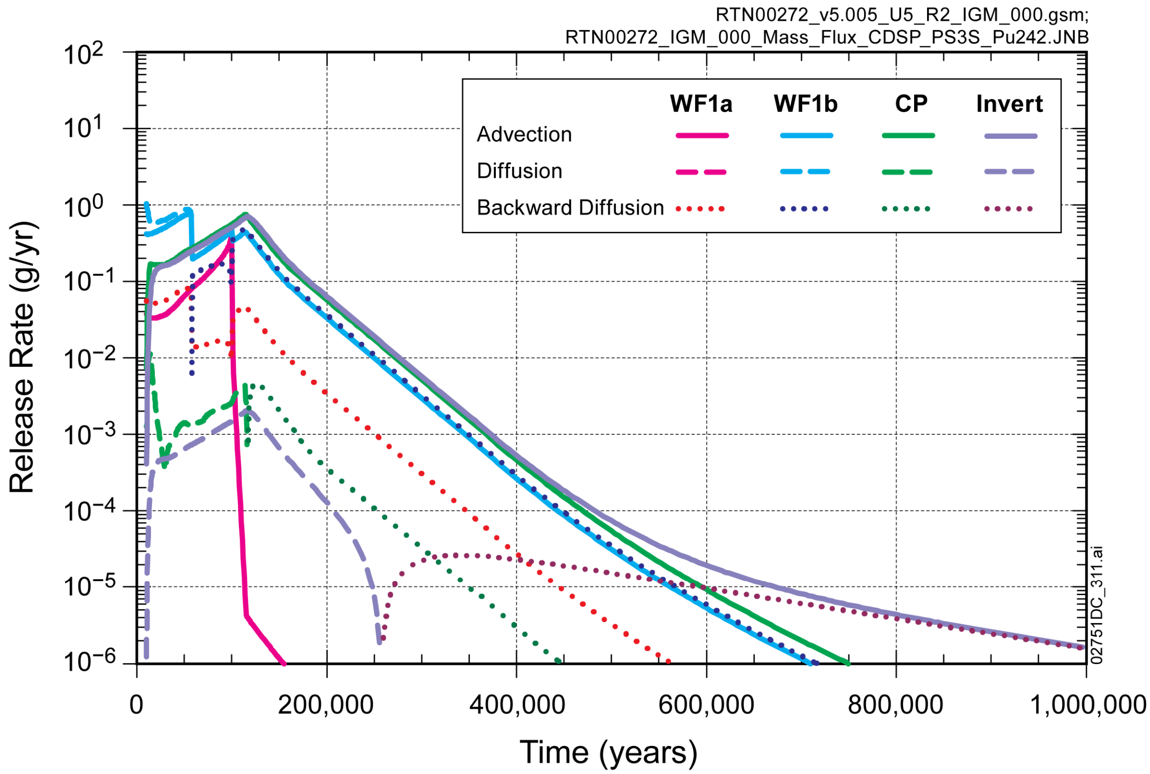


Figure 1.1-27. Mass of ^{242}Pu in the Invert from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



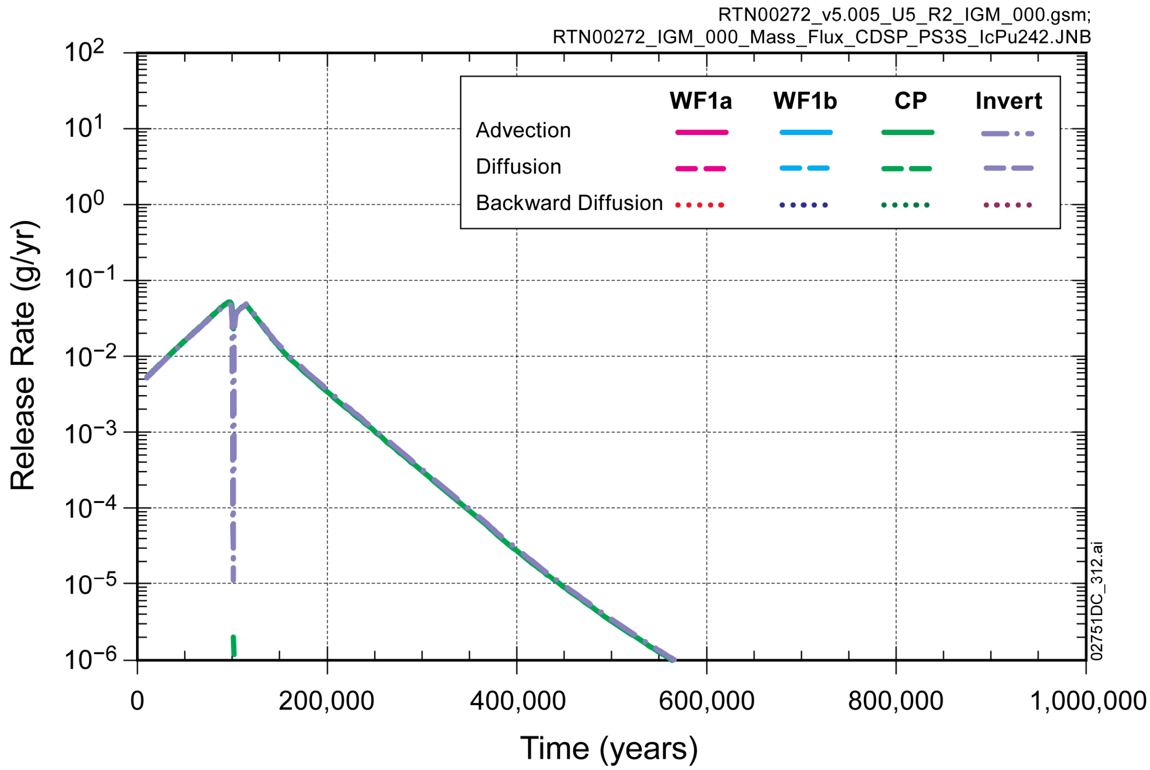
NOTE: WF1a Advection overlays WF1a Backward Diffusion (after 99,500 years), WF1b Advection overlays WF1b Backward Diffusion (after 99,500 years).

Figure 1.1-28. Release Rate of Total ^{242}Pu from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



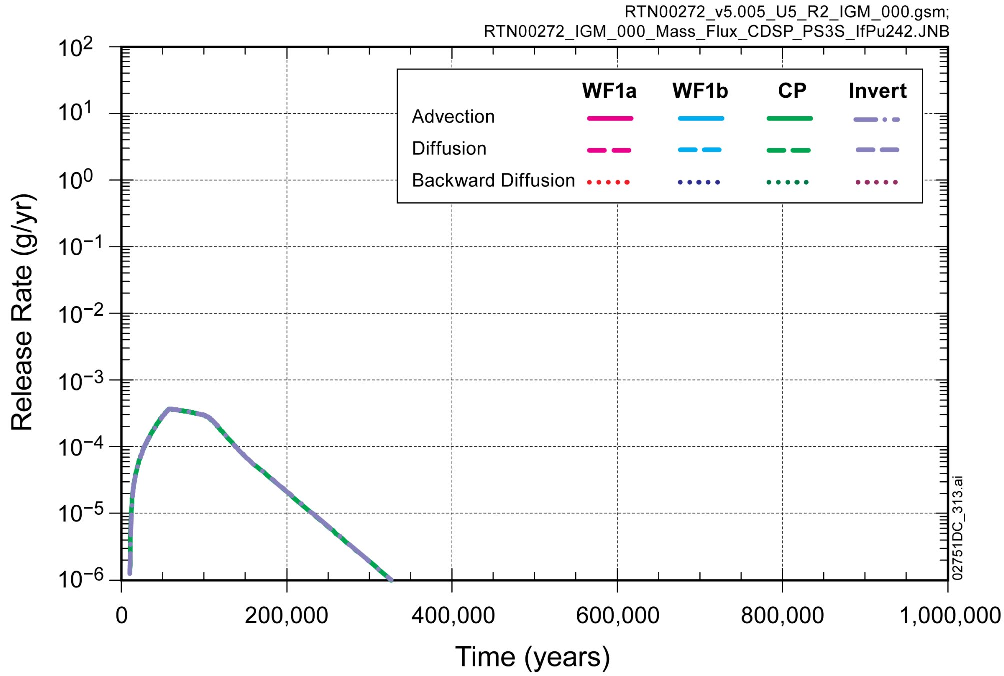
NOTE: WF1b Advection overlays WF1b Backward Diffusion (after 99,500 years).

Figure 1.1-29. Release Rate of ^{242}Pu Dissolved and Reversibly Sorbed from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



NOTE: WF1a Advection, WF1b Advection, CP Advection, and Invert Advection all overlay.

Figure 1.1-30. Release Rate of ^{242}Pu Irreversibly Attached to Waste Form (Ic) Colloids from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



NOTE: Invert Advection overlays CP Advection.

Figure 1.1-31. Release Rate of ^{242}Pu Irreversibly Attached to Iron Oxyhydroxide (If) Colloids from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

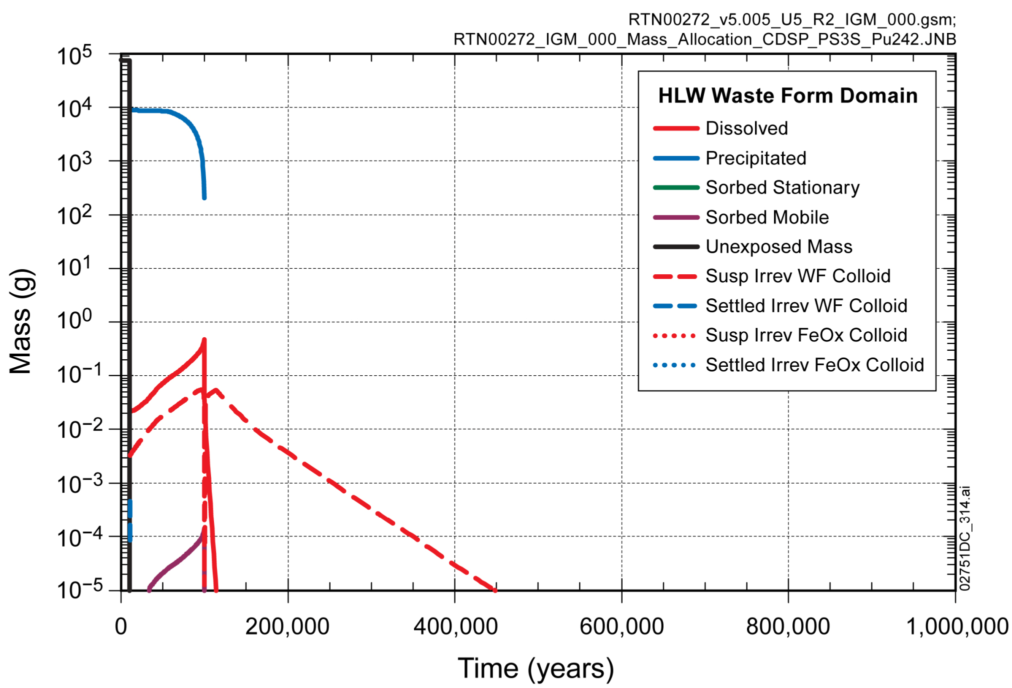


Figure 1.1-32. Mass of ^{242}Pu in the HLW Waste Form Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

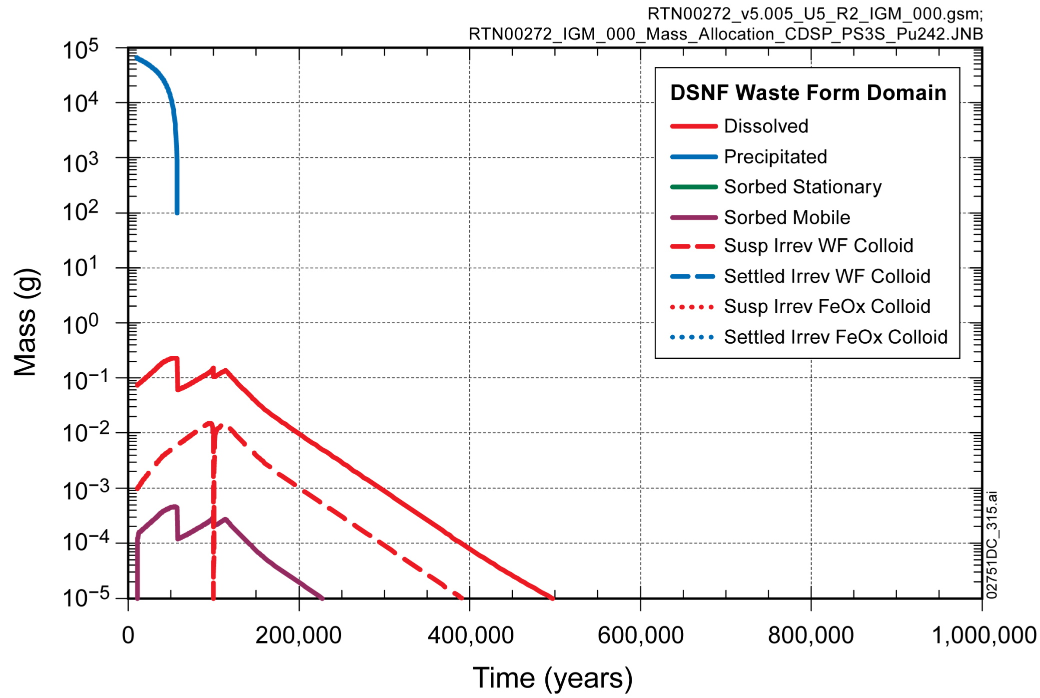


Figure 1.1-33. Mass of ^{242}Pu in the DOE SNF Waste Form Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

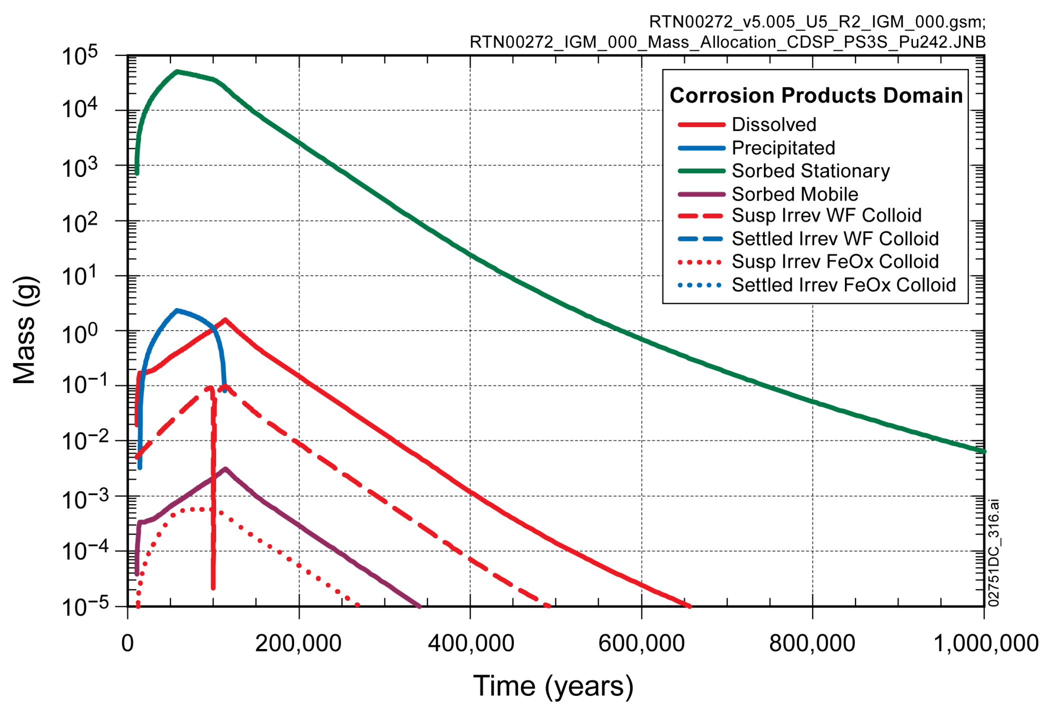


Figure 1.1-34. Mass of ^{242}Pu in the Corrosion Products Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

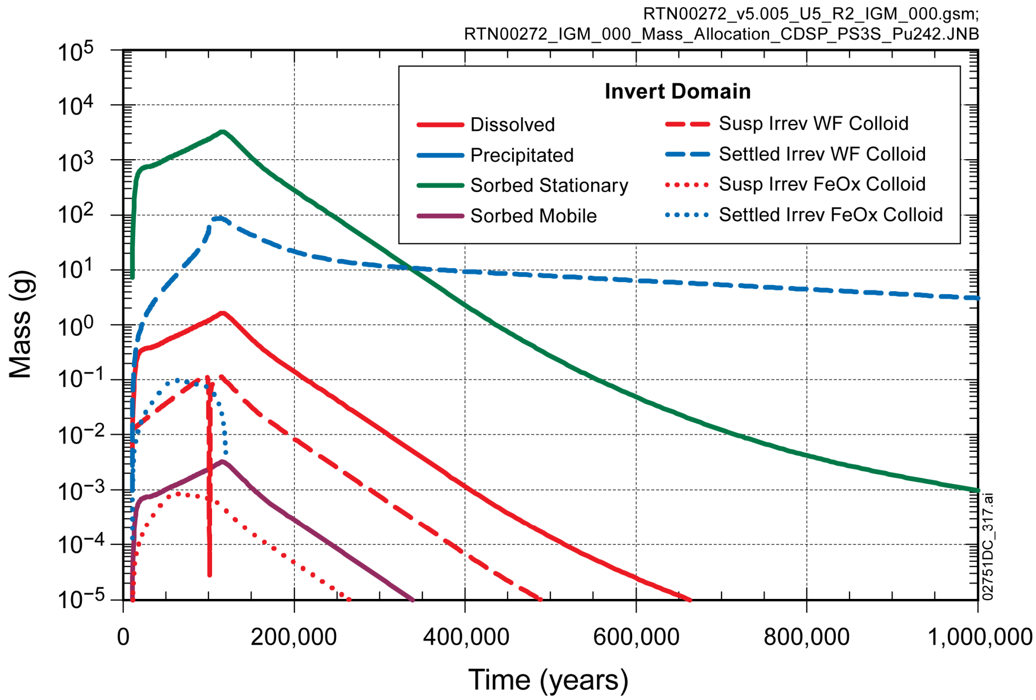
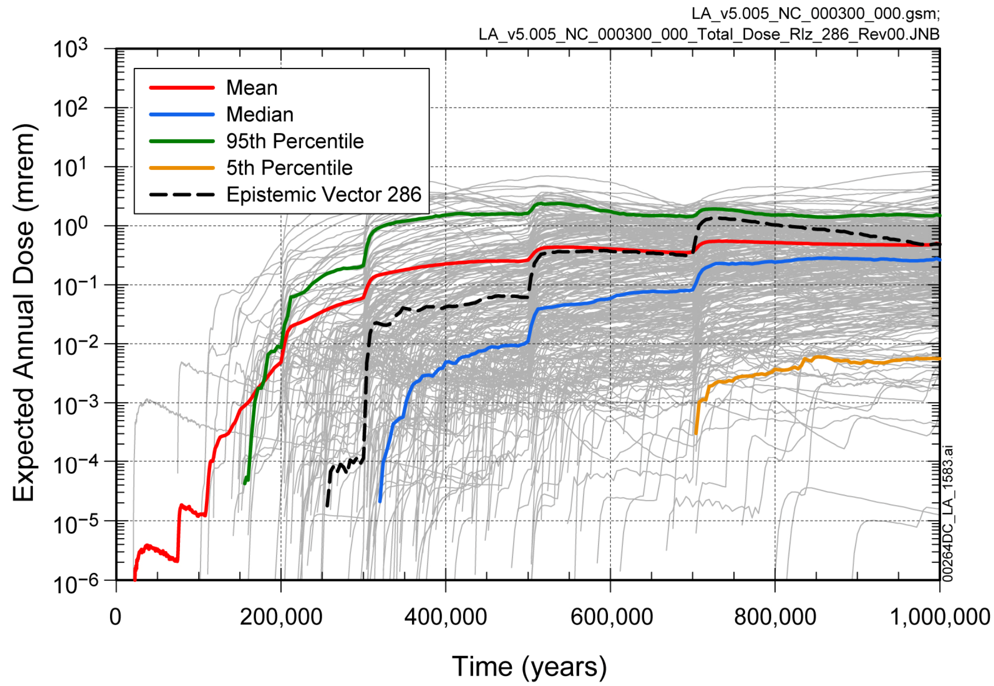
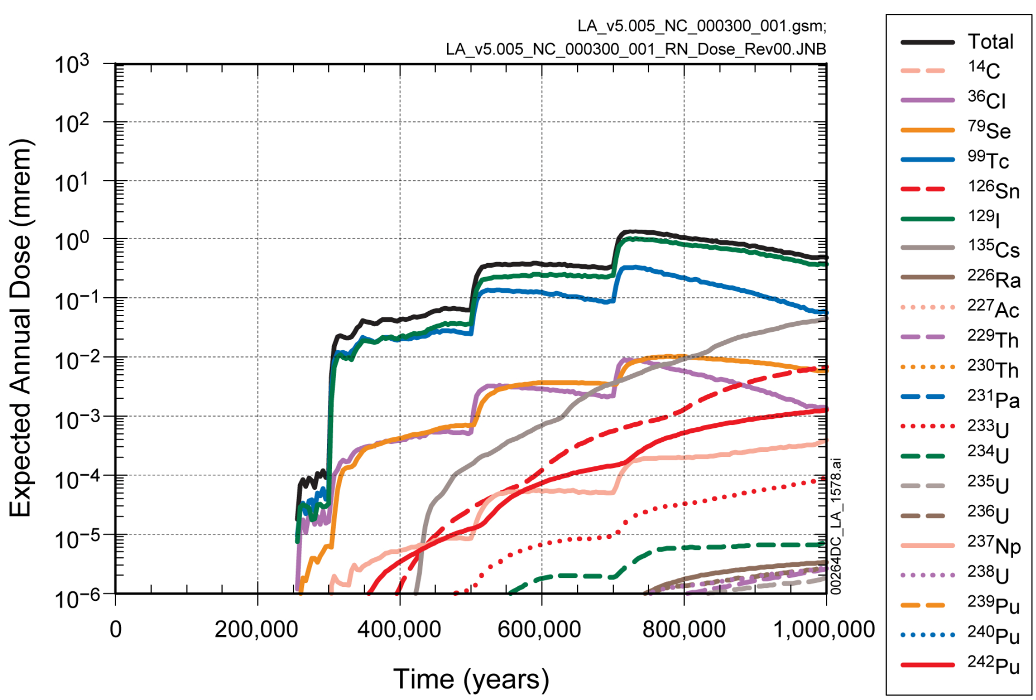


Figure 1.1-35. Mass of ^{242}Pu in the Invert from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure



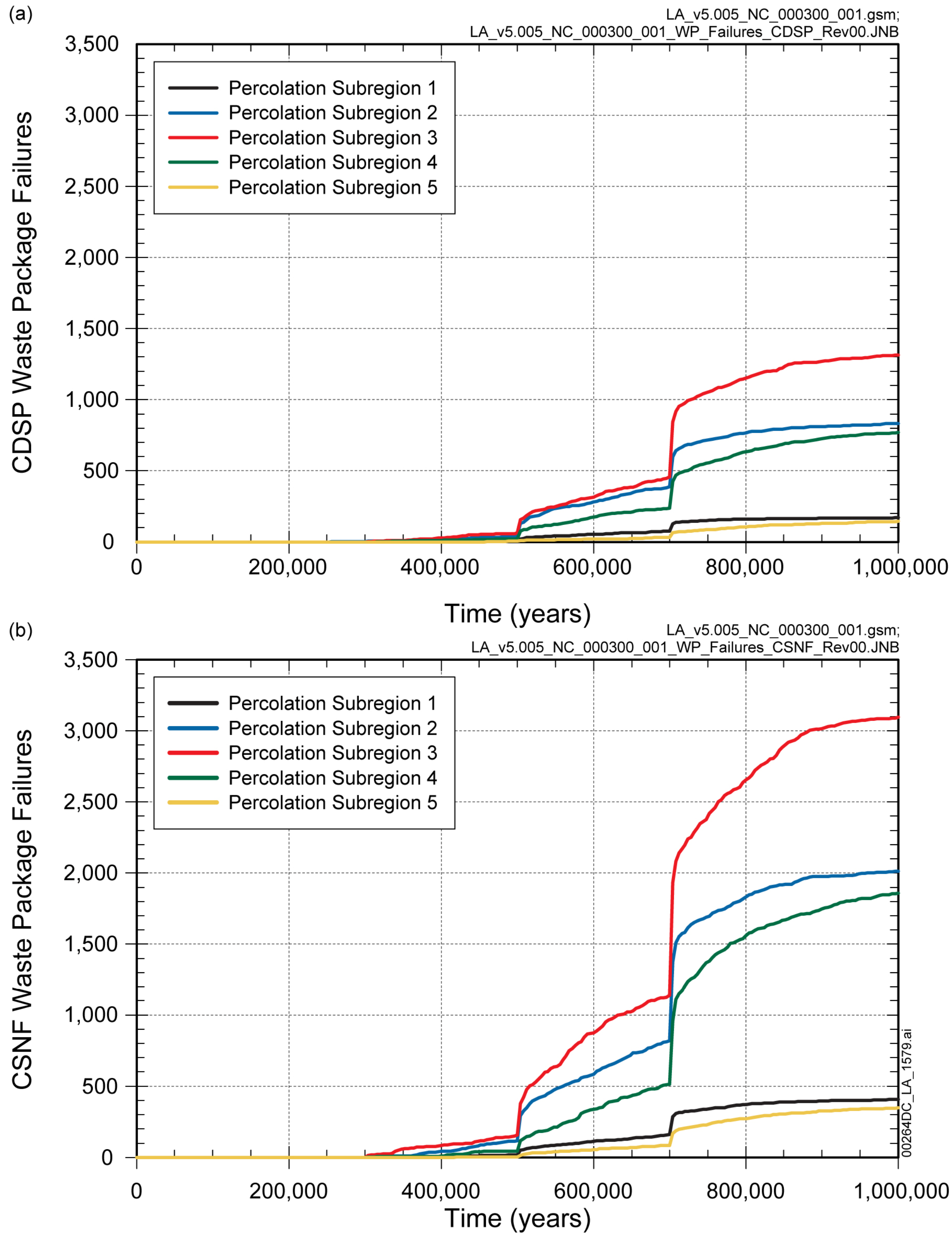
Source: SAR Figure 2.4-62.

Figure 1.2-1. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with Their Quantiles and Expected Dose from Epistemic Uncertainty Vector 286 for the Nominal Modeling Case for 1,000,000 Years after Repository Closure



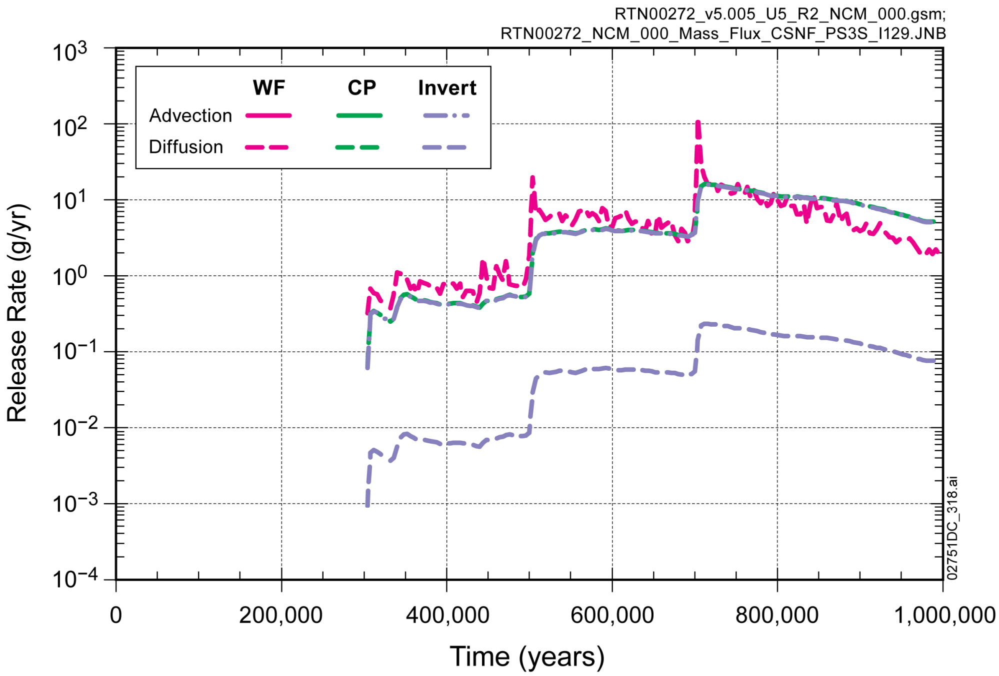
Source: SAR Figure 2.4-63.

Figure 1.2-2. Contribution of Individual Radionuclides to Expected Annual Dose for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure



Source: SAR Figure 2.4-64.

Figure 1.2-3. Cumulative Number of (a) Codisposal Waste Package Failures and (b) Commercial SNF Waste Package Failures by Percolation Subregion for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure



NOTE: Invert Advection overlays CP Diffusion.

Figure 1.2-4. Release Rate of ^{129}I from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

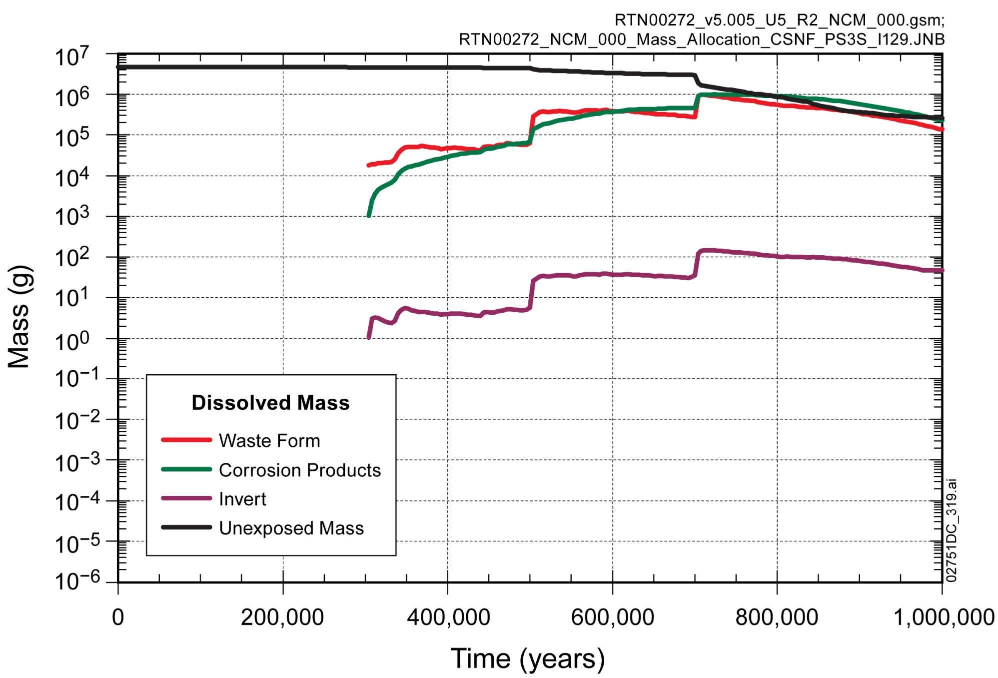


Figure 1.2-5. Mass of ^{129}I in Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

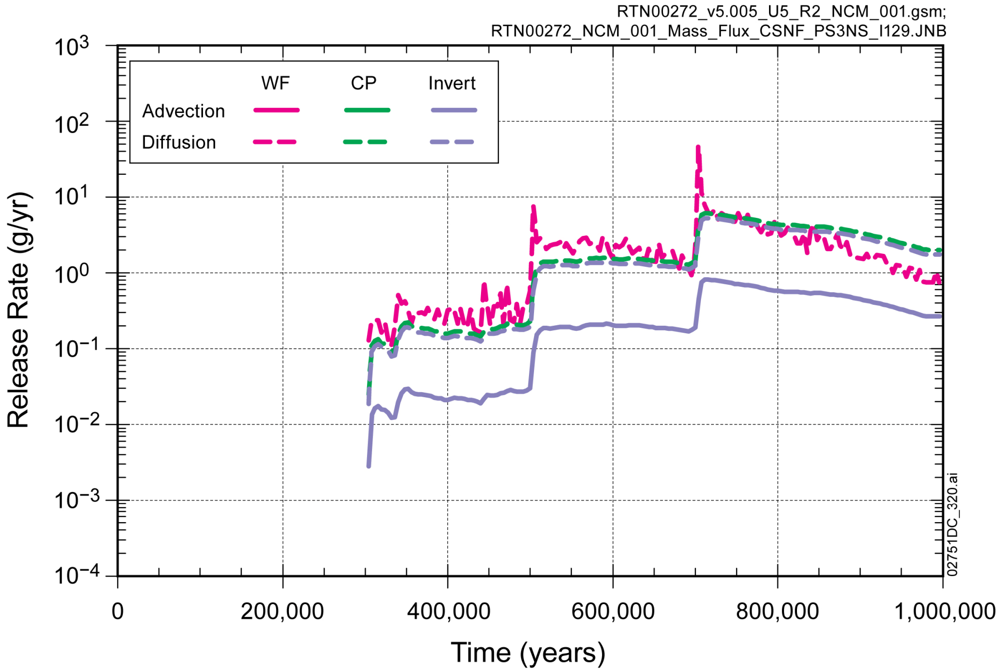


Figure 1.2-6. Release Rate of ^{129}I from Each EBS Domain from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

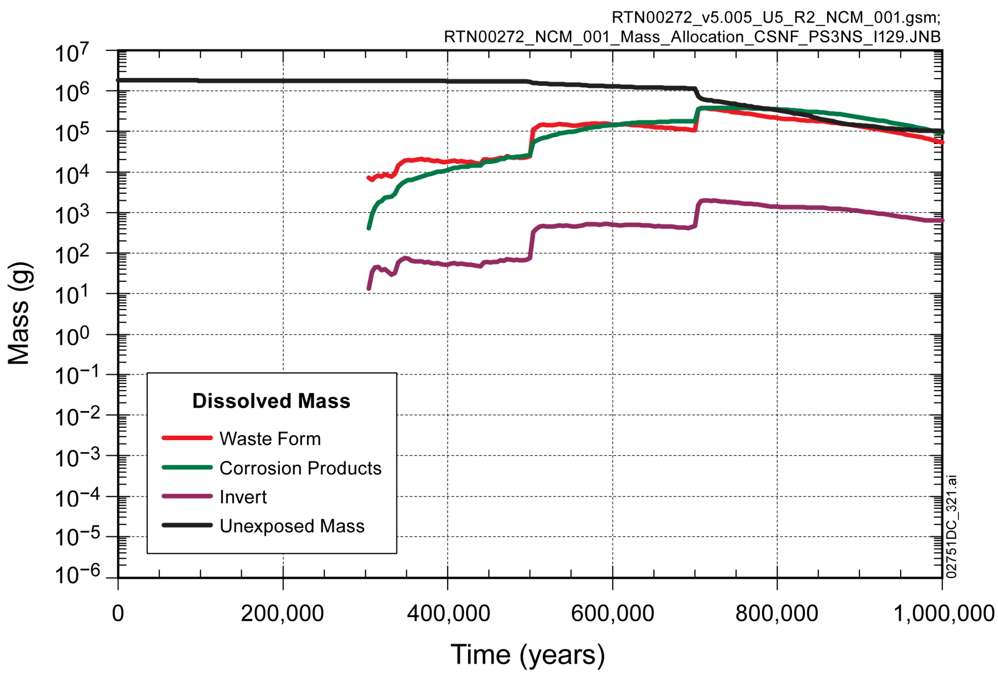
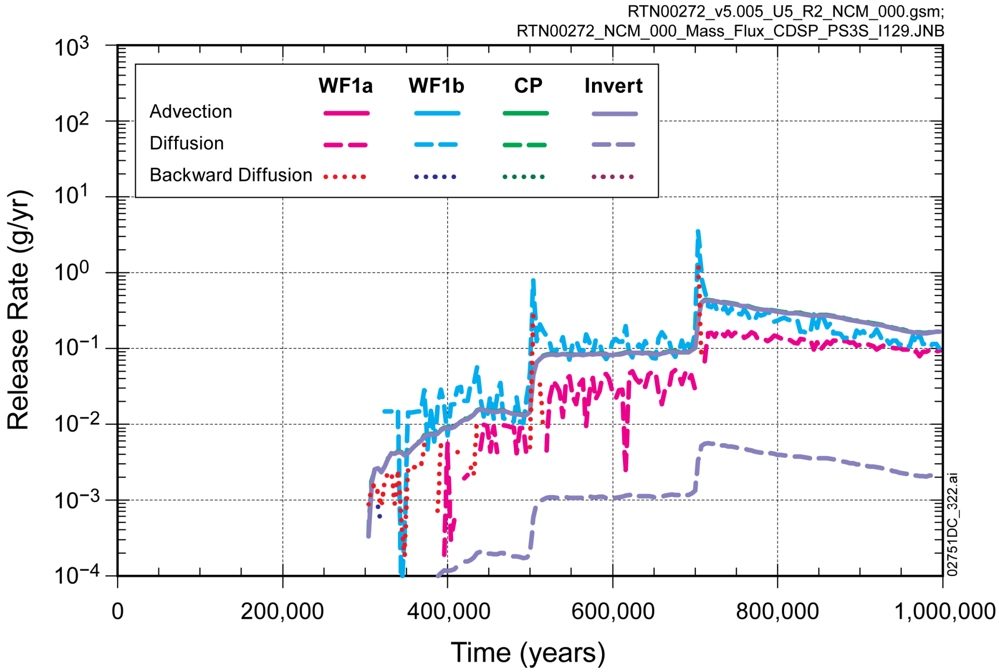


Figure 1.2-7. Mass of ^{129}I in Each EBS Domain from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure



NOTE: Invert Advection overlays CP Diffusion.

Figure 1.2-8. Release Rate of ^{129}I from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

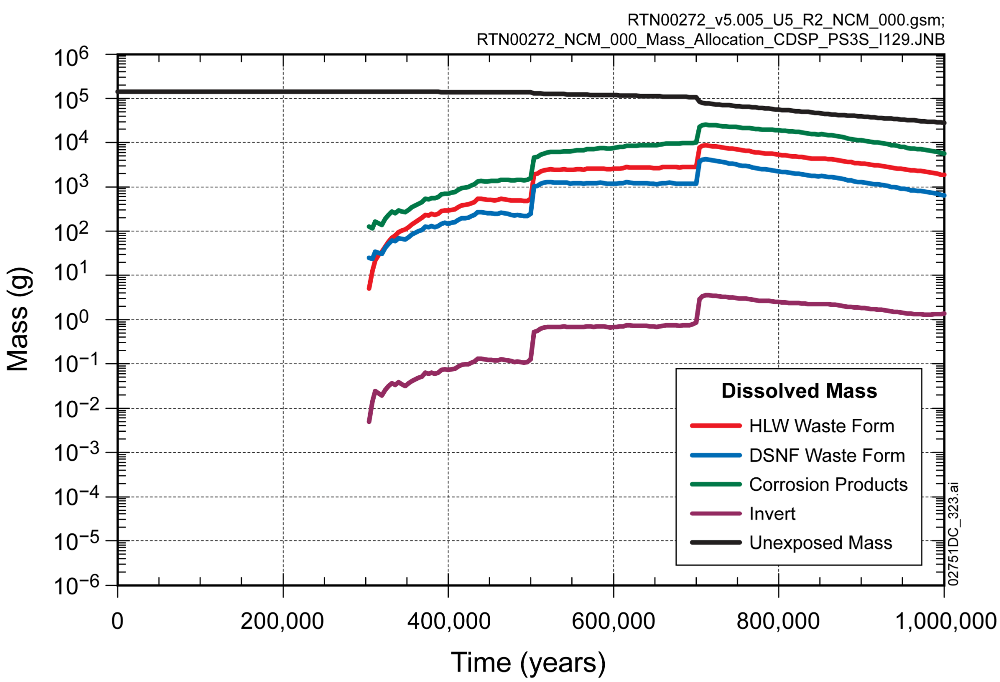


Figure 1.2-9. Mass of ^{129}I in Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

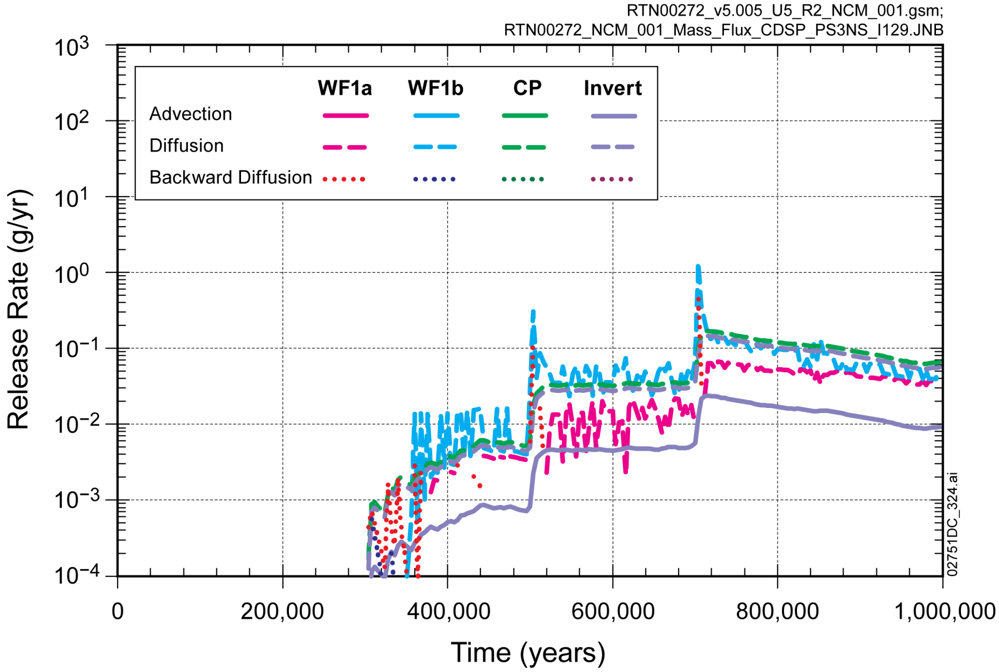


Figure 1.2-10. Release Rate of ^{129}I from Each EBS Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

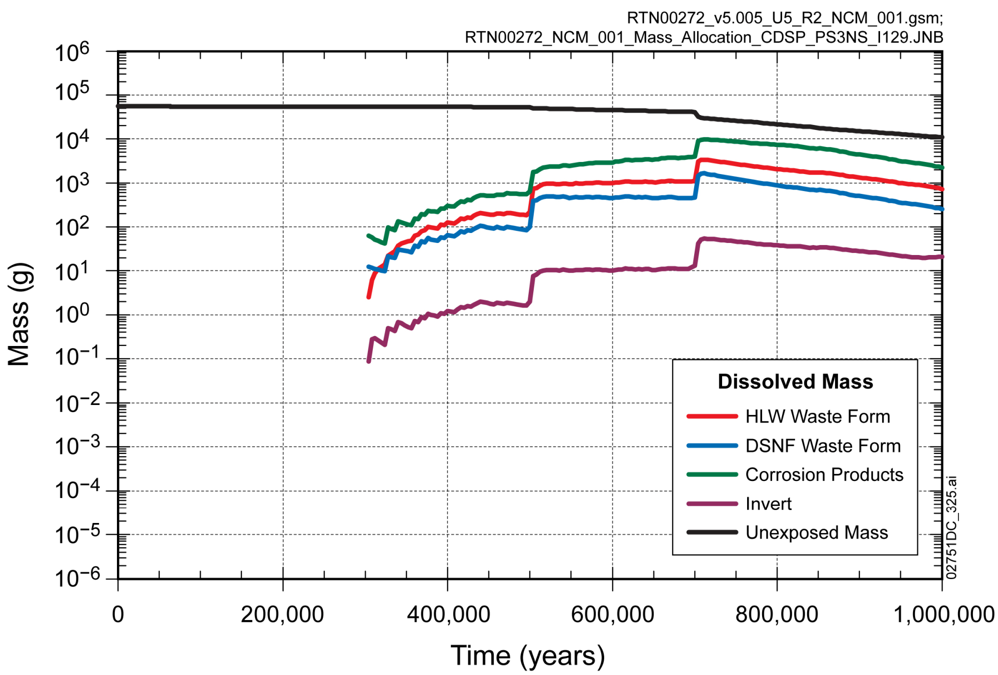
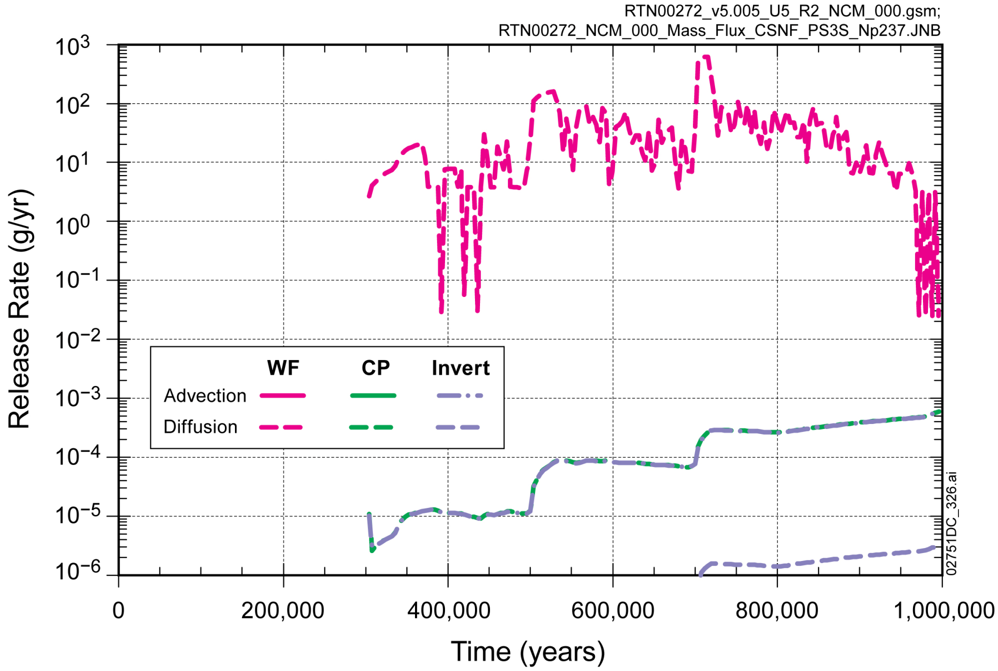


Figure 1.2-11. Mass of ^{129}I in Each EBS Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure



NOTE: Invert Advection overlays CP Diffusion.

Figure 1.2-12. Release Rate of ^{237}Np from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

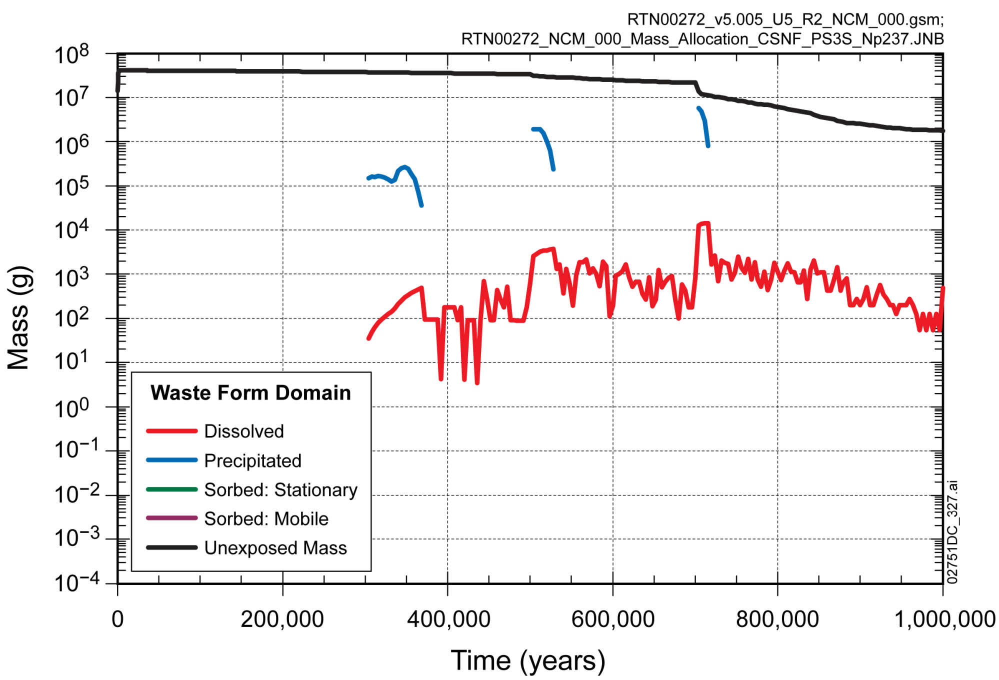


Figure 1.2-13. Mass of ^{237}Np in the Commercial SNF Waste Form Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

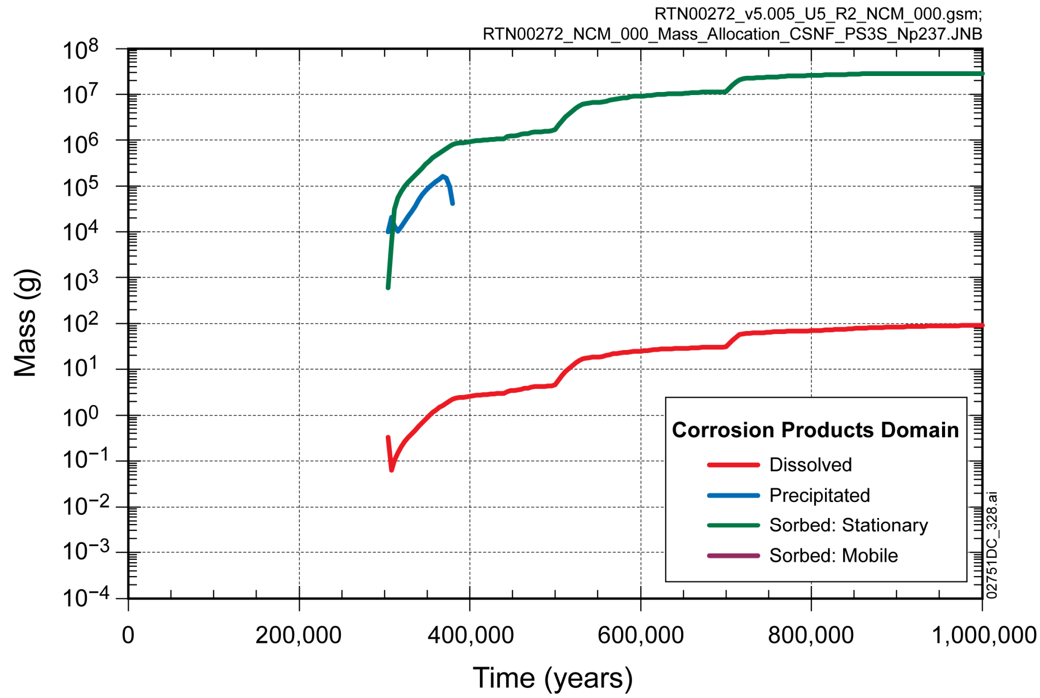


Figure 1.2-14. Mass of ^{237}Np in the Corrosion Products Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

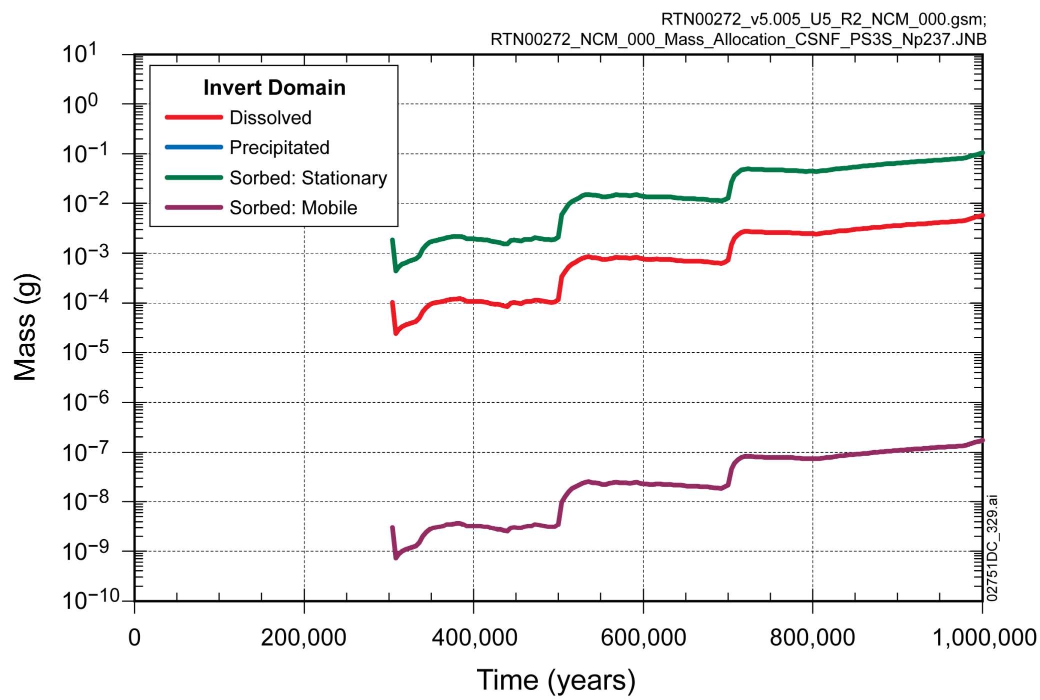


Figure 1.2-15. Mass of ^{237}Np in the Invert from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

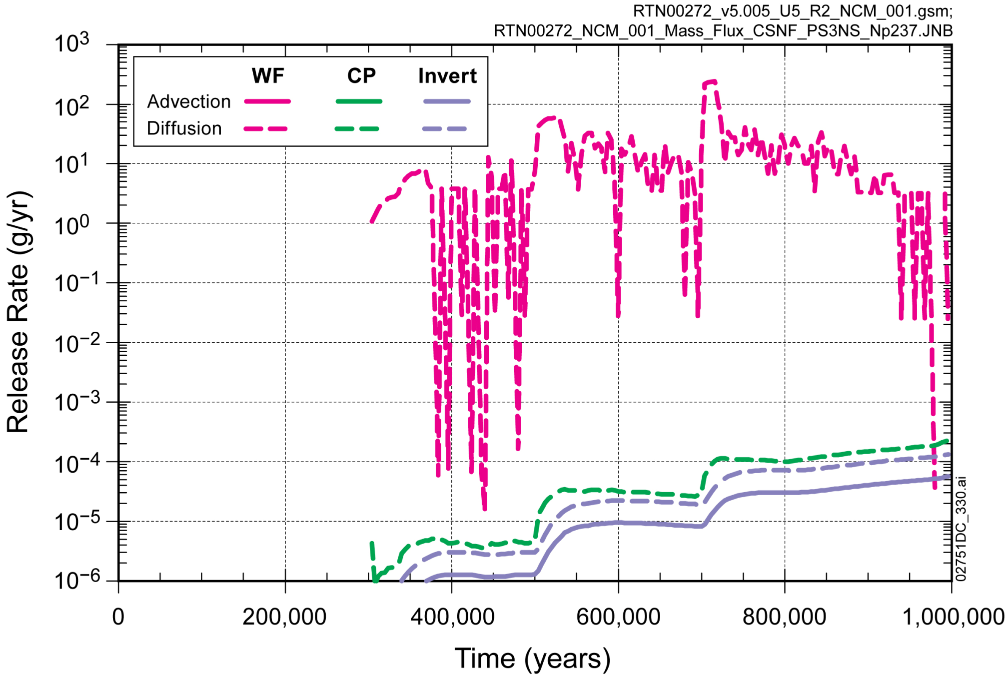


Figure 1.2-16. Release Rate of ^{237}Np from Each EBS Domain from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

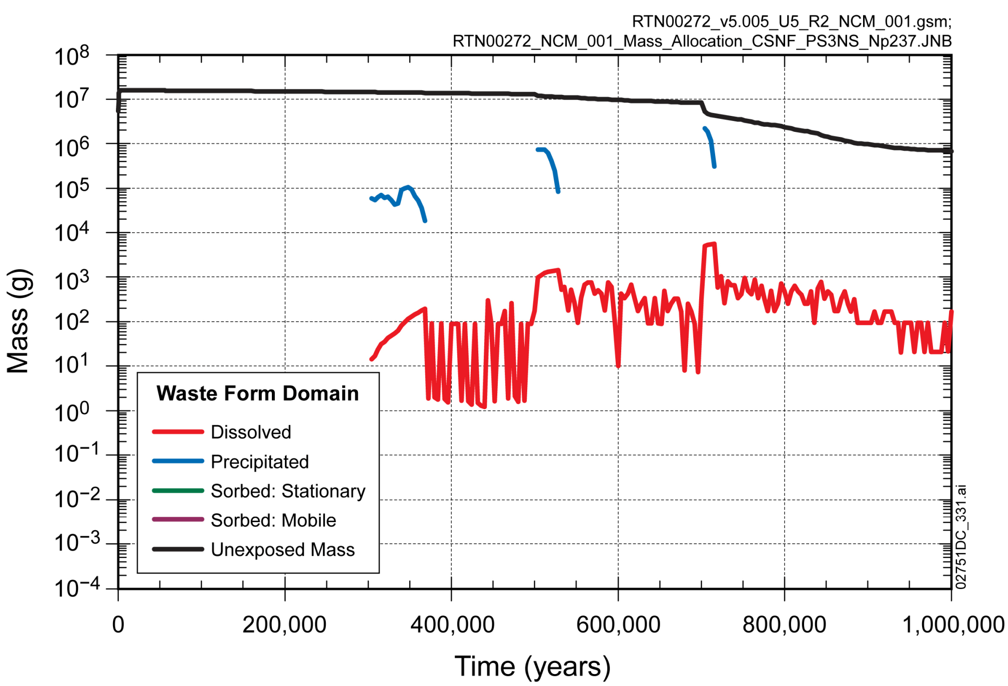


Figure 1.2-17. Mass of ^{237}Np in the Commercial SNF Waste Form Domain from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

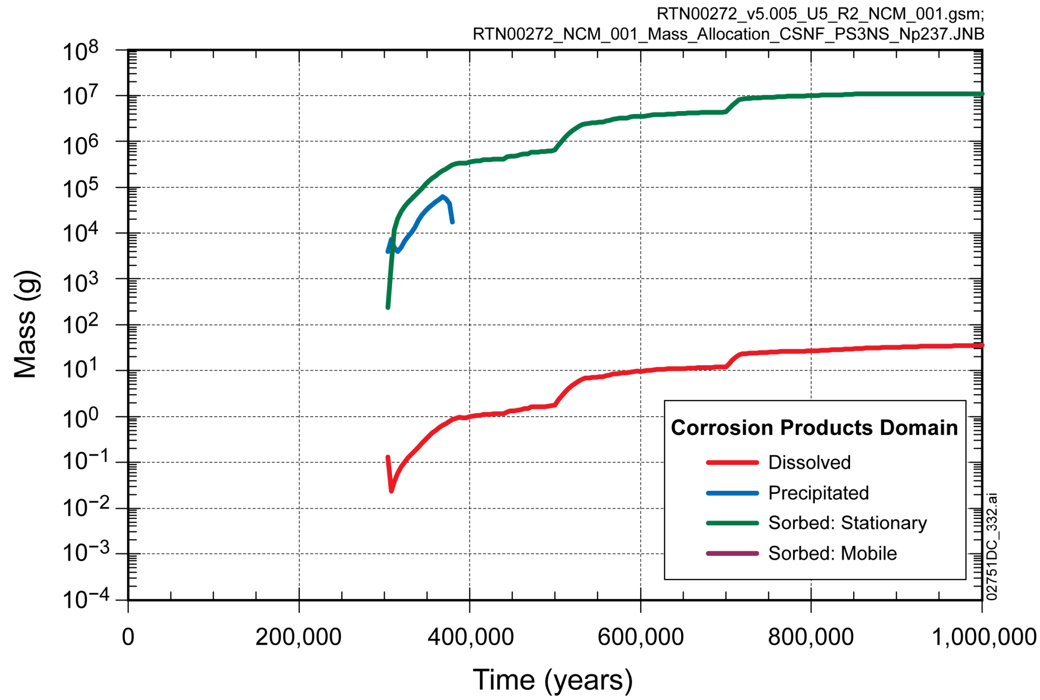


Figure 1.2-18. Mass of ^{237}Np in the Corrosion Products Domain from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

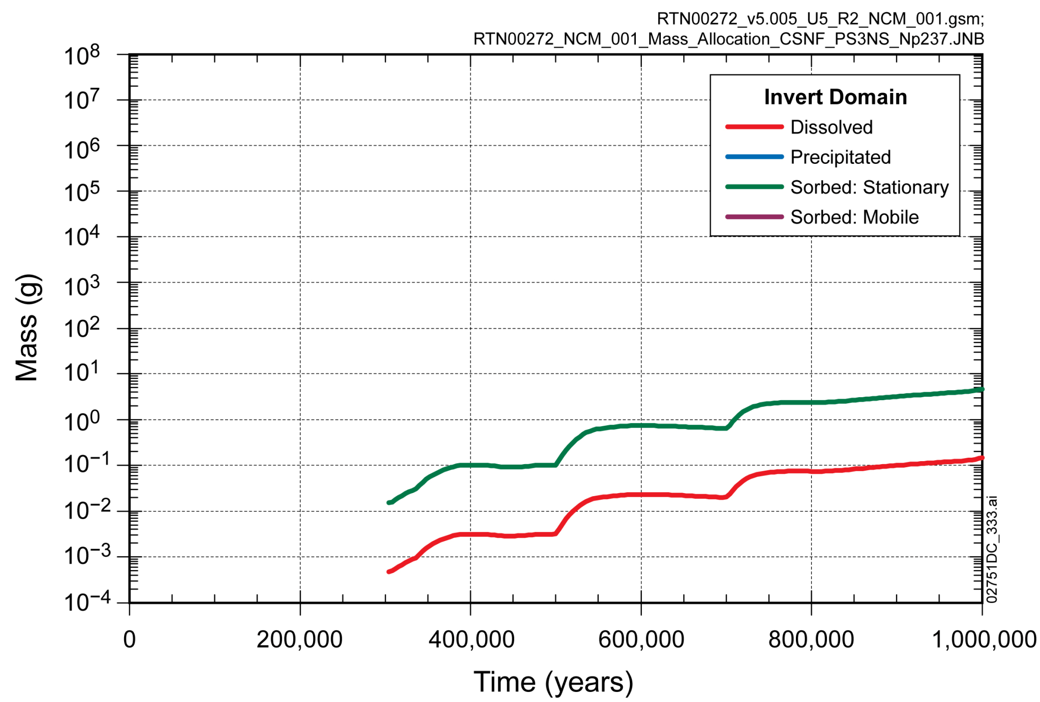
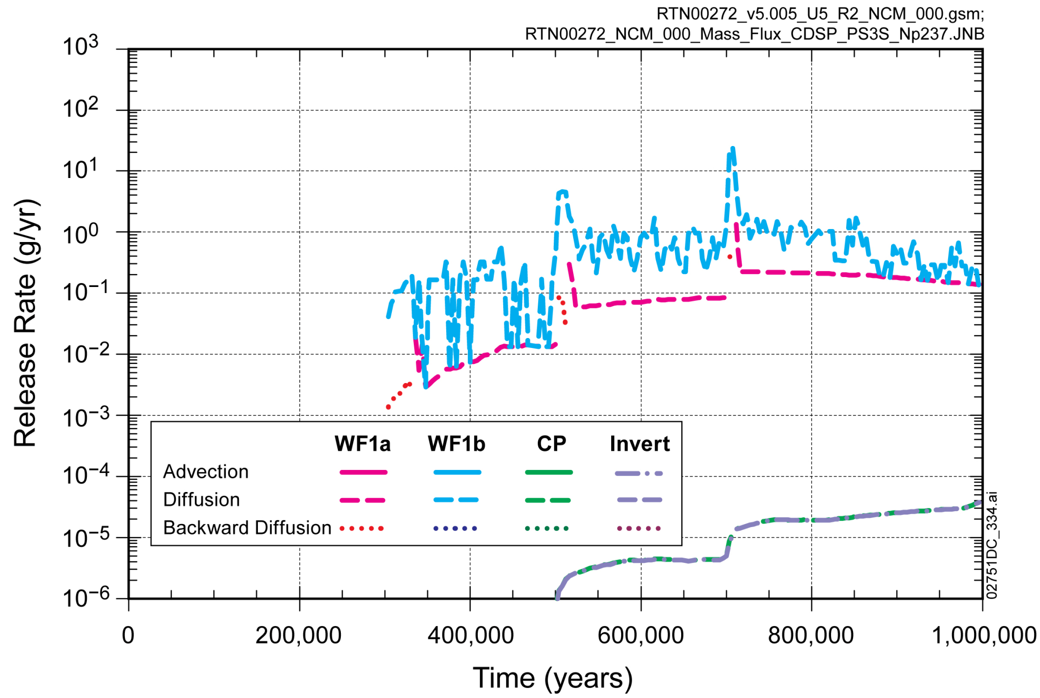


Figure 1.2-19. Mass of ^{237}Np in the Invert from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure



NOTE: Invert Advection overlays CP Diffusion.

Figure 1.2-20. Release Rate of ^{237}Np from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

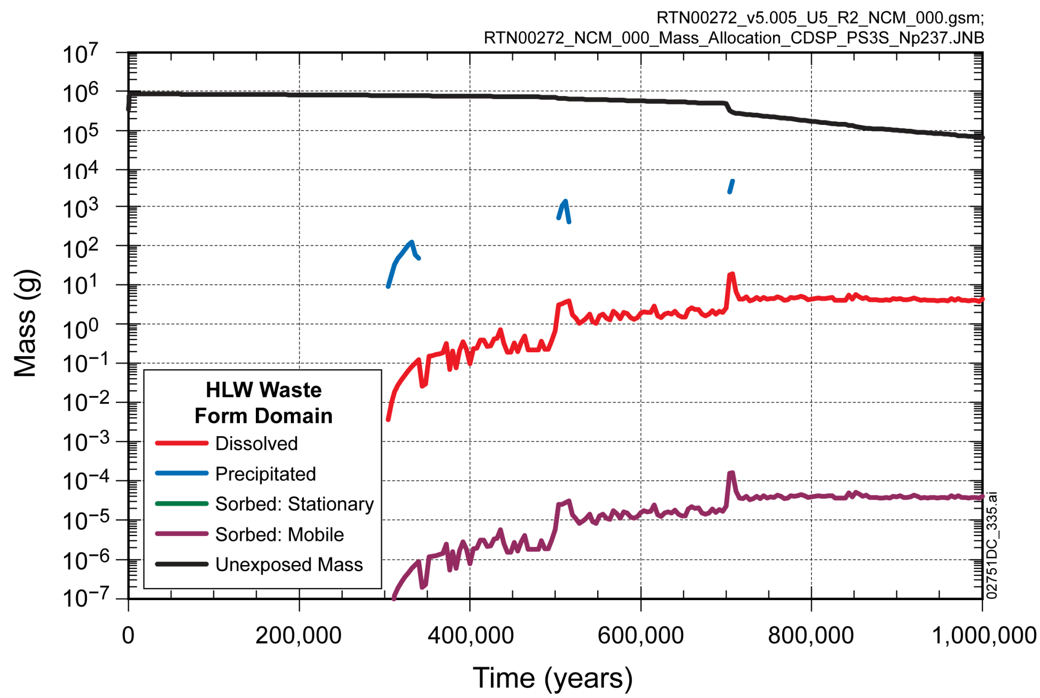


Figure 1.2-21. Mass of ^{237}Np in the HLW Waste Form Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

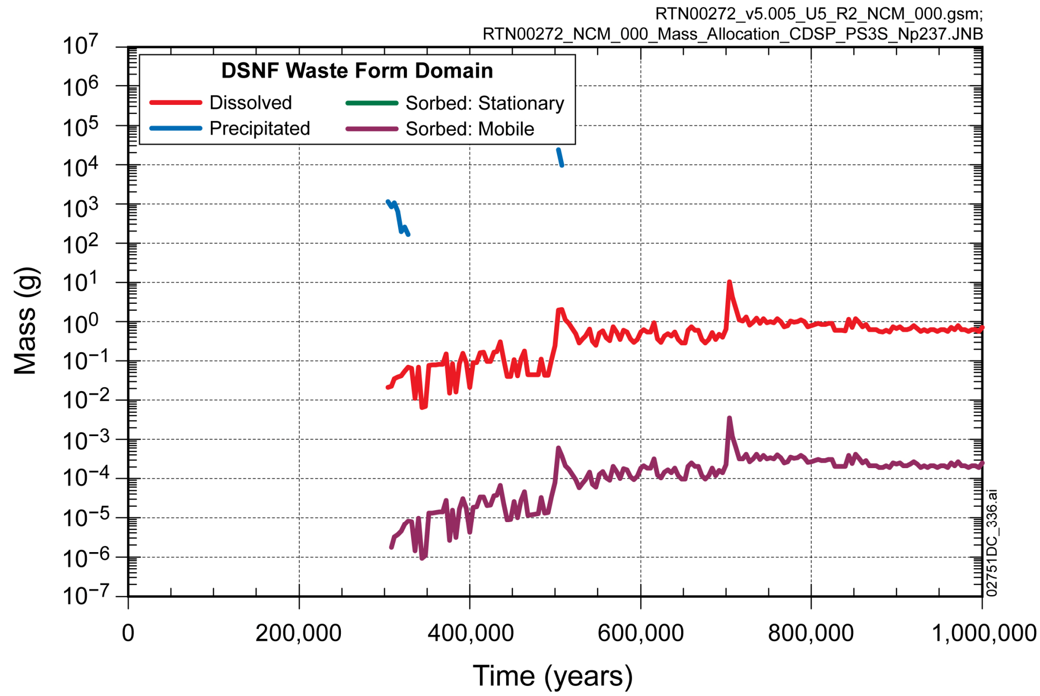


Figure 1.2-22. Mass of ^{237}Np in the DOE SNF Waste Form Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

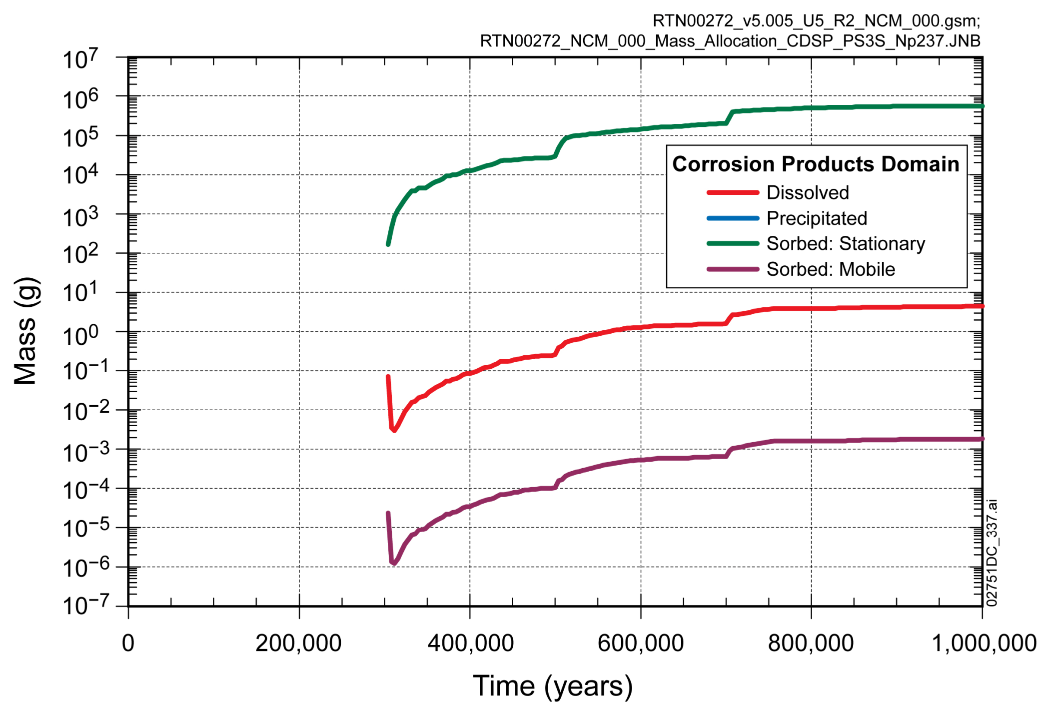


Figure 1.2-23. Mass of ^{237}Np in the Corrosion Products Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

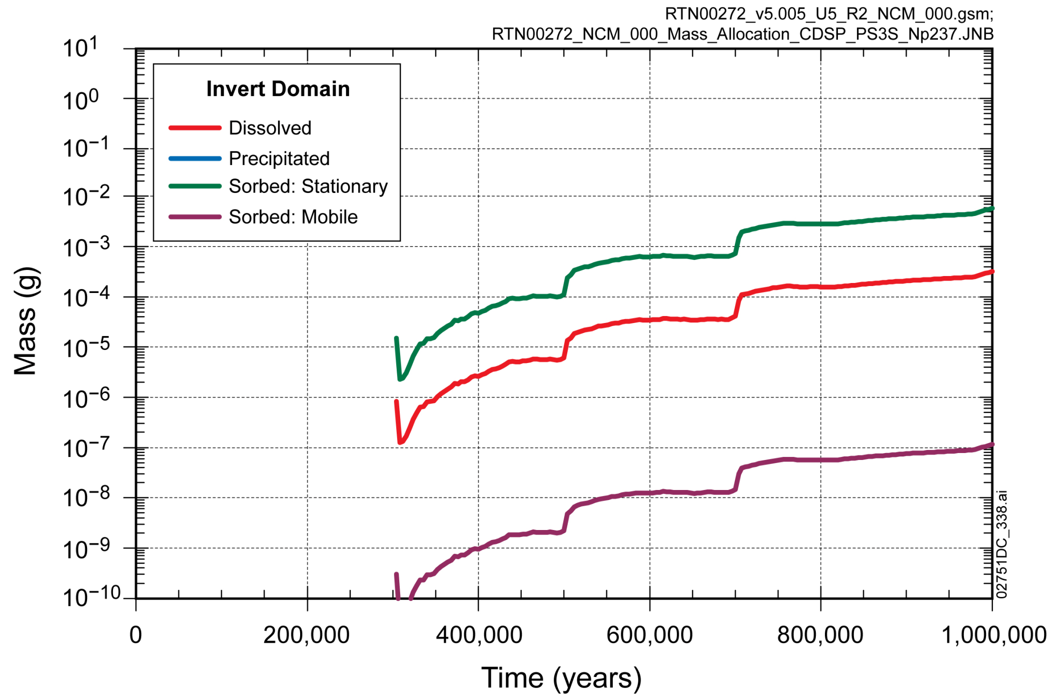


Figure 1.2-24. Mass of ^{237}Np in the Invert from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

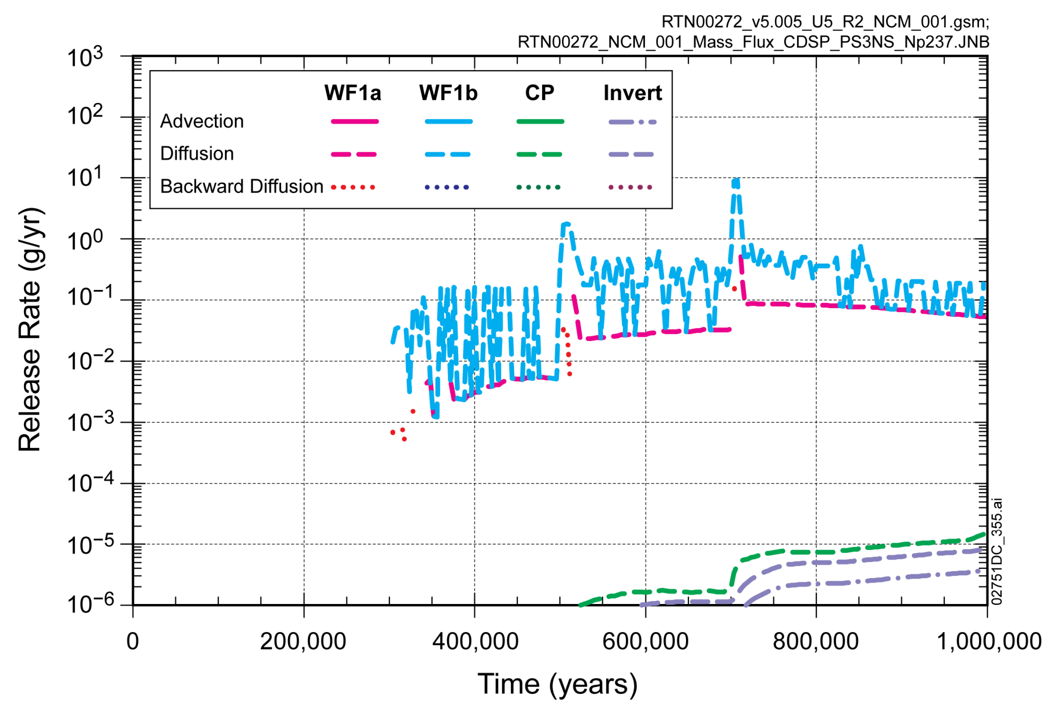


Figure 1.2-25. Release Rate of ^{237}Np from Each EBS Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

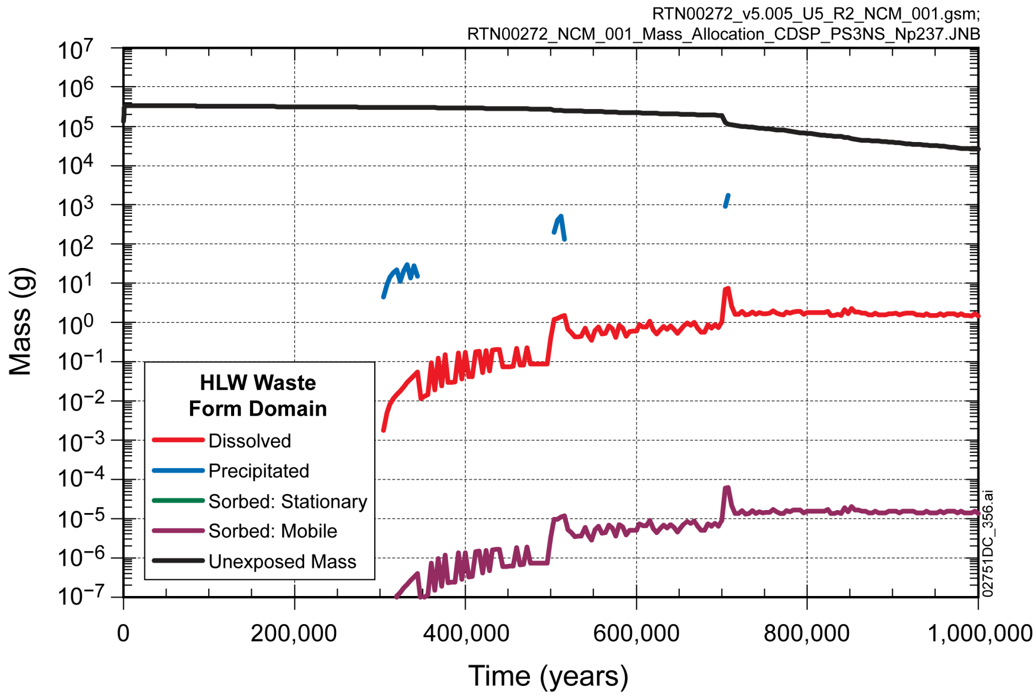


Figure 1.2-26. Mass of ^{237}Np in the HLW Waste Form Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

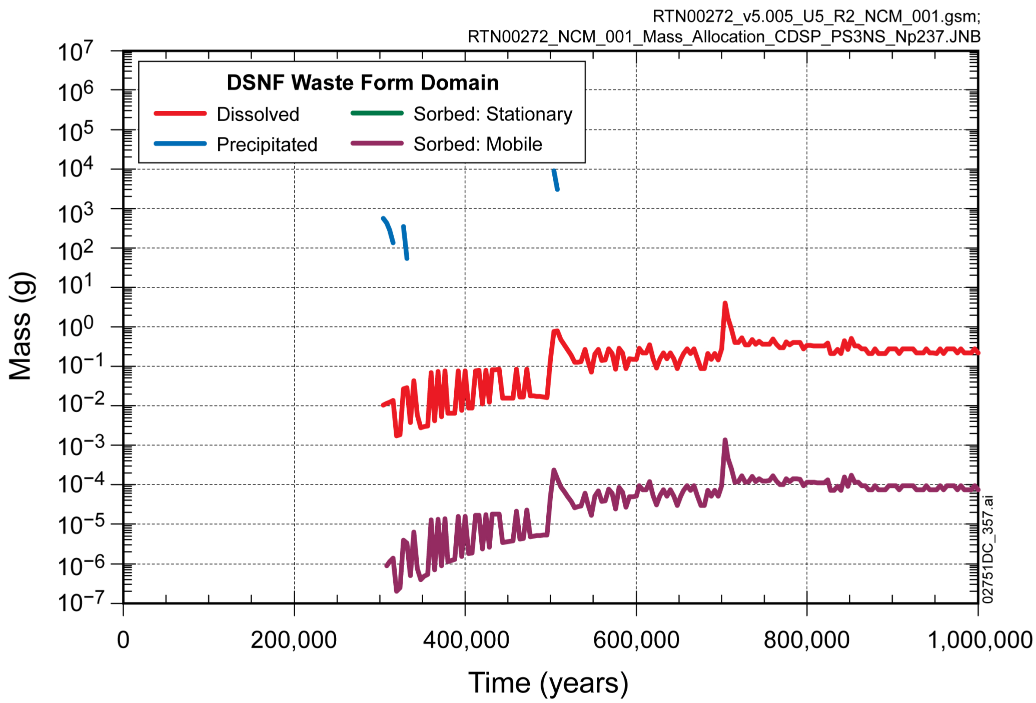


Figure 1.2-27. Mass of ^{237}Np in the DOE SNF Waste Form Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

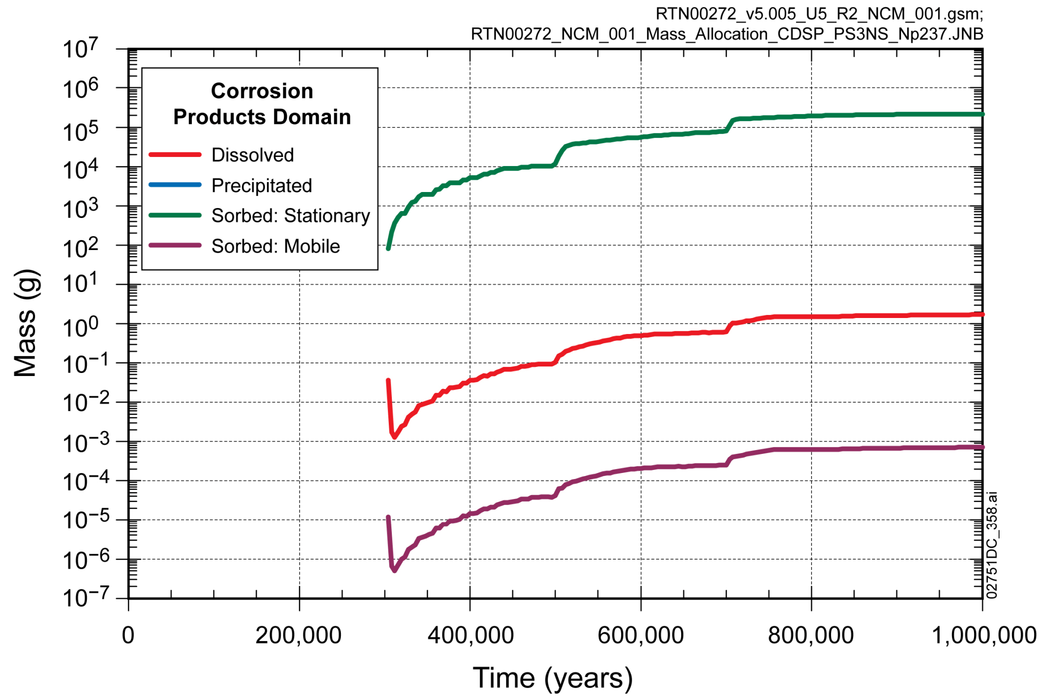


Figure 1.2-28. Mass of ^{237}Np in the Corrosion Products Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

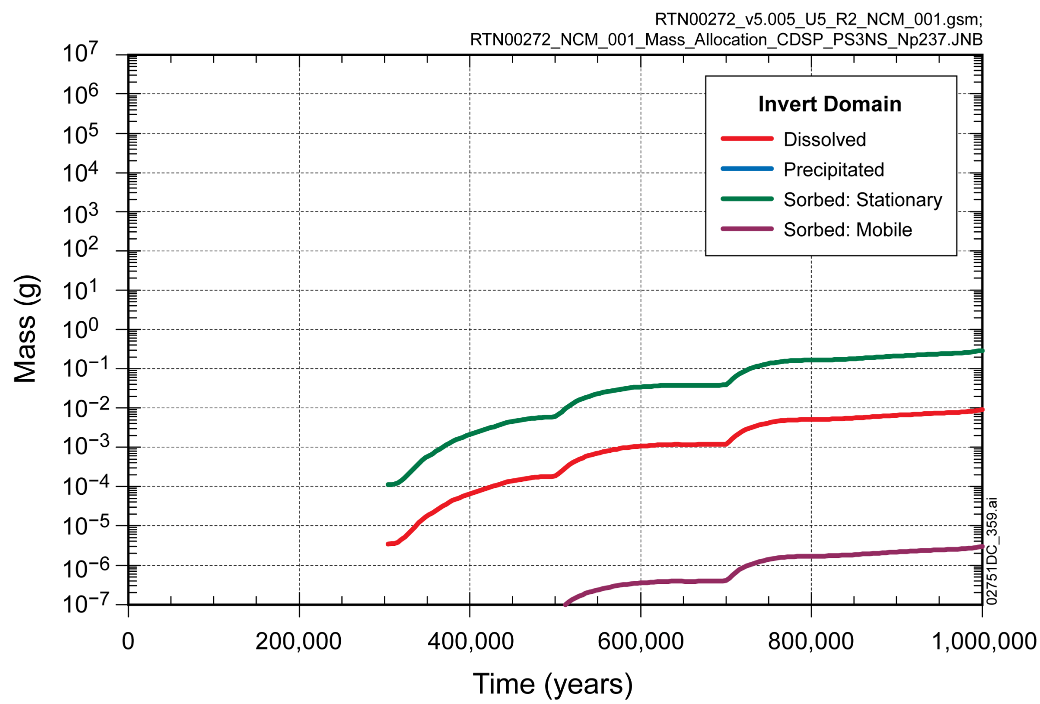


Figure 1.2-29. Mass of ^{237}Np in the Invert from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

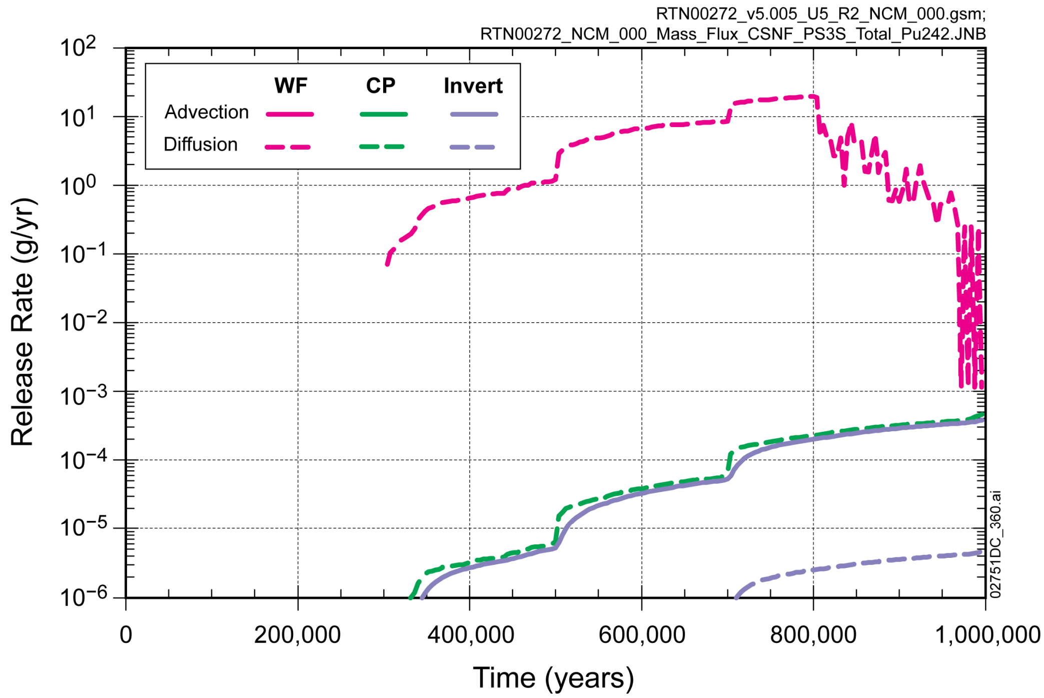


Figure 1.2-30. Release Rate of Total ^{242}Pu from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

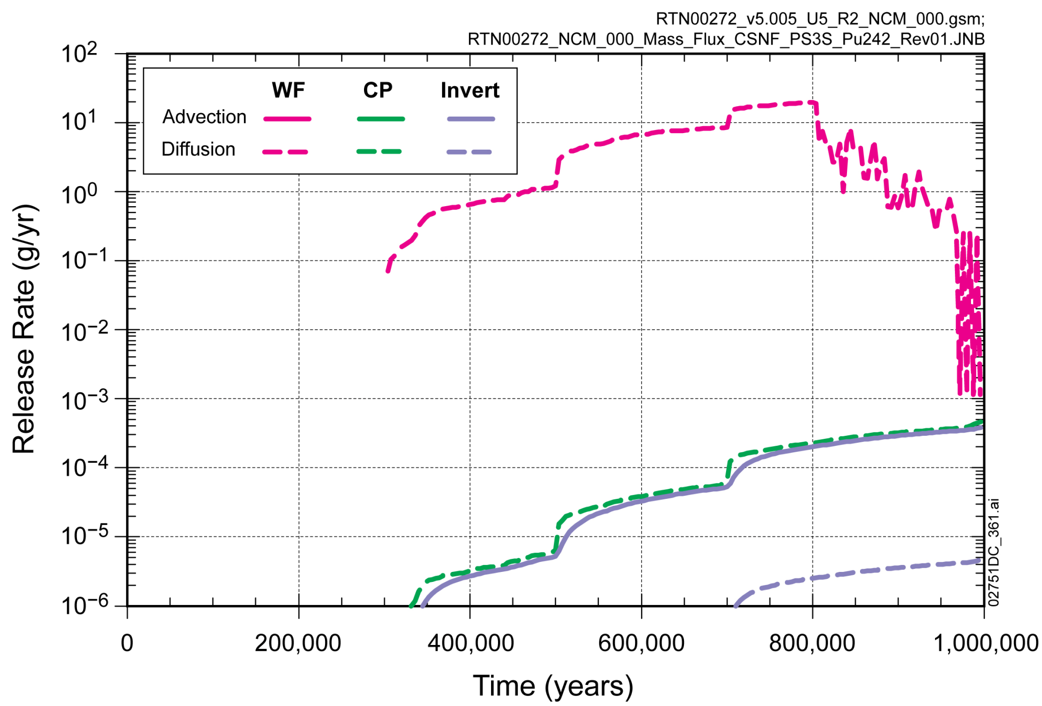


Figure 1.2-31. Release Rate of ^{242}Pu Dissolved and Reversibly Sorbed from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

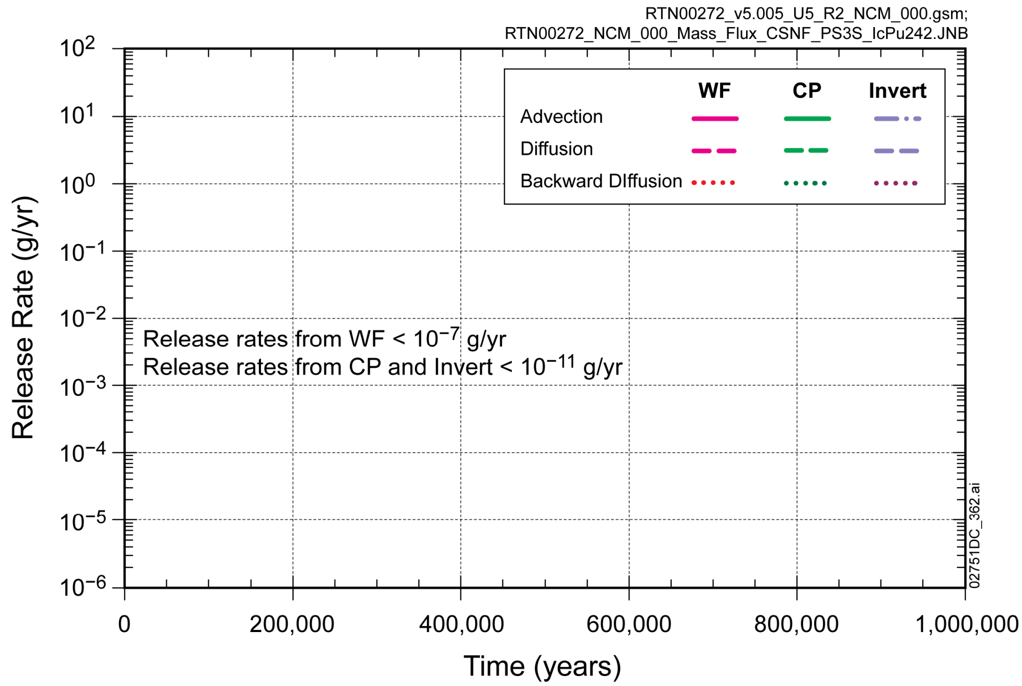


Figure 1.2-32. Release Rate of ^{242}Pu Irreversibly Attached to Waste Form (Ic) Colloids from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

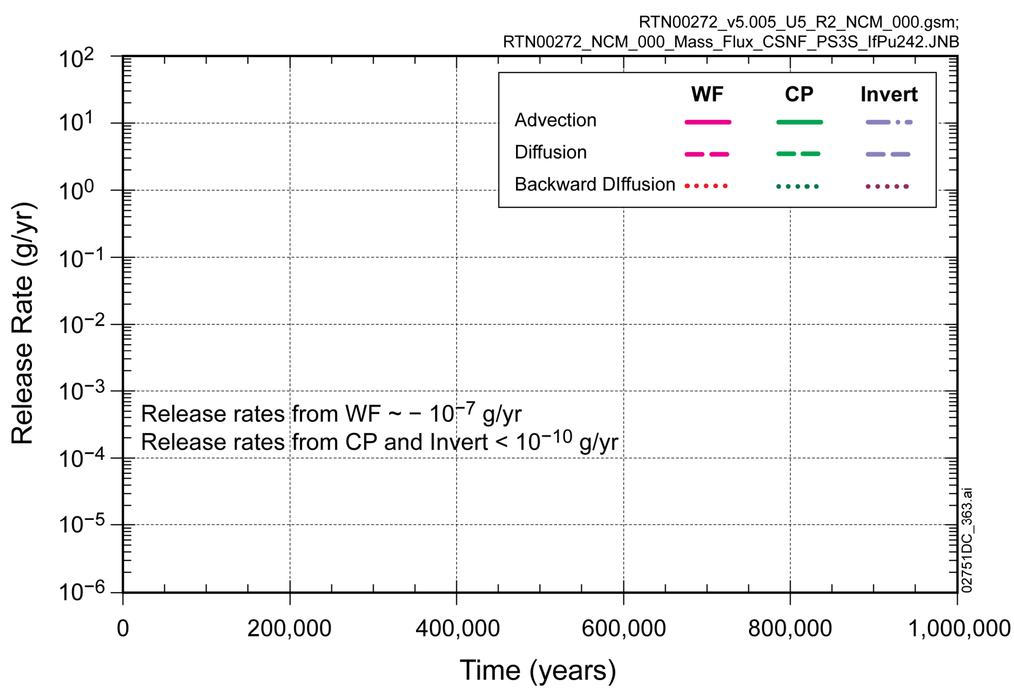


Figure 1.2-33. Release Rate of ^{242}Pu Irreversibly Attached to Iron Oxyhydroxide (If) Colloids from Each EBS Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

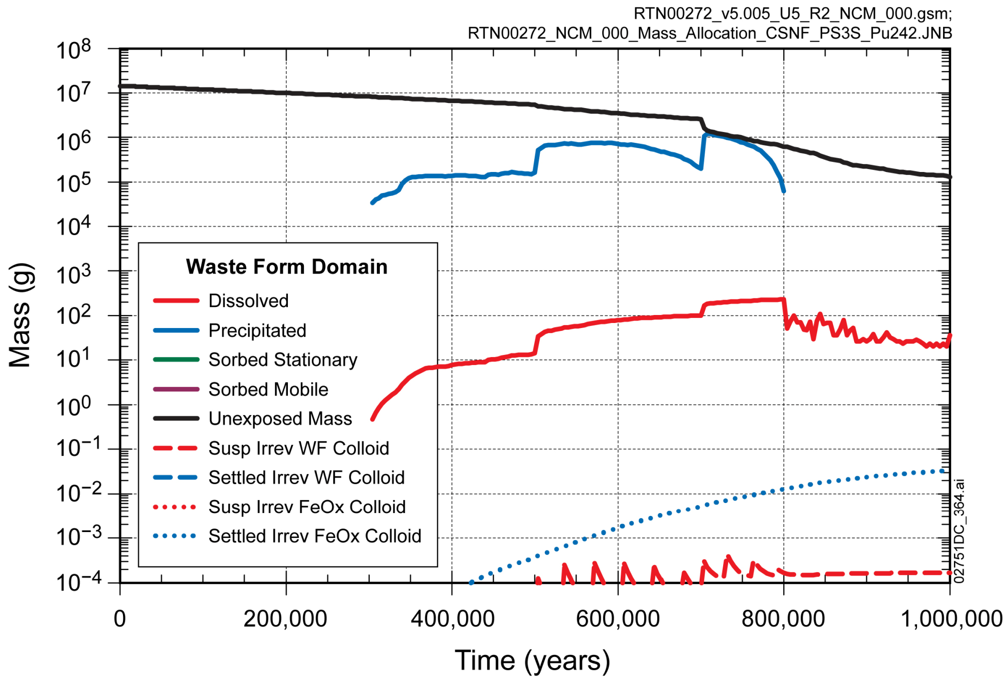


Figure 1.2-34. Mass of ^{242}Pu in the Commercial SNF Waste Form Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

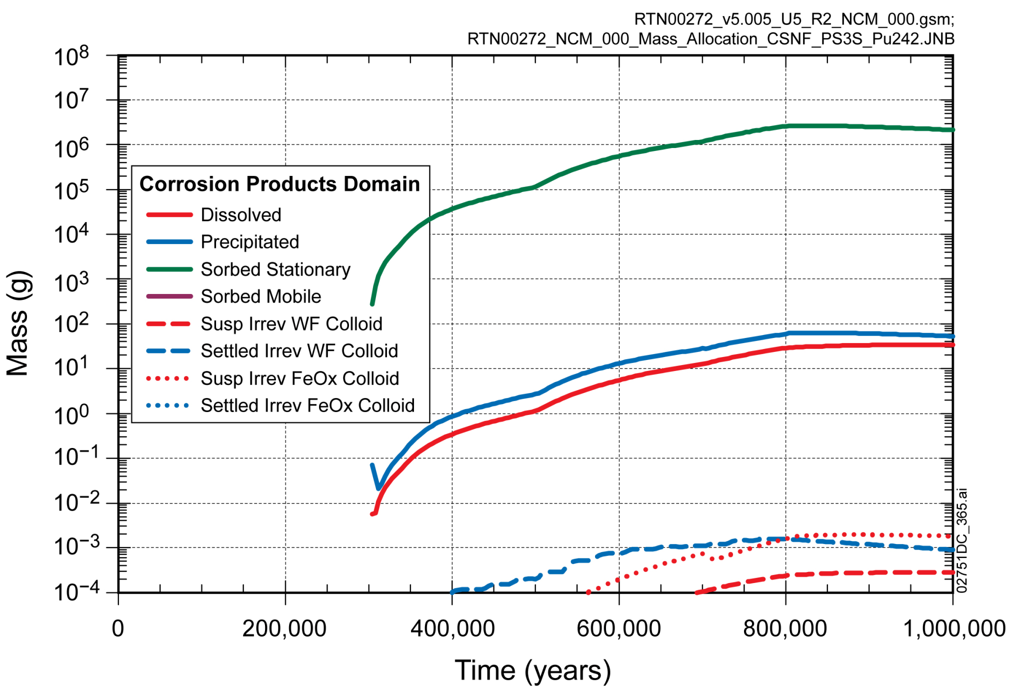


Figure 1.2-35. Mass of ^{242}Pu in the Corrosion Products Domain from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

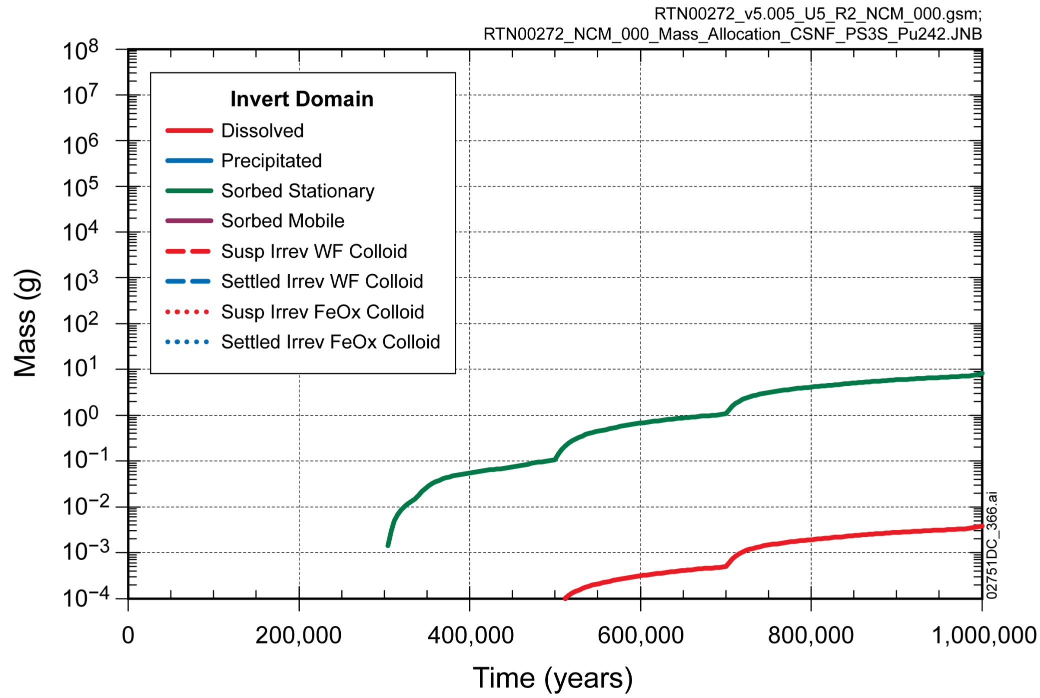


Figure 1.2-36. Mass of ^{242}Pu in the Invert from Commercial SNF Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

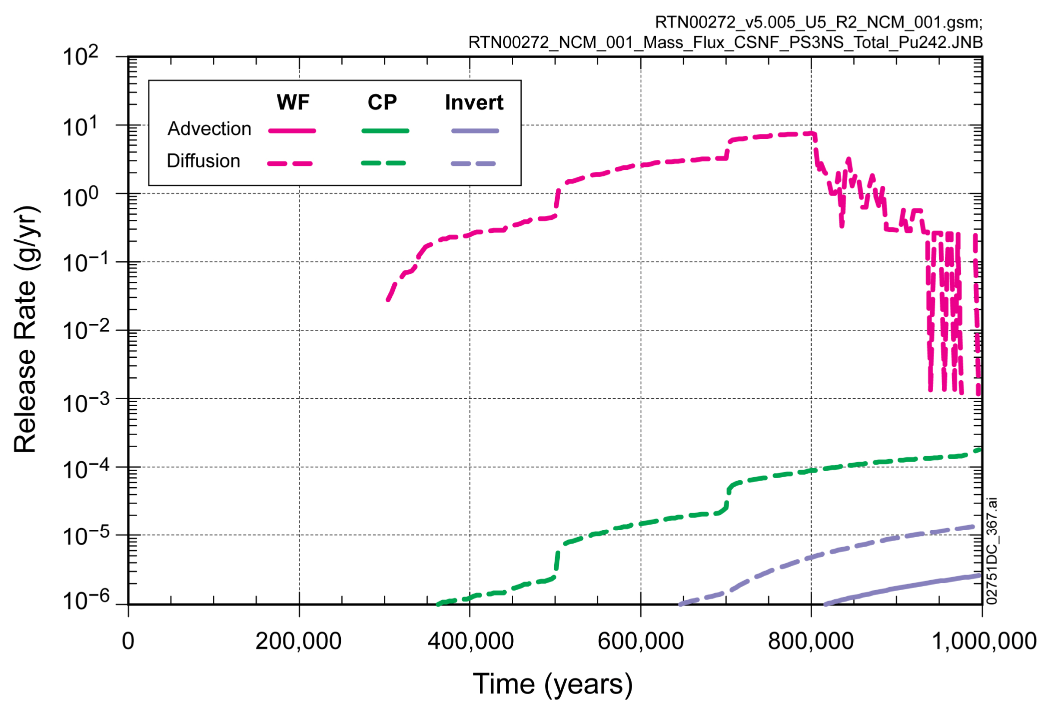


Figure 1.2-37. Release Rate of Total ^{242}Pu from Each EBS Domain from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

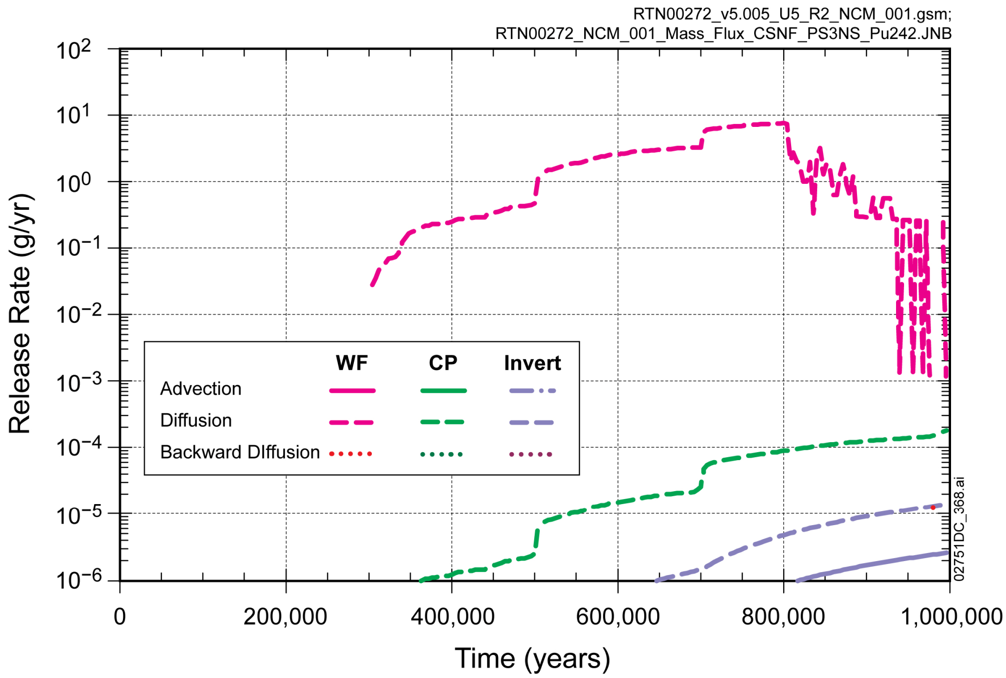


Figure 1.2-38. Release Rate of ^{242}Pu Dissolved and Reversibly Sorbed from Each EBS Domain from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

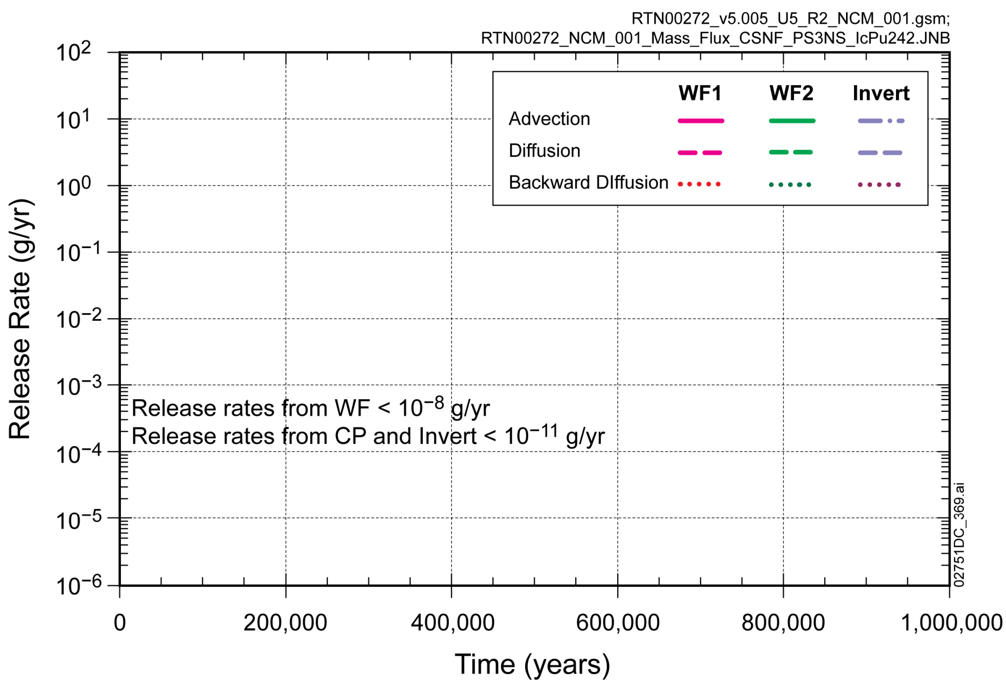


Figure 1.2-39. Release Rate of ^{242}Pu Irreversibly Attached to Waste Form (Ic) Colloids from Each EBS Domain from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

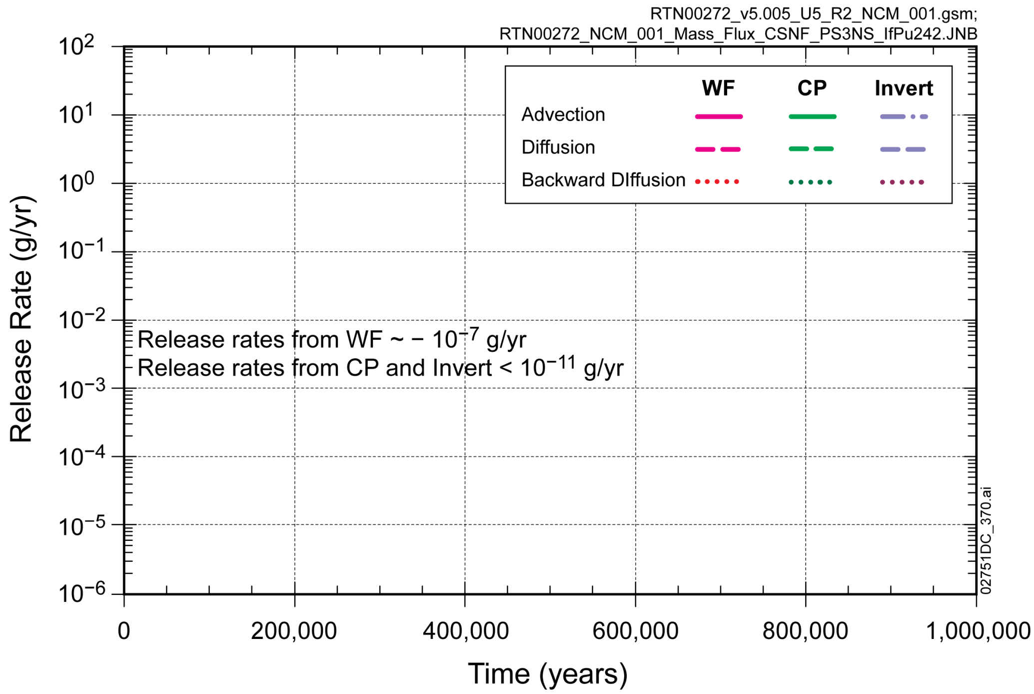


Figure 1.2-40. Release Rate of ^{242}Pu Irreversibly Attached to Iron Oxyhydroxide (If) Colloids from Each EBS Domain from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

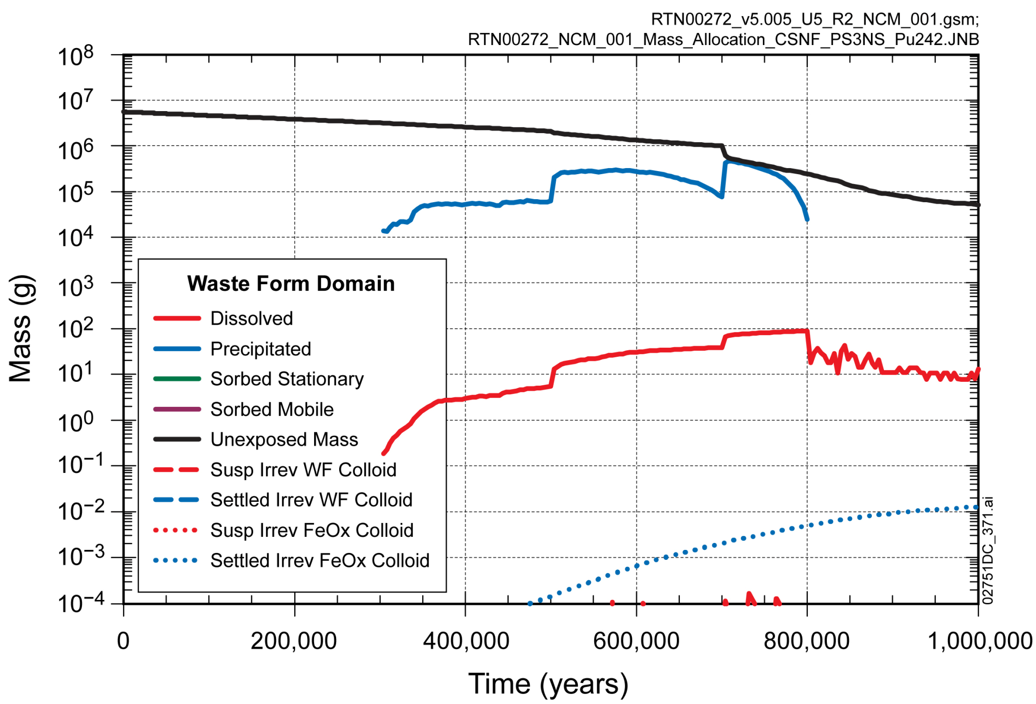


Figure 1.2-41. Mass of ^{242}Pu in the Commercial SNF Waste Form Domain from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

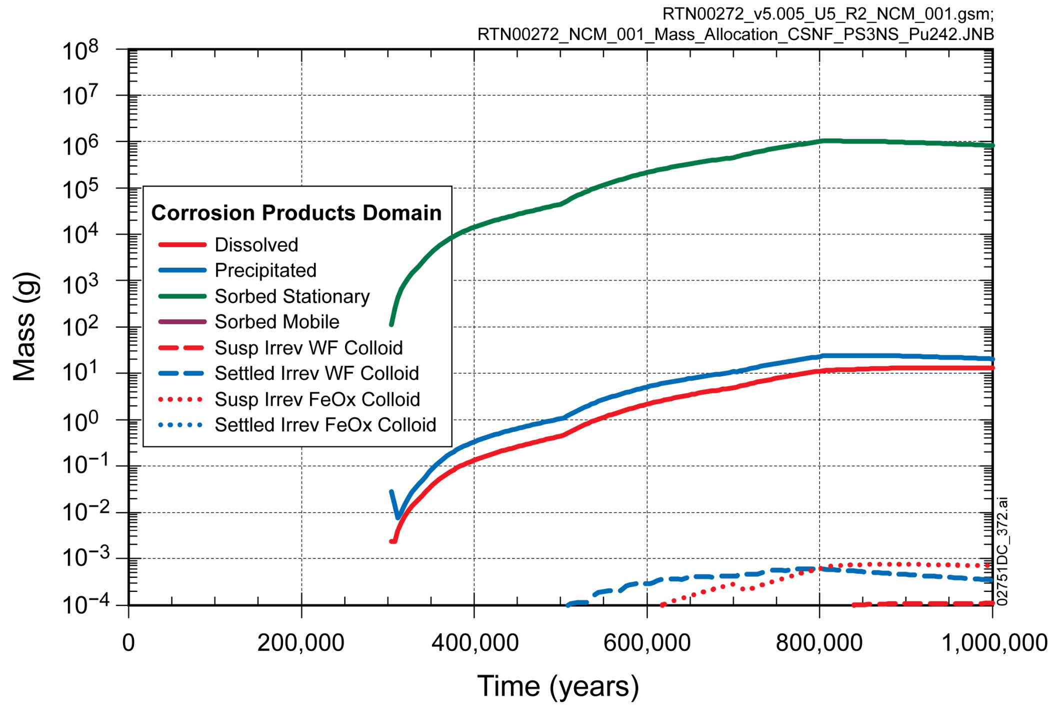


Figure 1.2-42. Mass of ^{242}Pu in the Corrosion Products Domain from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

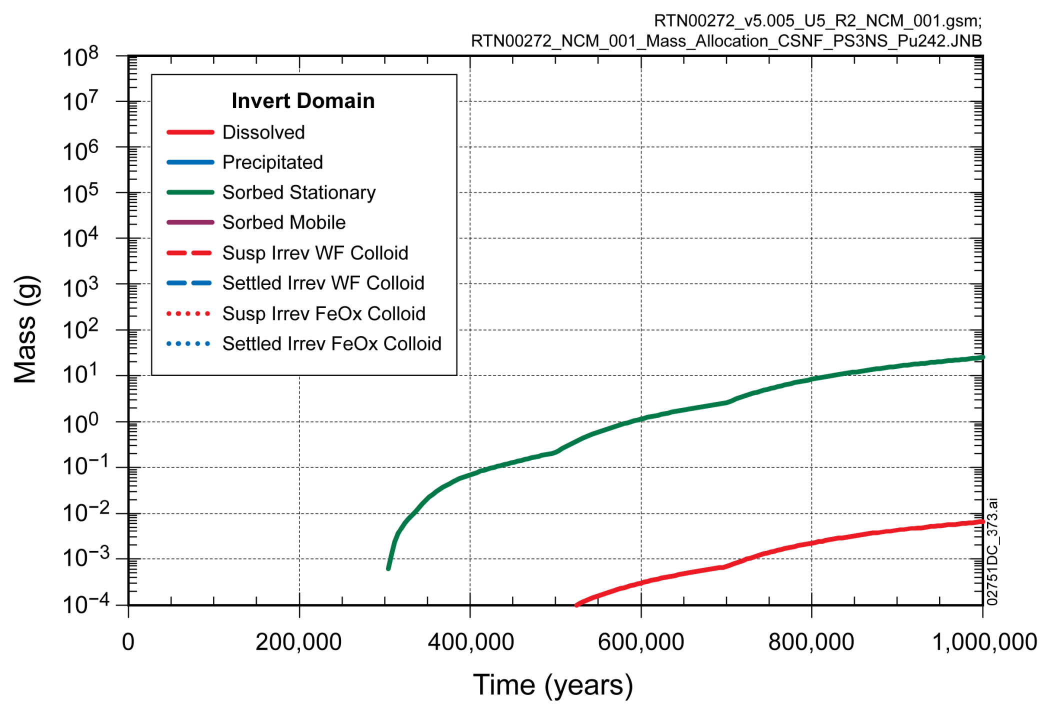


Figure 1.2-43. Mass of ^{242}Pu in the Invert from Commercial SNF Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

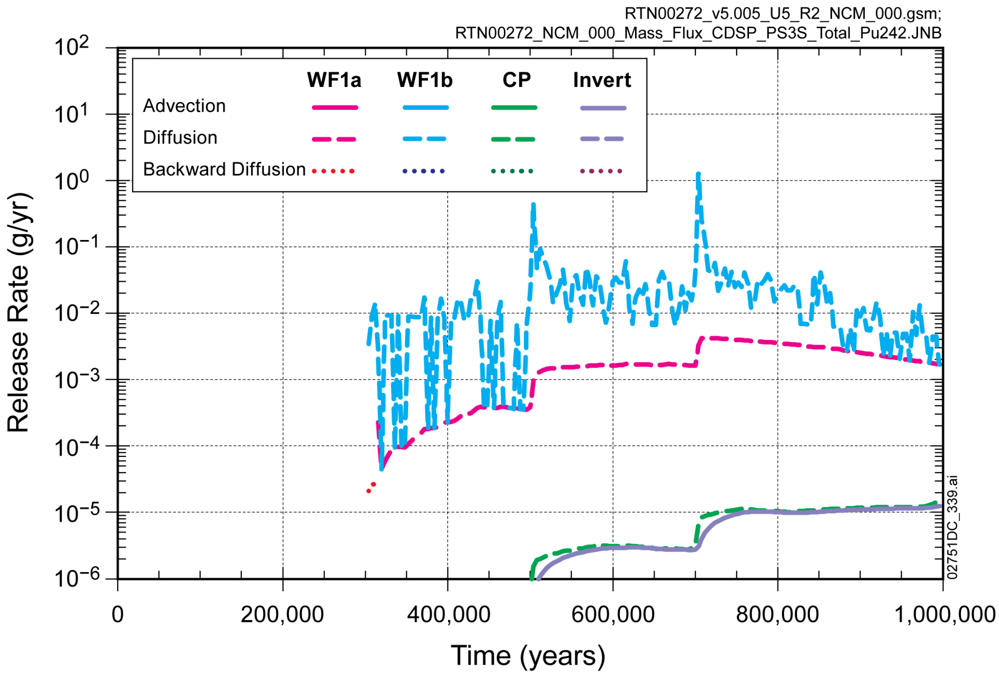


Figure 1.2-44. Release Rate of Total ^{242}Pu from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

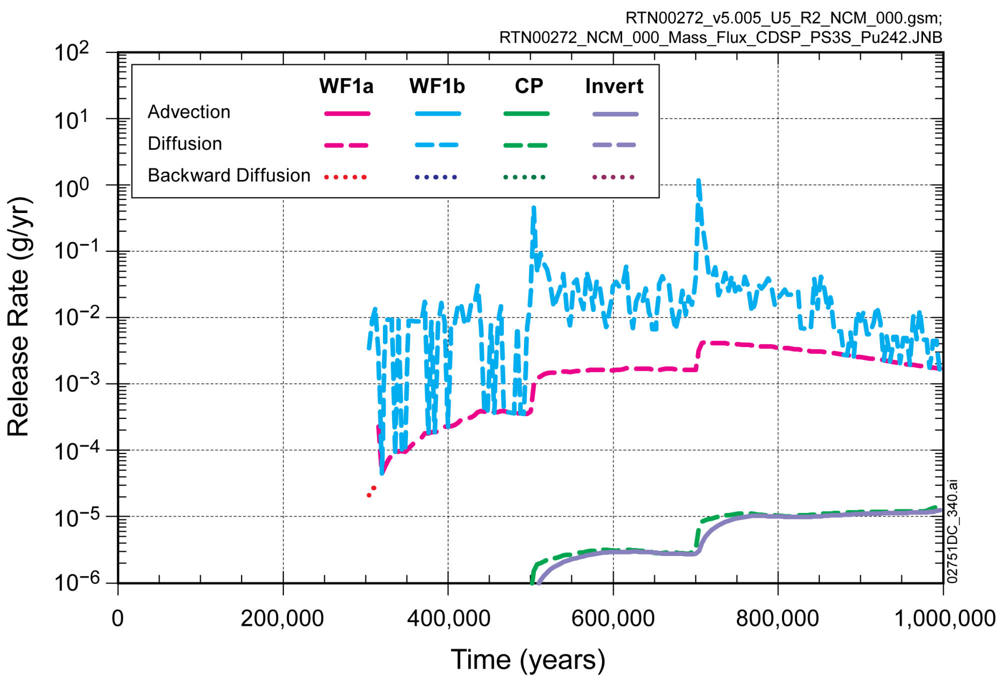


Figure 1.2-45. Release Rate of ^{242}Pu Dissolved and Reversibly Sorbed from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

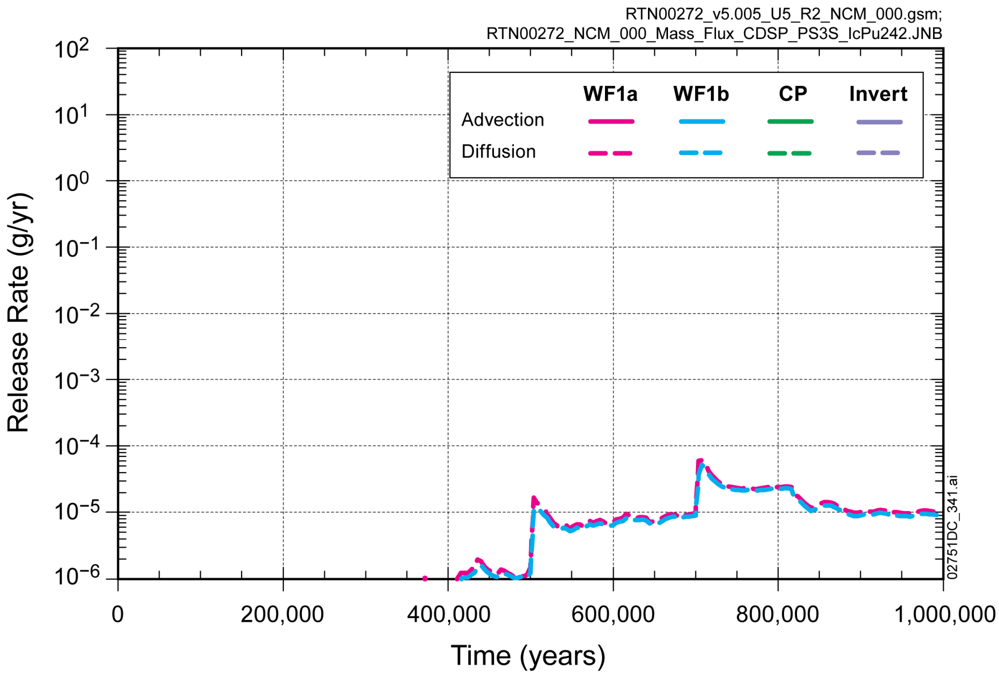


Figure 1.2-46. Release Rate of ^{242}Pu Irreversibly Attached to Waste Form (Ic) Colloids from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

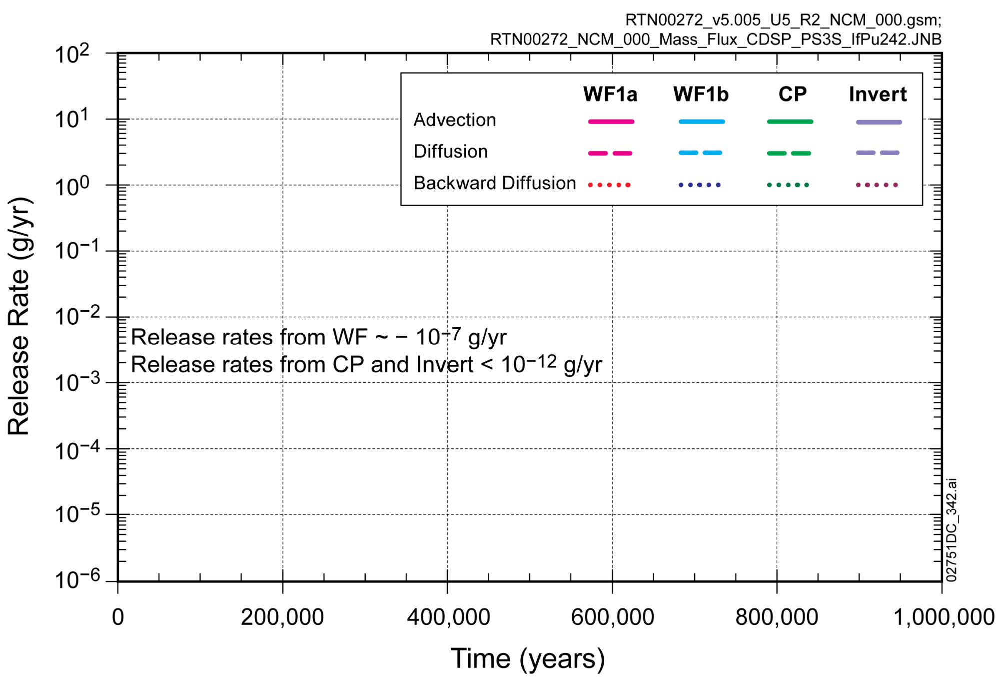


Figure 1.2-47. Release Rate of ^{242}Pu Irreversibly Attached to Iron Oxyhydroxide (If) Colloids from Each EBS Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

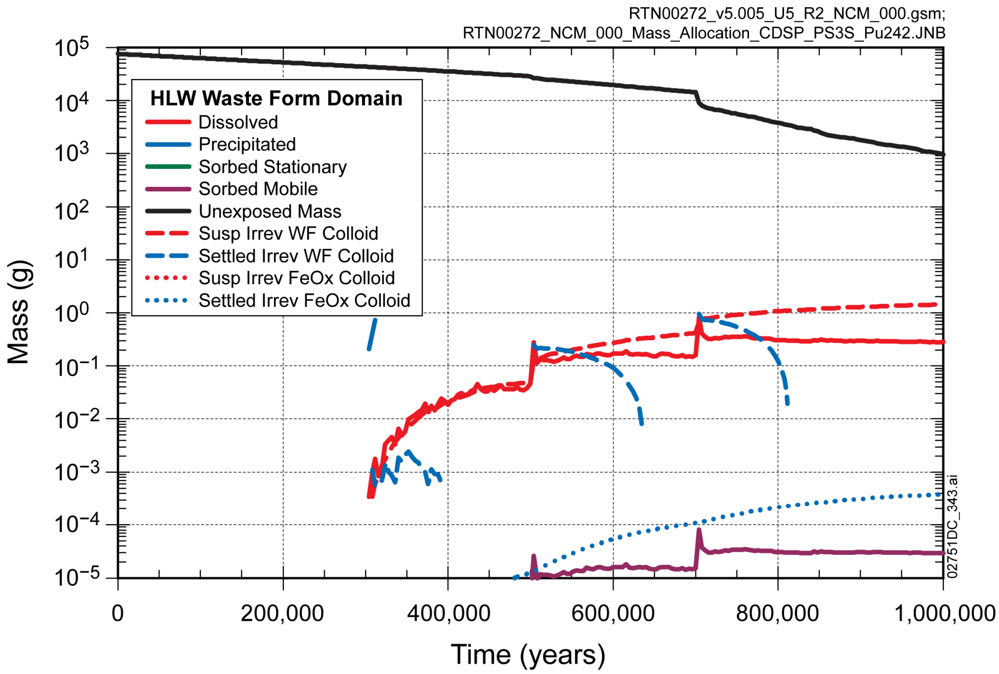


Figure 1.2-48. Mass of ^{242}Pu in the HLW Waste Form Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

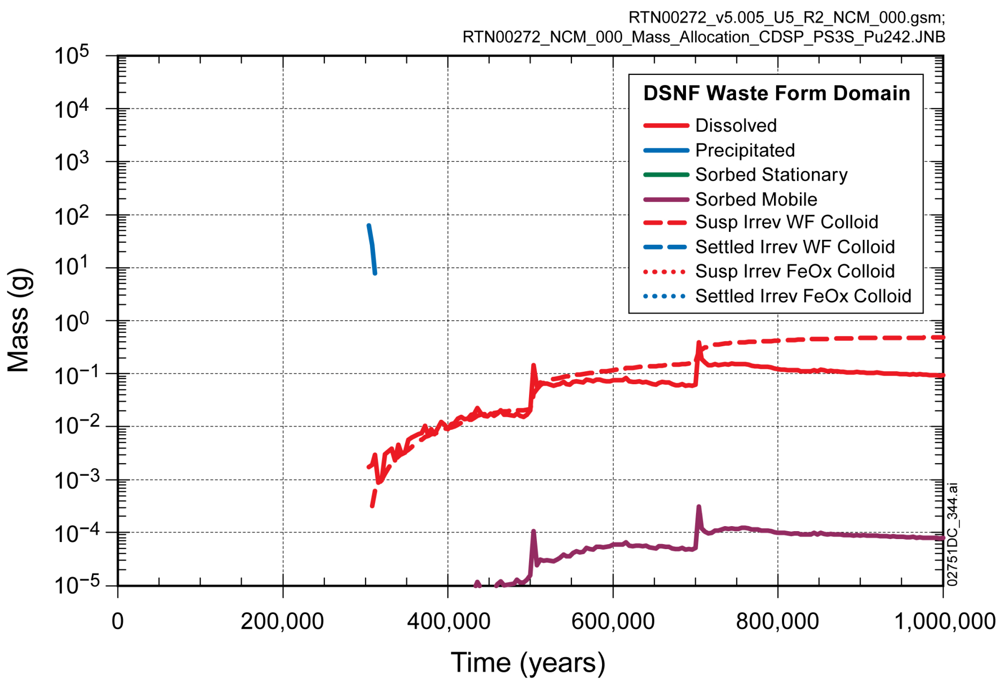


Figure 1.2-49. Mass of ^{242}Pu in the DOE SNF Waste Form Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

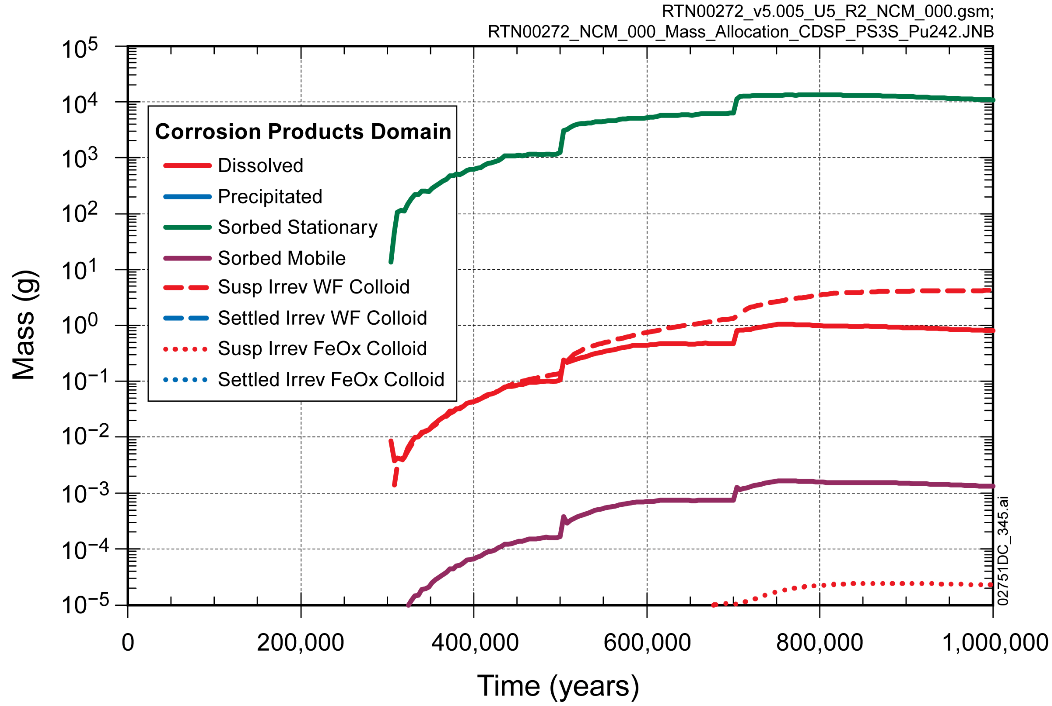


Figure 1.2-50. Mass of ^{242}Pu in the Corrosion Products Domain from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

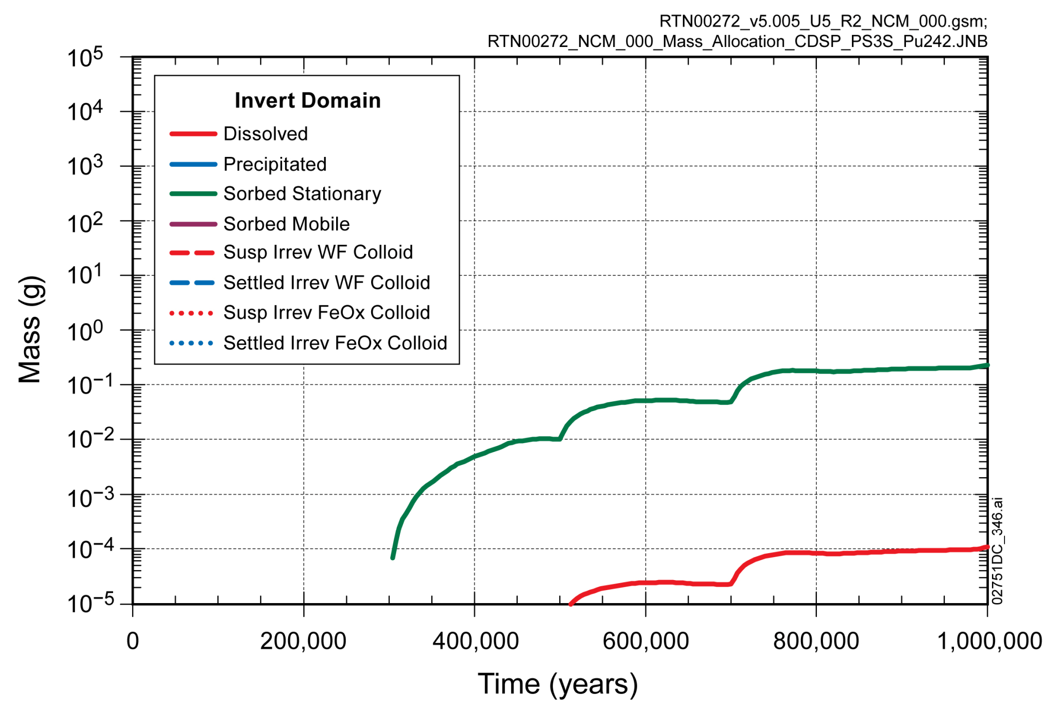


Figure 1.2-51. Mass of ^{242}Pu in the Invert from Codisposal Waste Packages in a Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

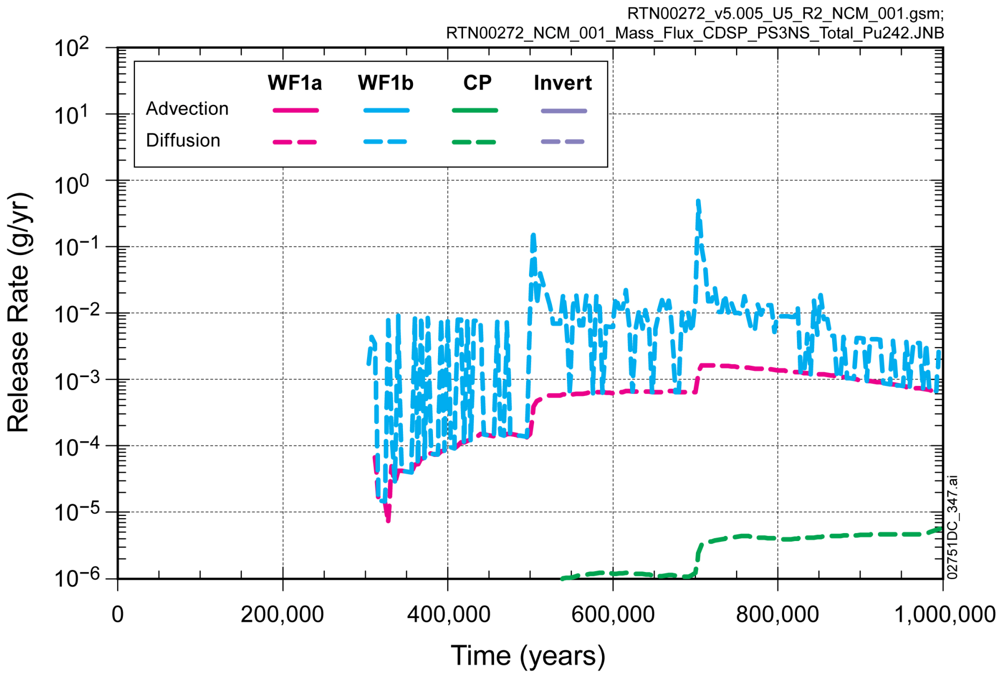


Figure 1.2-52. Release Rate of Total ^{242}Pu from Each EBS Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

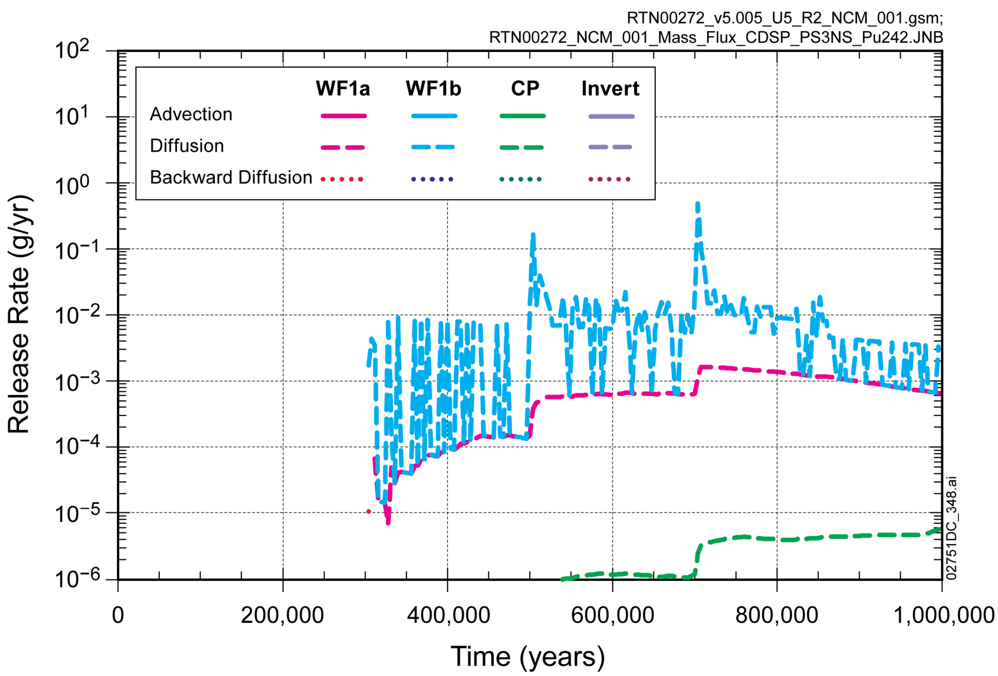


Figure 1.2-53. Release Rate of ^{242}Pu Dissolved and Reversibly Sorbed from Each EBS Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

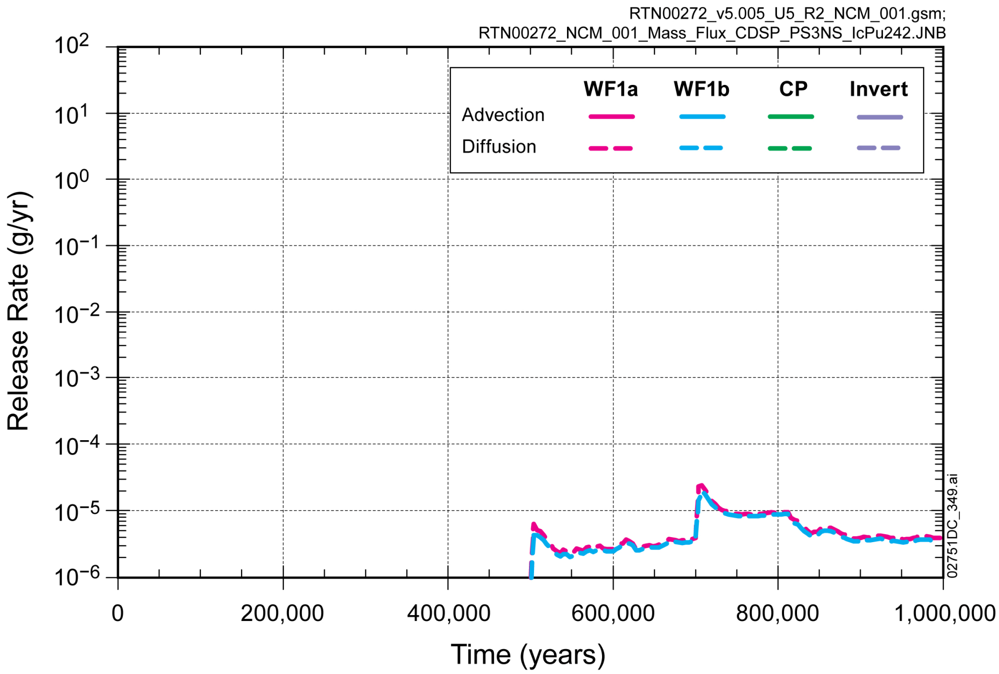


Figure 1.2-54. Release Rate of ^{242}Pu Irreversibly Attached to Waste Form (Ic) Colloids from Each EBS Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

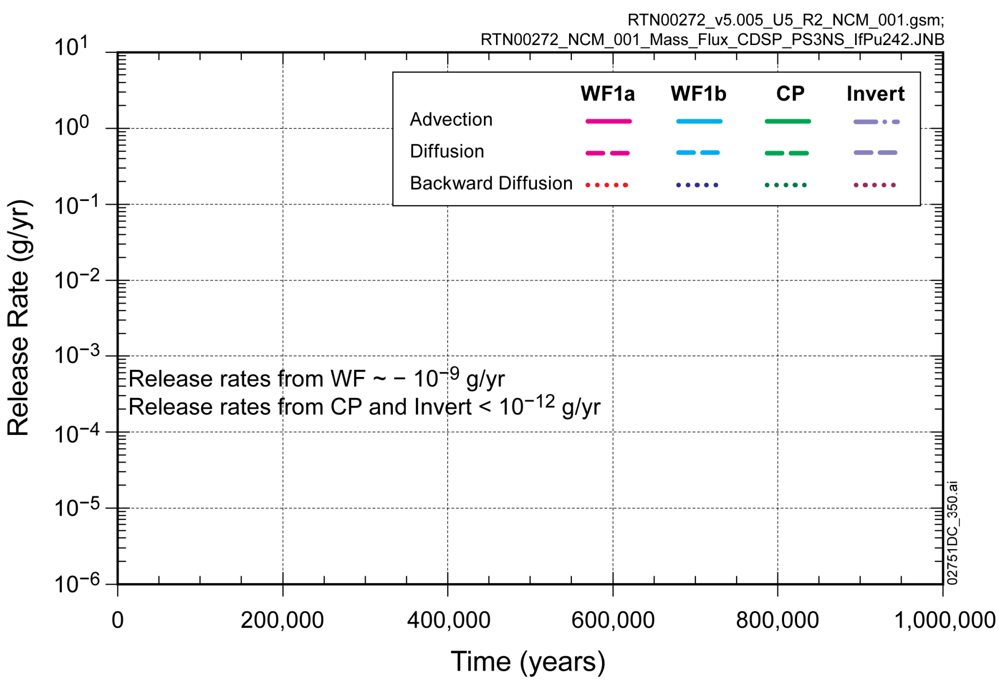


Figure 1.2-55. Release Rate of ^{242}Pu Irreversibly Attached to Iron Oxyhydroxide (If) Colloids from Each EBS Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

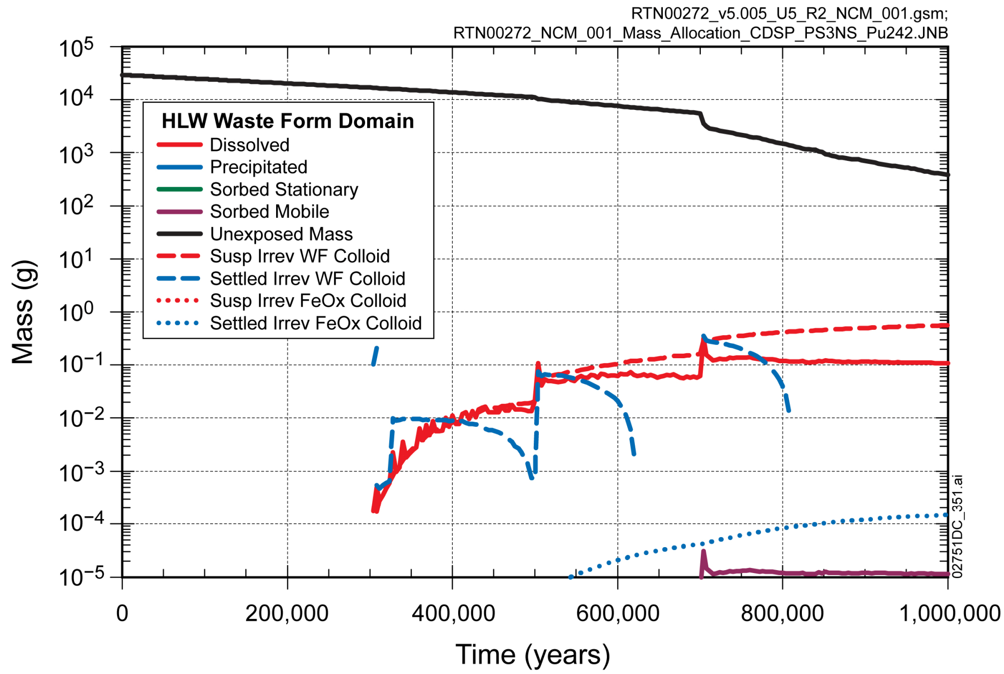


Figure 1.2-56. Mass of ^{242}Pu in the HLW Waste Form Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

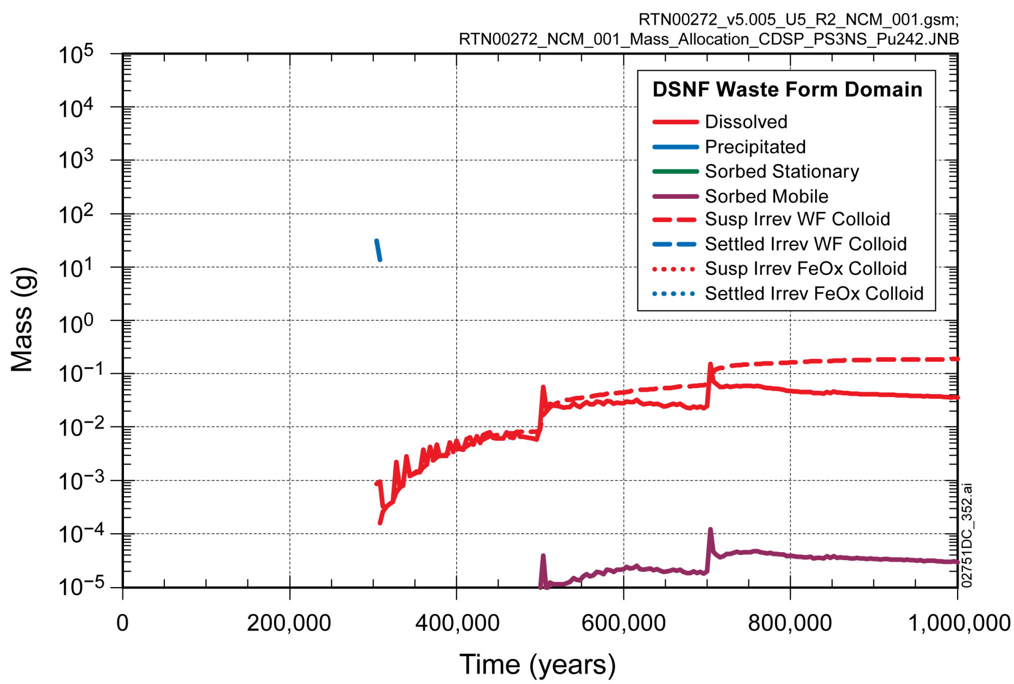


Figure 1.2-57. Mass of ^{242}Pu in the DOE SNF Waste Form Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

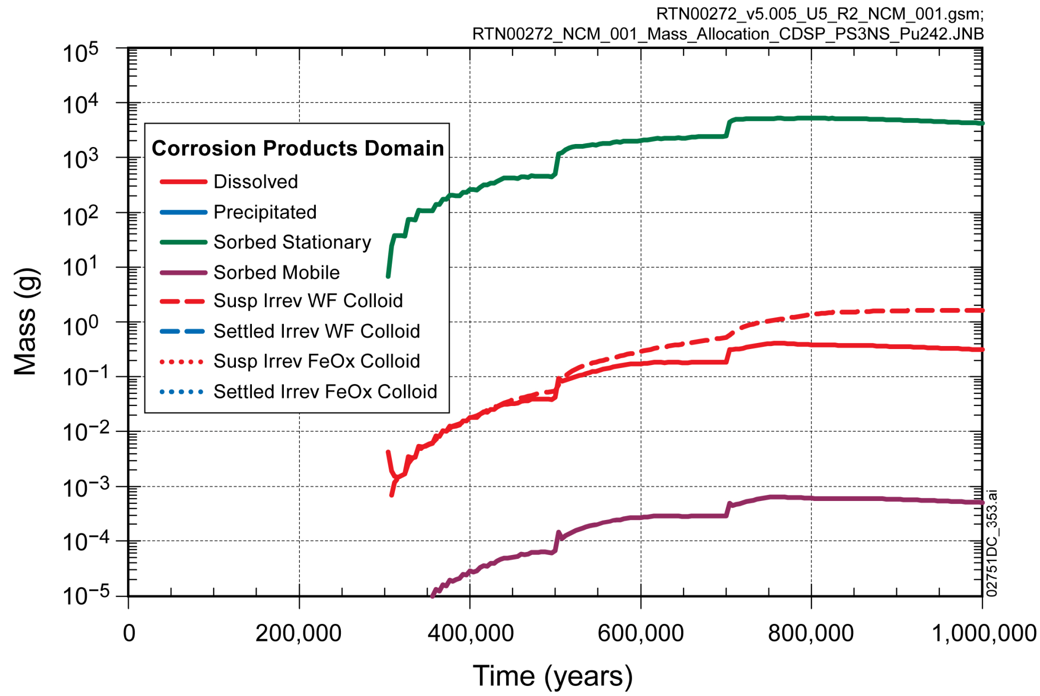


Figure 1.2-58. Mass of ^{242}Pu in the Corrosion Products Domain from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

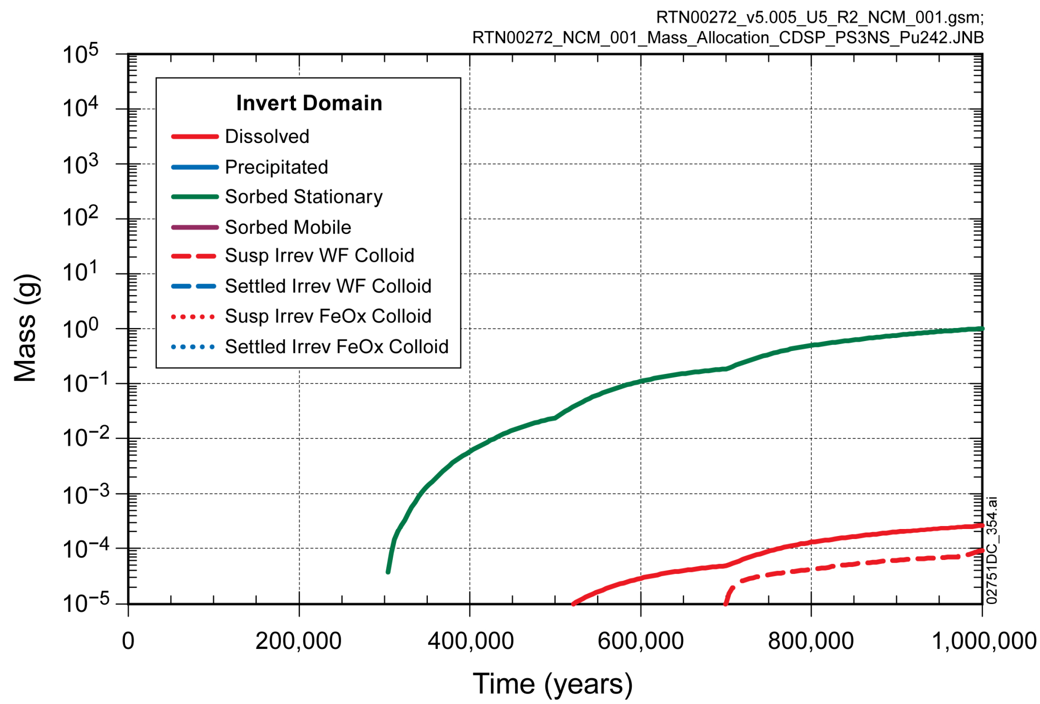


Figure 1.2-59. Mass of ^{242}Pu in the Invert from Codisposal Waste Packages in a Non-Seeping Environment of Percolation Subregion 3 for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure