# TASK 1.2: TECHNICAL MEMORANDUM – UPDATE WASTE INVENTORIES TO ACCOUNT FOR RADIOLOGICAL DECAY

**Revision 1**

*WEST VALLEY DEMONSTRATION PROJECT AND*
*WESTERN NEW YORK NUCLEAR SERVICE CENTER*

Prepared for:

**United States Department of Energy and**
**New York State Energy Research and Development Authority**

Prepared By:

**WEST VALLEY EXHUMATION WORKING GROUP**
**Enviro Compliance Solutions, Inc. (ECS)**

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***WEST VALLEY DEMONSTRATION PROJECT AND WESTERN NEW YORK NUCLEAR SERVICE CENTER***

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# Acronyms and Abbreviations

| | |
|---|---|
| Ac | actinium |
| Am | americium |
| At | astatine |
| Ba | barium |
| Bi | bismuth |
| BWR | boiling-water reactor |
| BWXT | Babcock & WilcoX Technologies, Inc. |
| C | carbon |
| CFR | *Code of Federal Regulations* |
| CHBWV | CH2M Hill BWXT West Valley, LLC |
| Ci | curie |
| Cm | curium |
| Co | cobalt |
| Cs | cesium |
| D&D | deactivation and decommissioning |
| DOE | United States Department of Energy |
| ECS | Enviro Compliance Solutions, Inc. |
| EXWG | West Valley Exhumation Working Group |
| FEIS | Final Environmental Impact Statement (DOE and NYSERDA 2010) |
| Fr | francium |
| Ft | foot/feet |
| $ft^3$ | cubic foot/feet |
| Gemini | Gemini Consulting Company |
| HLW | high-level waste |
| hr | hour(s) |
| m | meter(s) |
| MeV | mega-electron volt |
| min | minute(s) |
| MMC | Martin Marietta Corporation |
| mR/hr | milliroentgen per hour |
| mrem/hr | millirem per hour |
| Nb | niobium |
| NDA | NRC-Licensed Disposal Area |
| NFS | Nuclear Fuels Services, Inc. |
| Ni | nickel |
| Np | neptunium |
| NRC | United States Nuclear Regulatory Commission |
| ns | nanosecond |
| NYSERDA | New York State Energy Research and Development Authority |
| Pa | protactinium |
| Pb | lead |
| Pm | promethium |
| Pu | plutonium |
| PUREX | Plutonium-Uranium Recovery by EXtraction |
| R/hr | roentgen per hour |

| | |
|---|---|
| Ra | radium |
| rem/yr | rem per year |
| SDA | State-Licensed Disposal Area |
| sec | second(s) |
| Sr | strontium |
| STS IX | Supernatant Treatment System Ion Exchange column |
| Th | thorium |
| THOREX | THOrium Recovery by EXtraction |
| U | uranium |
| WNYNSC | Western New York Nuclear Service Center |
| WTF | Waste Tank Farm |
| WVDP | West Valley Demonstration Project |
| WVNSCO | West Valley Nuclear Services Company, Inc. |
| Y | yttrium |
| yr | year(s) |

# Executive Summary

Enviro Compliance Solutions, Inc. (ECS) and the West Valley Exhumation Working Group (EXWG) are performing exhumation-related studies as part of the Phase 1 Studies at the West Valley Demonstration Project (WVDP) and Western New York Nuclear Service Center (WNYNSC). The purpose of the collective Phase 1 exhumation studies is to enable improved scoping of future exhumation alternatives at the WVDP and WNYNSC, to evaluate and potentially reduce the associated uncertainty, and to assist the agencies in reaching consensus on those waste exhumation alternatives eventually selected for final analysis. The EXWG is concentrating on three areas within the WNYNSC: the State-Licensed Disposal Area (SDA), the U.S. Nuclear Regulatory Commission (NRC)-Licensed Disposal Area (NDA), and the Waste Tank Farm (WTF).

## A. Purpose of Task 1.2

In the case of the exhumation studies, the problems to be studied and the questions to be resolved are to be formulated in light of a series of seven topical questions previously prepared by the agencies to help the EXWG focus on those areas for which further analysis may facilitate interagency consensus related to exhumation alternatives. This technical memorandum has been prepared as a response to the following question:

> ***Question 5:*** Would answers to any of the above questions change if we waited for 30, 60, 90, or 120 years before undertaking the action? For example, could the action go from a remote action to a contact-handled action?

Task 1.2 was performed for the purpose of updating the most recent published inventories selected for use in the Phase I Studies to account for radioactive decay since the base year used in the original development of the inventories. In particular, URS (2002) SDA, URS (2000) NDA, and WVNSCO and Gemini (2005) WTF inventory estimates, as corrected based on results of the EXWG's Task 1.1 work, were decayed using the Bateman equation to 2020 (the new base year) and to 2050, 2080, 2110, and 2140, as specified in Question 5.

## B. Summary of Results

### 1. State-Licensed Disposal Area

Using the Bateman equation, the United Research Services Corporation (URS) SDA inventory (URS 2002; adjusted to account for strontium-90 [Sr-90] shipped from the Martin-Marietta – Quehanna facility) was decayed from the original Year 2000 base year to 2020 (the new base year) and to 2050, 2080, 2110, and 2140. In order to maintain consistency with the URS (2002) inventory, the decay calculations were performed by radionuclide for each trench and 50-foot trench segment for the SDA.

The volume of generated data is consequently very large and would require six 15-page tables, or a total of 90 pages, to include all the updated and projected data for the SDA in this report. Therefore, the more detailed decayed inventories are provided by radionuclide, trench, and 50-foot trench segment in six Microsoft Excel® files being provided separately (i.e., *SDA Inventory – 2000.xlsx*, *SDA Inventory – 2020.xlsx, SDA*

*Inventory – 2050.xlsx*, *SDA Inventory – 2080.xlsx*, *SDA Inventory – 2110.xlsx*, *SDA Inventory – 2140.xlsx*). The format used in these Excel files is similar to that used in Appendix C of the original inventory (URS 2002). The use of separate Excel files has the advantage of having the decayed SDA inventories readily available in electronic format for use by others in related studies.

To show the overall impact of radiological decay, Table ES-1 shows the SDA decayed total inventory at each of the six decay times.

**Table ES-1: SDA Decayed Total Inventory**

| Nuclide | SDA Decayed Inventory (Ci) | | | | | |
|---|---|---|---|---|---|---|
| | 2000 | 2020 | 2050 | 2080 | 2110 | 2140 |
| H-3 | 4.1E+04 | 1.3E+04 | 2.5E+03 | 4.5E+02 | 8.3E+01 | 1.5E+01 |
| Pu-238 | 2.7E+04 | 2.3E+04 | 1.8E+04 | 1.4E+04 | 1.1E+04 | 8.8E+03 |
| Ni-63 | 2.1E+04 | 1.8E+04 | 1.4E+04 | 1.2E+04 | 9.3E+03 | 7.5E+03 |
| Cs-137 | 1.3E+04 | 8.1E+03 | 4.1E+03 | 2.0E+03 | 1.0E+03 | 5.1E+02 |
| Sr-90 | 7.7E+03 | 4.7E+03 | 2.3E+03 | 1.1E+03 | 5.3E+02 | 2.6E+02 |
| Co-60 | 5.2E+03 | 3.8E+02 | 7.3E+00 | 1.4E-01 | 2.7E-03 | 5.3E-05 |
| Pu-241 | 3.8E+03 | 1.5E+03 | 3.5E+02 | 8.1E+01 | 1.9E+01 | 4.5E+00 |
| Ni-59 | 8.0E+02 | 8.0E+02 | 7.9E+02 | 7.9E+02 | 7.9E+02 | 7.9E+02 |
| Am-241 | 4.3E+02 | 5.0E+02 | 5.1E+02 | 4.9E+02 | 4.7E+02 | 4.5E+02 |
| C-14 | 3.0E+02 | 3.0E+02 | 3.0E+02 | 3.0E+02 | 3.0E+02 | 3.0E+02 |
| U-238 | 1.9E+02 | 1.9E+02 | 1.9E+02 | 1.9E+02 | 1.9E+02 | 1.9E+02 |
| Pu-239 | 1.8E+02 | 1.8E+02 | 1.8E+02 | 1.8E+02 | 1.8E+02 | 1.8E+02 |
| Pu-240 | 1.1E+02 | 1.1E+02 | 1.1E+02 | 1.1E+02 | 1.1E+02 | 1.1E+02 |
| Ra-226 | 2.7E+01 | 2.7E+01 | 2.7E+01 | 2.7E+01 | 2.7E+01 | 2.6E+01 |
| Th-230 | 1.2E+01 | 1.2E+01 | 1.2E+01 | 1.2E+01 | 1.2E+01 | 1.2E+01 |
| Th-232 | 6.6E+00 | 6.6E+00 | 6.6E+00 | 6.6E+00 | 6.6E+00 | 6.6E+00 |
| U-235 | 3.5E+00 | 3.5E+00 | 3.5E+00 | 3.5E+00 | 3.5E+00 | 3.5E+00 |
| I-129 | 2.9E+00 | 2.9E+00 | 2.9E+00 | 2.9E+00 | 2.9E+00 | 2.9E+00 |
| Tc-99 | 1.3E+00 | 1.3E+00 | 1.3E+00 | 1.3E+00 | 1.3E+00 | 1.3E+00 |
| All Others | 4.0E+02 | 7.9E+02 | 7.8E+02 | 7.8E+02 | 7.8E+02 | 7.8E+02 |
| Total | 1.2E+05 | 7.1E+04 | 4.4E+04 | 3.2E+04 | 2.5E+04 | 2.0E+04 |

Question 5 asked whether exhumation could "go from a remote action to a contact-handled action" if we waited for the specified times. The answer to that part of Question 5 is waste-area specific. In the case of the SDA, URS (2002) characterized 93.8% of the waste as Class A, and this analysis shows that by waiting approximately 90 years from the time of characterization, the Class A waste could be exhumed using contact-handled operations. Since URS (2002) used January 1, 2000, as its characterization date, contact-handled exhumation could begin as early as 2090. Additionally, it was shown that most (but not all) of the waste potentially requiring remote exhumation after 2090 is located in the special holes of Trench 6.

## 2. NRC-Licensed Disposal Area

Using the Bateman equation, the URS (2000) NDA inventory was decayed from the original base year of 2000 to 2020 (the new base year) and to 2050, 2080, 2110, and 2140, as specified in Question 5. A summary of the resulting decayed NDA inventory is provided in Table ES-2. The resulting decayed inventories for each NDA disposal hole are provided in the accompanying Excel file (i.e., *NDA Inventory by Hole – Decayed.xlsx*).

**Table ES-2: NDA Decayed Inventory**

| Nuclide | NDA Decayed Inventory (Ci) | | | | | |
|---|---|---|---|---|---|---|
| | 2000 | 2020 | 2050 | 2080 | 2110 | 2140 |
| Ni-63 | 1.2E+05 | 1.0E+05 | 8.1E+04 | 6.5E+04 | 5.3E+04 | 4.2E+04 |
| Cs-137 | 3.7E+04 | 2.3E+04 | 1.2E+04 | 5.9E+03 | 2.9E+03 | 1.5E+03 |
| Co-60 | 3.0E+04 | 2.1E+03 | 4.1E+01 | 8.0E-01 | 1.6E-02 | 3.0E-04 |
| Sr-90 | 2.9E+04 | 1.8E+04 | 8.6E+03 | 4.1E+03 | 2.0E+03 | 9.7E+02 |
| Pu-241 | 1.5E+04 | 5.9E+03 | 1.4E+03 | 3.3E+02 | 7.7E+01 | 1.8E+01 |
| Fe-55 | 1.8E+03 | 1.1E+01 | 4.9E-03 | 2.2E-06 | 9.9E-10 | 4.5E-13 |
| Am-241 | 1.8E+03 | 2.0E+03 | 2.1E+03 | 2.0E+03 | 1.9E+03 | 1.8E+03 |
| Ni-59 | 1.1E+03 | 1.1E+03 | 1.1E+03 | 1.1E+03 | 1.1E+03 | 1.1E+03 |
| Pu-239 | 5.8E+02 | 5.8E+02 | 5.8E+02 | 5.8E+02 | 5.8E+02 | 5.8E+02 |
| C-14 | 5.2E+02 | 5.2E+02 | 5.1E+02 | 5.1E+02 | 5.1E+02 | 5.1E+02 |
| Pu-240 | 4.0E+02 | 4.0E+02 | 4.0E+02 | 4.0E+02 | 3.9E+02 | 3.9E+02 |
| H-3 | 6.5E+01 | 2.1E+01 | 3.9E+00 | 7.1E-01 | 1.3E-01 | 2.4E-02 |
| Tc-99 | 1.0E+01 | 1.0E+01 | 1.0E+01 | 1.0E+01 | 1.0E+01 | 1.0E+01 |
| U-238 | 1.5E+00 | 1.5E+00 | 1.5E+00 | 1.5E+00 | 1.5E+00 | 1.5E+00 |
| U-235 | 1.2E-01 | 1.2E-01 | 1.2E-01 | 1.2E-01 | 1.2E-01 | 1.2E-01 |
| I-129 | 2.1E-02 | 2.1E-02 | 2.1E-02 | 2.1E-02 | 2.1E-02 | 2.1E-02 |
| Th-232 | 8.9E-03 | 8.9E-03 | 8.9E-03 | 8.9E-03 | 8.9E-03 | 8.9E-03 |
| Th-230 | 3.7E-04 | 4.8E-04 | 6.4E-04 | 8.1E-04 | 9.9E-04 | 1.2E-03 |
| Ra-226 | 4.1E-06 | 7.7E-06 | 1.5E-05 | 2.4E-05 | 3.5E-05 | 4.9E-05 |
| All Others | 4.6E+02 | 3.7E+02 | 3.0E+02 | 2.5E+02 | 2.0E+02 | 1.7E+02 |
| Total | 3.0E+05 | 1.9E+05 | 1.3E+05 | 9.0E+04 | 6.7E+04 | 5.2E+04 |

It was found that about 52.1% of the waste disposed in the NDA could be exhumed using contact-handled operations in 2020, and that the percentage would increase to about 78.7% by waiting until 2140. Although most of the dose rate at the NDA is controlled by the decay of cesium-137 (Cs-137) (similar to both the SDA and WTF), a small volume of NDA waste (about 2.3%) contains sufficient niobium-94 (Nb-94) such that it would always require a shielded, remote action. Nb-94 is formed by the neutron activation of naturally occurring, stable Nb-93 that is added to stainless steel and Inconel® to increase their strength.

The plutonium distribution within the NDA was also evaluated. With the exception of about six holes, the plutonium-239 (Pu-239) inventory was found to be spread more or less uniformly throughout the NDA. The spent fuel disposed in Deep Hole 48 and the waste in Special Hole sh-99 each account for about 13% of the NDA Pu-239 inventory, and four other holes contain a total of 15.4%, which leaves about 59.5% of the Pu-239 activity spread throughout the remainder of the NDA. For example, each of the 12 WVDP trenches in the NDA is estimated to contain a total of 0.7% of the NDA Pu-239 inventory.

## 3. Waste Tank Farm

Using the Bateman equation, the West Valley Nuclear Services Company, Inc. and Gemini Consulting Company (WVNSCO and Gemini 2005) WTF inventory and the CH2M Hill BWXT West Valley, LLC (CHBWV 2012) WTF inventory were decayed from their respective base years to 2020 (the new base year) and to 2050, 2080, 2110, and 2140. A summary of the resulting decayed WTF inventories is provided in Table ES-3. More detailed decayed inventories, broken down by individual tank as well as by areas within

each tank, are provided in an accompanying Excel file (i.e., *WTDF Inventory – Decayed.xlsx*).

**Table ES-3: WTF Decayed Inventory**

| Nuclide | WTF Decayed Inventory (Ci) | | | | | |
|---|---|---|---|---|---|---|
| | 2005/12* | 2020 | 2050 | 2080 | 2110 | 2140 |
| Cs-137 | 3.49E+05 | 2.49E+05 | 1.25E+05 | 6.27E+04 | 3.15E+04 | 1.58E+04 |
| Sr-90 | 3.84E+04 | 2.70E+04 | 1.30E+04 | 6.30E+03 | 3.04E+03 | 1.47E+03 |
| Pu-241 | 7.84E+02 | 3.81E+02 | 8.99E+01 | 2.12E+01 | 5.00E+00 | 1.18E+00 |
| Pu-238 | 1.78E+02 | 1.59E+02 | 1.25E+02 | 9.89E+01 | 7.80E+01 | 6.16E+01 |
| Tc-99 | 9.40E+00 | 9.40E+00 | 9.40E+00 | 9.40E+00 | 9.40E+00 | 9.40E+00 |
| Pu-239 | 4.41E+01 | 4.41E+01 | 4.40E+01 | 4.40E+01 | 4.40E+01 | 4.39E+01 |
| Pu-240 | 2.71E+01 | 2.71E+01 | 2.70E+01 | 2.69E+01 | 2.68E+01 | 2.67E+01 |
| Am-241 | 4.35E+02 | 4.39E+02 | 4.28E+02 | 4.10E+02 | 3.91E+02 | 3.73E+02 |
| U-233 | 3.19E-01 | 3.19E-01 | 3.19E-01 | 3.19E-01 | 3.19E-01 | 3.19E-01 |
| U-234 | 1.34E-01 | 1.41E-01 | 1.53E-01 | 1.62E-01 | 1.70E-01 | 1.76E-01 |
| U-238 | 3.70E-02 | 3.70E-02 | 3.70E-02 | 3.70E-02 | 3.70E-02 | 3.70E-02 |
| Np-237 | 5.38E-01 | 5.40E-01 | 5.44E-01 | 5.48E-01 | 5.52E-01 | 5.56E-01 |
| C-14 | 3.20E-02 | 3.19E-02 | 3.18E-02 | 3.17E-02 | 3.16E-02 | 3.15E-02 |
| I-129 | 2.46E-02 | 2.46E-02 | 2.46E-02 | 2.46E-02 | 2.46E-02 | 2.46E-02 |
| U-235 | 4.68E-03 | 4.68E-03 | 4.68E-03 | 4.68E-03 | 4.68E-03 | 4.69E-03 |
| All Others | 0.00E+00 | 6.19E-01 | 6.23E-01 | 6.27E-01 | 6.31E-01 | 6.35E-01 |
| Total | 3.89E+05 | 5.39E+05 | 2.70E+05 | 1.35E+05 | 6.79E+04 | 3.42E+04 |

* For Tanks 8D-1 and 8D-2 WVNSCO and Gemini (2005) estimated the inventory at 2005; for Tank 8D-4 CHBWV (2012) estimated the inventory at 2012. For this summary table they have been added together, however, they were kept separate when the decay calculations were performed, as shown in the accompanying Excel file, *WTDF Inventory – Decayed.xlsx*.

For the WTF, it was shown that for quite some time past the 120-year time period of interest for this study, the residual inventory in Tanks 8D-1 and 8D-2 would remain large enough to require shielding and remote operations during any exhumation action. This conclusion was not only based on the WVNSCO and Gemini (2005) inventory estimates, but also on the actual Tank 8D-1 radiation measurements that were taken in February 2001.

# I. Introduction and Background

Enviro Compliance Solutions, Inc. (ECS) and the West Valley Exhumation Working Group (EXWG) are performing exhumation-related studies as part of the Phase 1 Studies at the West Valley Demonstration Project (WVDP) and Western New York Nuclear Service Center (WNYNSC). The purpose of the collective Phase 1 exhumation studies is to enable improved scoping of future exhumation alternatives at the WVDP and WNYNSC, to evaluate and potentially reduce the associated uncertainty, and to assist the agencies in reaching consensus on those waste exhumation alternatives eventually selected for final analysis.

## A. Purpose of Task 1.2

In the case of the exhumation studies, the problems to be studied and the questions to be resolved are to be formulated in light of a series of seven topical questions previously prepared by the agencies to help the EXWG focus on those areas for which further analysis may facilitate interagency consensus related to exhumation alternatives. This technical memorandum has been prepared as a response to the following agencies prepared question:

> ***Question 5:*** Would answers to any of the above questions change if we waited for 30, 60, 90, or 120 years before undertaking the action? For example, could the action go from a remote action to a contact-handled action?

Current and former EXWG members were the primary developers of the most current waste inventories for the State-Licensed Disposal Area (SDA), U.S. Nuclear Regulatory Commission (NRC)-Licensed Disposal Area (NDA), and Waste Tank Farm (WTF), as reported in the following documents:

- *Estimated Radionuclide Inventory for the NRC-Licensed Disposal Area at the West Valley Demonstration Project Volume 1 Main Report* (URS Corporation (URS) 2000)
- *SDA Radiological Characterization Report* (URS 2002)
- *Residual Radionuclide Inventory Estimate for the Waste Tank Farm, Supplemental Report* (West Valley Nuclear Services Company, Inc. and Gemini Consulting Company [WVNSCO and Gemini] 2005)

The recently completed Task 1.1 technical memorandum (ECS 2016) compared the inventories from these three documents to other attempts to quantify the waste inventories of the SDA, NDA, and WTF over the last 40 years and concluded that these inventories are the most recent and robust waste inventories yet developed for the corresponding waste areas. The three inventories, including minor corrections documented in the Task 1.1 work, were thus selected for use in the proposed Phase I studies.

Because the three reports estimate the inventories as of 2000 (URS 2000 and URS 2002) or 2005 (WVNSCO 2005), Task 1.2 was performed for the purpose of updating the inventories to account for radioactive decay and ingrowth since the base year used in

the original development of the inventories. The first step in this study was to update the inventories to a new base year of 2020. Once the new base year inventories had been calculated, then the effects of waiting for each of the four periods specified in Question 5 were determined.

## B. Report Organization

This technical memorandum is organized into the following six sections in addition to the introductory section (Section I: Introduction and Background):

- Section II: Methodology
- Section III: State-Licensed Disposal Area
- Section IV: NRC-Licensed Disposal Area
- Section V: Waste Tank Farm
- Section VI: Summary of Results
- Section VII: References

Section II: Methodology briefly describes the approach that has been taken to calculate the radiological decay and buildup of the radionuclides contained within the inventory estimates, including an explanation of how the well-known Bateman equation was applied. Within each of the next three main sections (Sections III–V), a brief description of the inventory for each of the respective waste areas, as presented in URS (2002), URS (2000), and WVNSCO and Gemini (2005), is provided. This is followed in Section VI by a presentation and discussion of the projected inventories for each waste area for the Year 2020 and for each of the other four specified wait times. A discussion of what effects the projected waste inventory estimates will have on the shielding requirements for each of the three waste areas is also included in Section VI.

# II. Methodology

For the NDA and SDA, URS 2000 and URS 2002 present estimates for 230 radionuclides, including a significant number of radionuclides with zero reported inventory values (e.g., 87 radionuclides for the SDA). However, URS 2002 indicates that over 99% of the activity is due to 17 "Principal Radionuclides." To limit the amount of work to be performed in this task while still meeting the project objectives, 58 radionuclides were selected for inclusion in the waste inventory updates. Among the 58 radionuclides are those that are either (1) required for Part 61 waste classification, (2) potentially important to public health and worker safety, (3) required as part of a natural decay series.

Using these criteria, the updated inventory estimates were calculated for the 58 radionuclides identified in Table II-1. The selected list includes all 17 of the "Principal Radionuclides" from the URS 2002 inventory, as well as 31 of the 33 "Primary Nuclides" analyzed by Garrick et al. (2009). The other two primary radionuclides from the Garrick et al. study, promethium-137 (Pm-137) and curium-242 (Cm-242), were not included in the proposed study because they are not part of a decay chain, they were not a significant term in the 2000 inventory, and they have short half-lives.

**Table II-1: Radionuclides Included in the SDA and NDA Inventories**

| | | | | | |
|---|---|---|---|---|---|
| H-3 ^* | Kr-85 | Pu-238 ^* | Pb-214 | Ra-224 | Pa-231 * |
| Ni-63 ^* | Cs-135 * | U-238 ^* | Bi-214 | Rn-220 | Ac-227 * |
| Cs-137 ^* | I-129 * | Th-234 ^ | Po-214 | Po-216 | Th-227 |
| Ba-137m ^ | Am-243 | Pa-234m ^ | Pb-210 * | Pb-212 | Pu-241 ^* |
| Co-60 ^* | Np-239 | Pa-234 | Bi-210 | Bi-212 | Am-241 ^* |
| Ni-59 ^* | Tc-99 * | U-234 * | Po-210 * | Po-212 | Np-237 |
| C-14 ^* | Cl-36 | Th-230 * | Th-232 * | Tl-208 | Pa-233 |
| Fe-55 ^* | Zr-93 * | Ra-226 * | Ra-228 * | Pu-239 ^* | U-233 * |
| Sr-90 ^* | Nb-94 * | Rn-222 | Ac-228 | U-235 * | |
| Y-90 ^ | Pu-240 * | Po-218 | Th-228 * | Th-231 | |

^ Indicates a URS 2002 "Principal Radionuclide."
* Indicates a Garrick et al. 2009 "Primary Nuclide."

The 2005 WTF inventory was based on conditions in Year 2005. This inventory was developed only for the 18 radionuclides determined to be important with respect to conducting the 2010 WVDP Performance Assessment. The revised 2020 base inventory and the projected future inventories included these same 18 radionuclides, as identified in Table II-2. The 18 WTF radionuclides differ somewhat from the 17 URS 2002 "Principal Radionuclides," primarily because the WTF does not contain activation products that do not carry over into high-level waste (HLW).

**Table II-2: Radionuclides Included in the WTF Inventory**

| | | | | | |
|---|---|---|---|---|---|
| C-14 | I-129 | U-233 | Np-237 | Pu-239 | Am-241 |
| Sr-90 | Cs-137 | U-234 | U-238 | Pu-240 | Cm-243 |
| Tc-99 | U-232 | U-235 | Pu-238 | Pu-241 | Cm-244 |

Many radionuclides do not decay directly to a stable state but rather undergo a series of decays until a stable isotope is eventually reached. There are four such radionuclide decay series, commonly called the uranium, thorium, neptunium, and actinium series. Radionuclides from each of these four decay series are included in both Table II-1 and Table II-2, and how their radionuclide decays (of daughter) products were included in the decayed inventories is discussed in the sections below. In addition, there are a number of radionuclides that are not part of a decay series but rather decay directly to a stable isotope.

In order to explain their experiments with radioactive substances, Ernest Rutherford and Frederick Soddy first formulated the exponential laws which govern the decay and growth of radioactive substances in 1902. In 1910, a useful mathematical generalization of the Rutherford and Soddy radioactive decay and in-growth laws were made by mathematician Harry Bateman. Thus, the more general form of the decay and in-growth equation, shown below, is often referred to as the "Bateman equation."

$$N_n(t) = \sum_{i=1}^{n}\left[N_i(0)\times\left(\prod_{j=i}^{n-1}\lambda_j\right)\times\left(\sum_{j=i}^{n}\left(\frac{e^{-\lambda_j t}}{\prod_{k=i,k\neq j}^{n}(\lambda_k-\lambda_j)}\right)\right)\right] \quad \text{II-1}$$

where:
$N_n(t)$ = Amount of radionuclide *n* at time *t* (atoms)
$N_i(0)$ = Initial amount of radionuclide *i* (atoms)
$\lambda_i$ = Radionuclide *i* decay constant ($yr^{-1}$)
$t$ = Time (yr)

The Bateman equation can be used to calculate the abundance of a radionuclide, whether it is a single radionuclide or a member of a long decay series. The following subsections describe how the Bateman equation was applied to the SDA, NDA, and WTF inventory estimates to arrive at new base year estimates and estimates for the four future time periods specified in Question 5.

## A. Simple Decay

For simple radiological decay (i.e., the decay of a single radionuclide), the Bateman equation reduces to the familiar:

$$N_1(t) = N_1(0)\,e^{-\lambda_1 t} \quad \text{II-2}$$

or

$$A_1(t) = A_1(0)\,e^{-\lambda_1 t} \quad \text{II-3}$$

where:
$A_1(t)$ = Activity of radionuclide *i* at time *t* (Ci)
All other terms previously defined.

Likewise, for the buildup of the first daughter radionuclide, it can be shown that the Bateman equation reduces to:

$$N_2(t) = N_1(0)\,\frac{\lambda_1}{\lambda_2-\lambda_1}\left(e^{-\lambda_1 t}-e^{-\lambda_2 t}\right)+N_2(0)e^{-\lambda_2 t} \quad \text{II-4}$$

or

$$A_2(t) = A_1(0)\,\frac{\lambda_2}{\lambda_2-\lambda_1}\left(e^{-\lambda_1 t}-e^{-\lambda_2 t}\right)+A_2(0)e^{-\lambda_2 t} \quad \text{II-5}$$

All terms previously defined.

If in Equation II-5 the half-life (T½) of the parent is long compared to the half-life of the daughter, then the term $\frac{\lambda_2}{\lambda_2-\lambda_1}$ approaches 1 (e.g., for strontium-90 [Sr-90] [T½ = 28.6 yr] and yttrium-90 [Y-90] [T½ = 64 hr], $\frac{\lambda_2}{\lambda_2-\lambda_1}$ = 1.000255); and if the time period is long compared to the half-life of the daughter, then the term $e^{-\lambda_2 t}$ approaches 0 (e.g., if $t$ = 10 × T½, $e^{-\lambda_2 t}$ = 0.000977). When these two conditions are met, Equation II-5 reduces to:

$$A_2(t) = A_1(0)\, e^{-\lambda_1 t} \qquad \text{II-6}$$

Notice that the right-hand term of Equation II-6 is the same as the right-hand term of Equation II-3, meaning that the daughter's radioactivity is the same as the parent's radioactivity and secular equilibrium has been reached. Due to the long time periods of interest for this study (e.g., 30 years), all radionuclides with a half-life of 1 year or less are assumed to be in equilibrium with their parent radionuclide.

Table II-3 lists the radionuclides included in this analysis that were evaluated using simple radiological decay, including cesium-137 (Cs-137) and Sr-90 and their short-lived daughters, barium-137m (Ba-137m) and Y-90, which were assumed to be in equilibrium. Table II-3 also shows the effect that radiological decay has on these simple decay radionuclides over the time periods of interest. In Table II-3, the radionuclides are presented from short to long half-life, so that those radionuclides near the top of the table show the greatest amount of radiological decay, while those near the bottom show virtually no decay.

**Table II-3: Non-Series Radionuclide Simple Decay**

| Nuclide | Half-Life | | Remaining Percentage of Year 2000 Amount | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2000 | 2020 | 2050 | 2080 | 2110 | 2140 |
| Fe-55 | 2.7 | yr | 100.0% | 0.6% | 0.0% | 0.0% | 0.0% | 0.0% |
| Co-60 | 5.271 | yr | 100.0% | 7.2% | 0.1% | 0.0% | 0.0% | 0.0% |
| Kr-85 | 10.72 | yr | 100.0% | 27.4% | 3.9% | 0.6% | 0.1% | 0.0% |
| H-3 | 12.28 | yr | 100.0% | 32.3% | 5.9% | 1.1% | 0.2% | 0.0% |
| Sr-90 | 28.6 | yr | 100.0% | 61.6% | 29.8% | 14.4% | 7.0% | 3.4% |
| Y-90 | 64 | hr | 100.0% | 61.6% | 29.8% | 14.4% | 7.0% | 3.4% |
| Cs-137 | 30.17 | yr | 100.0% | 63.2% | 31.7% | 15.9% | 8.0% | 4.0% |
| Ba-137m | 2.552 | min | 100.0% | 63.2% | 31.7% | 15.9% | 8.0% | 4.0% |
| Ni-63 | 96 | yr | 100.0% | 86.6% | 69.7% | 56.1% | 45.2% | 36.4% |
| C-14 | 5,730 | yr | 100.0% | 99.8% | 99.4% | 99.0% | 98.7% | 98.3% |
| Pu-240 | 6,560 | yr | 100.0% | 99.8% | 99.5% | 99.2% | 98.8% | 98.5% |
| Nb-94 | 20,300 | yr | 100.0% | 99.9% | 99.8% | 99.7% | 99.6% | 99.5% |
| Ni-59 | 75,000 | yr | 100.0% | 100.0% | 100.0% | 99.9% | 99.9% | 99.9% |
| Tc-99 | 213,000 | yr | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| Cl-36 | 301,000 | yr | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| Zr-93 | 1,530,000 | yr | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| Cs-135 | 2,300,000 | yr | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |
| I-129 | 15,700,000 | yr | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

## B. Decay Series

As stated above, many radionuclides do not decay to a stable isotope; rather, they decay to another radionuclide, which in turn decays. This process can occur multiple times before a stable nuclide is reached. The Bateman equation, discussed above and shown in Equation II-1, is used to calculate the radiological decay and buildup of the members of these radiological decay series. Several of these radiological decay chains or series are naturally occurring and well known, and have been included (either wholly or partially) in this analysis as discussed below.

Figure II-1 shows the members of the uranium decay series. Those members of the series that were specifically analyzed in this study using the Bateman equation are shown with an orange background in Figure II-1, while those members with short half-lives (i.e., less than 1 year) that were assumed to be in equilibrium with their long-lived parent (or sometimes grandparent or great-grandparent) are shown with a purple background. Nuclides with a green background are stable. As Figure II-1 shows, the 14 radionuclides of the uranium decay series collapse to only five radionuclides that require the Bateman equation to solve.

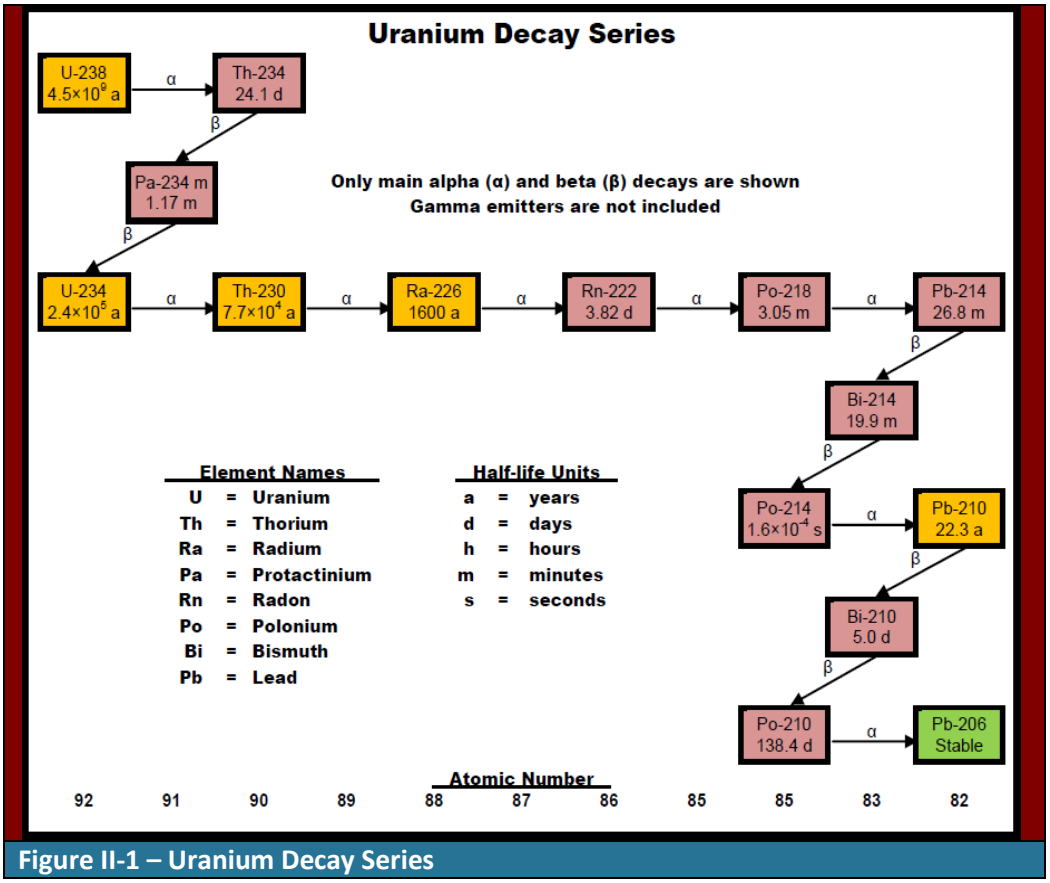


**Figure II-1 – Uranium Decay Series**

Table II-4 shows the effects on the radionuclides of the uranium decay series of radiological decay over the time period of interest for this study. It shows that only the three short-lived daughters of uranium-238 (U-238)—thorium-234 (Th-234), protactinium-234m (Pa-234m), and Pa-234—are impacted by its decay. Too few atoms of U-238 decay to U-234 to affect the U-234 radioactivity during the short time periods (relative to the U-238 and U-234 half-lives) of this study.

**Table II-4: Uranium Series Radionuclide Decay**

| Nuclide | Half-Life | | Percentage of Initial Activity of Parent | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2000 | 2020 | 2050 | 2080 | 2110 | 2140 |
| Initial Amount of U-238 | | | | | | | | |
| U-238 | 4.47E+09 | yr | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| Th-234 | 24.1 | day | 0.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| Pa-234m | 1.17 | min | 0.00% | 99.84% | 99.84% | 99.84% | 99.84% | 99.84% |
| Pa-234 | 6.7 | hr | 0.00% | 0.16% | 0.16% | 0.16% | 0.16% | 0.16% |
| U-234 | 244,500 | yr | 0.00% | 0.01% | 0.01% | 0.02% | 0.03% | 0.04% |
| Initial Amount of U-234 | | | | | | | | |
| U-234 | 244,500 | yr | 100.00% | 99.99% | 99.99% | 99.98% | 99.97% | 99.96% |
| Th-230 | 77,000 | yr | 0.00% | 0.02% | 0.04% | 0.07% | 0.10% | 0.13% |
| Initial Amount of Th-230 | | | | | | | | |
| Th-230 | 77,000 | yr | 100.00% | 99.98% | 99.96% | 99.93% | 99.90% | 99.87% |
| Ra-226 | 1,600 | yr | 0.00% | 0.86% | 2.14% | 3.41% | 4.65% | 5.88% |
| Initial Amount of Ra-226 | | | | | | | | |
| Ra-226 | 1,600 | yr | 100.00% | 99.14% | 97.86% | 96.59% | 95.35% | 94.12% |
| Rn-222 | 3.8235 | day | 0.00% | 99.14% | 97.86% | 96.59% | 95.35% | 94.12% |
| Po-218 | 3.05 | min | 0.00% | 99.14% | 97.86% | 96.59% | 95.35% | 94.12% |
| Pb-214 | 26.8 | min | 0.00% | 99.14% | 97.86% | 96.59% | 95.35% | 94.12% |
| Bi-214 | 45.65 | min | 0.00% | 99.14% | 97.86% | 96.59% | 95.35% | 94.12% |
| Po-214 | 0.000164 | sec | 0.00% | 99.14% | 97.86% | 96.59% | 95.35% | 94.12% |
| Pb-210 | 22.26 | yr | 0.00% | 46.13% | 77.86% | 89.56% | 93.39% | 94.15% |
| Bi-210 | 5.013 | day | 0.00% | 46.13% | 77.86% | 89.56% | 93.39% | 94.15% |
| Po-210 | 138.378 | day | 0.00% | 46.13% | 77.86% | 89.56% | 93.39% | 94.15% |
| Initial Amount of Pb-210 | | | | | | | | |
| Pb-210 | 22.26 | yr | 100.00% | 53.65% | 21.08% | 8.28% | 3.25% | 1.28% |
| Bi-210 | 5.013 | day | 0.00% | 53.65% | 21.08% | 8.28% | 3.25% | 1.28% |
| Po-210 | 138.378 | day | 0.00% | 53.65% | 21.08% | 8.28% | 3.25% | 1.28% |

Similarly, the decay of an initial amount of U-234 will have a minor effect on the buildup of Th-230 activity over the time period of concern, but if the initial amount of Th-230 is small, the in-growth from U-234 decay may be noticeable. However, the decay of an initial amount of Th-230 does have an effect on the buildup of radium-226 (Ra-226), with the final Ra-226 activity being about 6% of the initial Th-230 activity. Likewise, the effect of the decay of an initial amount of Ra-226 can be seen in the bottom portion of Table II-4 as the buildup of lead-210 (Pb-210), with the Pb-210 activity arriving at equilibrium with Ra-226 by the end of the period of concern.

Although not usually considered part of the uranium decay series, plutonium-238 (Pu-238) decays into U-234, which then follows the remainder of the uranium decay series, as shown in Figure II-2.

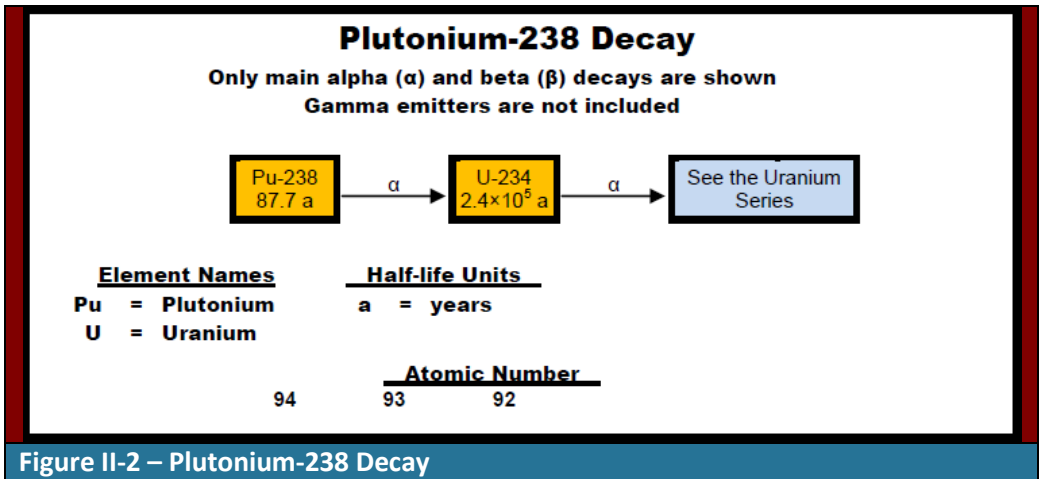


**Figure II-2 – Plutonium-238 Decay**

Table II-5 shows the decay of Pu-238 and buildup of U-234 over the time period of interest for this study. It indicates that the decay of Pu-238 will have a small impact on the inventory of U-234 (and its decay products); i.e., for every 10,000 curie (Ci) of Pu-238 in 2020, there will be about 2.4 Ci of U-234 in 2140.

**Table II-5: Pu-238 Decay**

| Nuclide | Half-Life | Percentage of Initial Activity of Parent | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1/1/2000 | 1/1/2020 | 1/1/2050 | 1/1/2080 | 1/1/2110 | 1/1/2140 |
| Initial Amount of Pu-238 | | | | | | | |
| Pu-238 | 87.74 yr | 100.00% | 85.38% | 67.37% | 53.15% | 41.94% | 33.09% |
| U-234 | 244,500 yr | 0.00% | 0.01% | 0.01% | 0.02% | 0.02% | 0.02% |

Figure II-3 shows the members of the thorium decay series. As in Figure II-1, those members of the thorium decay series that were specifically analyzed in this study using the Bateman equation are shown with an orange background in Figure II-3, while those members with short half-lives (i.e., less than 1 year) that were assumed to be in equilibrium with their long-lived parent (or sometimes grandparent or great-grandparent) are shown with a purple background. Nuclides with a green background are stable. As Figure II-3 shows, the 11 radionuclides of the thorium decay series collapse to only three radionuclides that require the Bateman equation to solve.

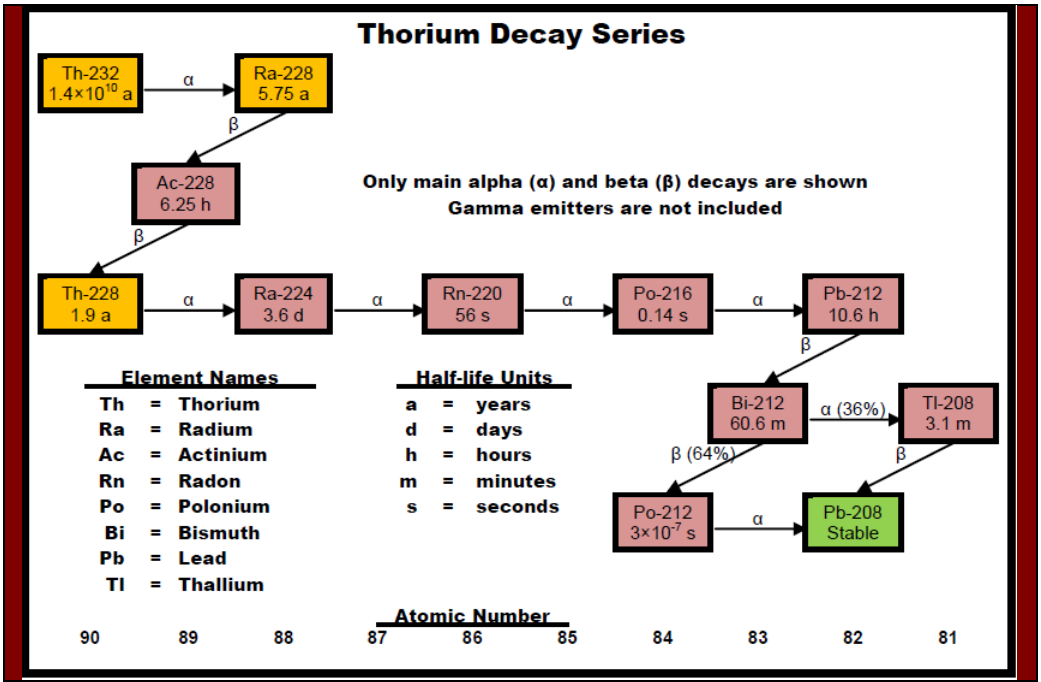


**Figure II-3 – Thorium Decay Series**

Table II-6 shows the decay of the thorium series radionuclides over the time period of interest for this study. It indicates that all 11 of the series members quickly (i.e., by about 2050, or sooner) reach equilibrium with Th-232.

**Table II-6: Thorium Series Radionuclide Decay**

| Nuclide | Half-Life | | Percentage of Initial Activity of Parent | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2000 | 2020 | 2050 | 2080 | 2110 | 2140 |
| Initial Amount of Th-232 | | | | | | | | |
| Th-232 | 1.41E+10 | yr | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| Ra-228 | 5.75 | yr | 0.00% | 91.03% | 99.76% | 99.99% | 100.00% | 100.00% |
| Ac-228 | 6.25 | hr | 0.00% | 91.03% | 99.76% | 99.99% | 100.00% | 100.00% |
| Th-228 | 1.9116 | yr | 0.00% | 86.59% | 99.64% | 99.99% | 100.00% | 100.00% |
| Ra-224 | 3.6319 | day | 0.00% | 86.59% | 99.64% | 99.99% | 100.00% | 100.00% |
| Rn-220 | 55.6 | sec | 0.00% | 86.59% | 99.64% | 99.99% | 100.00% | 100.00% |
| Po-216 | 0.145 | sec | 0.00% | 86.59% | 99.64% | 99.99% | 100.00% | 100.00% |
| Pb-212 | 10.64 | hr | 0.00% | 86.59% | 99.64% | 99.99% | 100.00% | 100.00% |
| Bi-212 | 60.55 | min | 0.00% | 86.59% | 99.64% | 99.99% | 100.00% | 100.00% |
| Po-212 | 299 | ns | 0.00% | 55.47% | 63.83% | 64.05% | 64.06% | 64.06% |
| Tl-208 | 3.053 | min | 0.00% | 31.12% | 35.81% | 35.94% | 35.94% | 35.94% |

Figure II-4 shows the naturally occurring members of the actinium decay series. In addition to the orange, purple, and green backgrounds representing long-lived, short-lived, and stable radionuclides, respectively, a light purple background represents a short-lived radionuclide that was not included in the inventory lists used in this study.

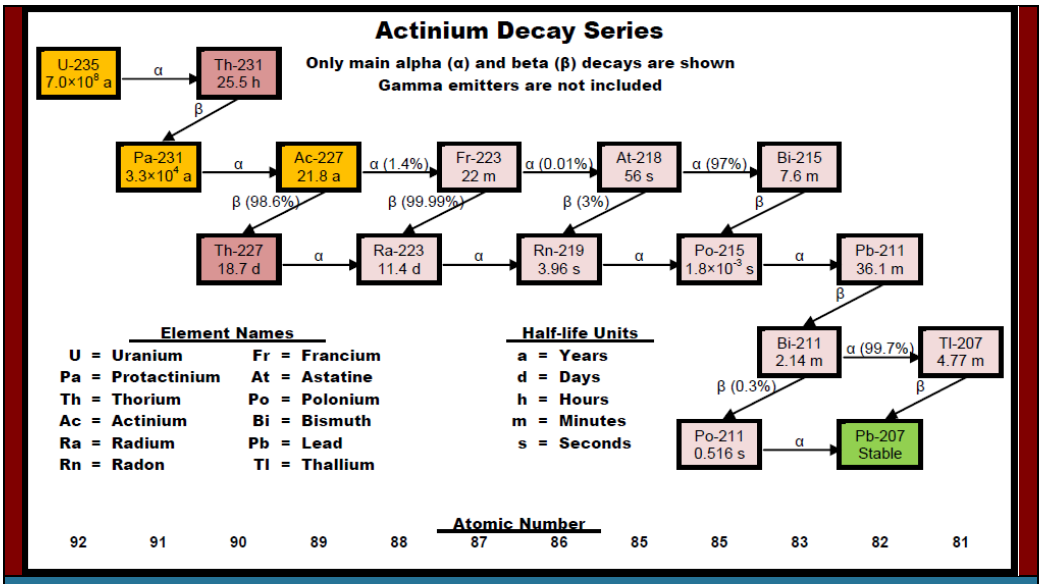


**Figure II-4 – Actinium Decay Series**

In addition to the naturally occurring members of the actinium decay series, the artificially produced radionuclides Am-243 and Pu-239 decay to U-235, as shown in Figure II-5.

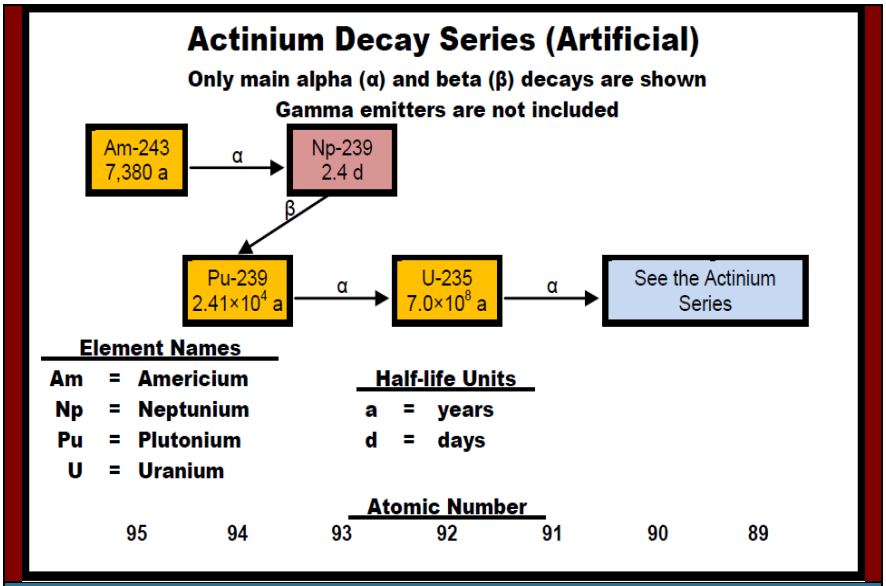


**Figure II-5 – Actinium Decay Series (Artificial)**

Table II-7 shows the decay of the actinium series radionuclides over the time period of interest for this study. While short-lived Th-231 quickly reaches equilibrium with U-235, the decay of U-235 has only a small impact on the longer-lived Pa-231 and its decay products. Although the resolution of Table II-7 is not fine enough to show it, the Th-227 inventory (0.227%) in 2140 is actually only 98.6% of the actinium-227 (Ac-227) inventory (0.230%). As stated above, some of the short-lived actinium series radionuclides were not included in this study's inventory estimates. If considered, each of the inventories for these short-lived members would be the same as the Ac-227 inventory, adjusted for

any branching that may occur. For example, francium-223 (Fr-223) would be 1.4% of the Ac-227 inventory, astatine-218 (At-218) would be (0.014 × 0.0001 =) 0.00014% of the Ac-227 inventory, and, since it gets fed by both branches, Ra-223 would be 99.99986% of the Ac-227 inventory.

**Table II-7: Actinium Series Radionuclide Decay**

| Nuclide | Half-Life | | Percentage of Initial Activity of Parent | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2000 | 2020 | 2050 | 2080 | 2110 | 2140 |
| Initial Amount of Am-243 | | | | | | | | |
| Am-243 | 7,380 | yr | 100.00% | 99.81% | 99.53% | 99.25% | 98.97% | 98.69% |
| Np-239 | 2.4 | day | 0.00% | 99.81% | 99.53% | 99.25% | 98.97% | 98.69% |
| Pu-239 | 24,100 | yr | 0.00% | 0.06% | 0.14% | 0.23% | 0.31% | 0.40% |
| Initial Amount of Pu-239 | | | | | | | | |
| Pu-239 | 24,100 | yr | 100.00% | 99.94% | 99.86% | 99.77% | 99.68% | 99.60% |
| U-235 | 7.04E+08 | yr | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Initial Amount of U-235 | | | | | | | | |
| U-235 | 7.04E+08 | yr | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| Th-231 | 25.52 | hr | 0.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| Pa-231 | 32,760 | yr | 0.00% | 0.04% | 0.11% | 0.17% | 0.23% | 0.30% |
| Ac-227 | 21.77 | yr | 0.00% | 0.01% | 0.05% | 0.11% | 0.17% | 0.23% |
| Th-227 | 18.68 | day | 0.00% | 0.01% | 0.05% | 0.11% | 0.17% | 0.23% |

The inventories for this study include Pu-241, whose decay scheme is shown in Figure II-6. As shown, Pu-241 decays through four stages to U-233, which is part of the neptunium series. Figure II-6 does not include the neptunium series radionuclides after Th-229, because (with one exception) they are all short-lived and assumed to be in equilibrium with Th-229. The one exception is bismuth-209 (Bi-209), at the very end of the neptunium series, which has a very long half-life (1.9E+19 years) and for the purposes of this study can be considered to be stable.

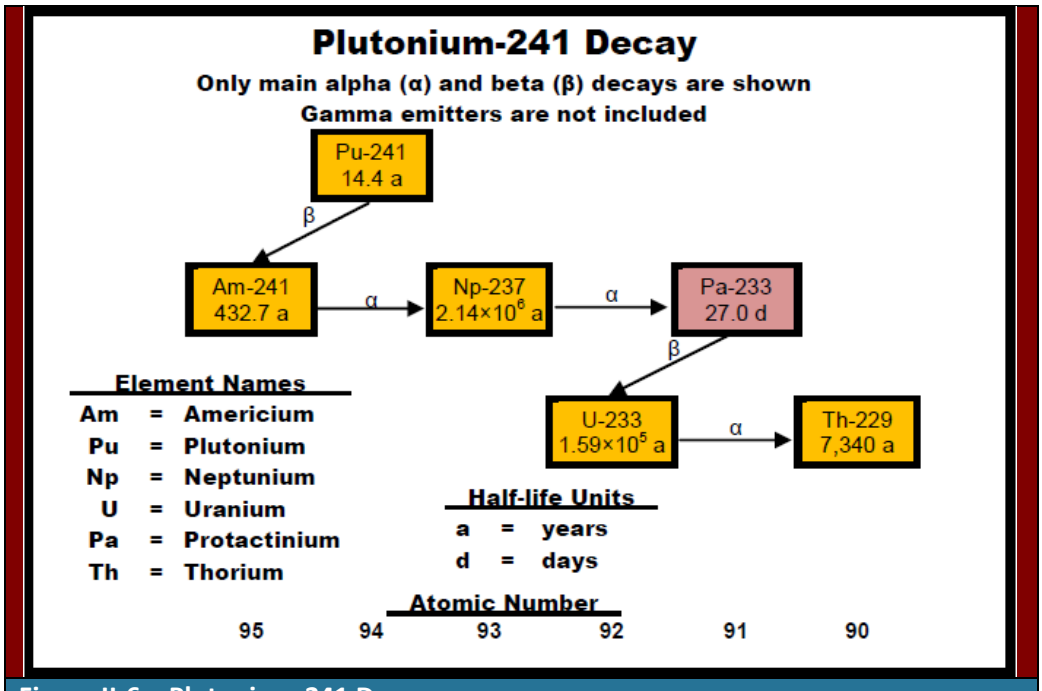


**Figure II-6 – Plutonium-241 Decay**

Table II-8 shows that most of the initial Pu-241 inventory decays away over the time period of interest for this study. While there is some increase in the americium-241 (Am-241) inventory that results from the Pu-241 decay, the neptunium-237 (Np-237) inventory is essentially unaffected. Alternatively, if there is an initial inventory of Np-237, that inventory will remain essentially unchanged over the time period of interest, while the Pa-233 inventory will quickly reach equilibrium with Np-237 and the U-233 inventory will remain essentially unchanged.

**Table II-8: Pu-241 and Np-237 Decay**

| Nuclide | Half-Life | | Percentage of Initial Activity of Parent | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1/1/2000 | 1/1/2020 | 1/1/2050 | 1/1/2080 | 1/1/2110 | 1/1/2140 |
| Initial Amount of Pu-241 | | | | | | | | |
| Pu-241 | 14.4 | yr | 100.00% | 38.19% | 9.01% | 2.13% | 0.50% | 0.12% |
| Am-241 | 432.7 | yr | 0.00% | 2.02% | 2.87% | 2.96% | 2.87% | 2.75% |
| Np-237 | 2.14E+06 | yr | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Initial Amount of Np-237 | | | | | | | | |
| Np-237 | 2.14E+06 | yr | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| Pa-233 | 27 | day | 0.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| U-233 | 159,200 | yr | 0.00% | 0.01% | 0.02% | 0.03% | 0.05% | 0.06% |

# III. State-Licensed Disposal Area

From 1963 to 1975, low-level radioactive wastes were received at the SDA for burial from six types of sources: nuclear power plants; institutional and educational facilities and hospitals; Federal government facilities; industrial, pharmaceutical manufacturing, and industrial research facilities; Nuclear Fuel Services operations; and waste disposal and decontamination companies. The SDA is approximately 6.1 hectares (15 acres) in size, divided into North and South Disposal Areas, and consists of 14 disposal trenches. A more complete description of the SDA, including figures, is provided in the Task 1.1 technical memorandum (ECS 2016).

## A. URS (2002) Inventory Estimate

URS (2002) provided two sets of SDA radionuclide inventory estimates, identified as the fixed concentration method and the variable concentration method. Because URS (2002) states that "the fixed concentration method should not be used in analyses of radiological impacts involving SDA wastes," this report uses only the variable concentration method inventory estimate. All values in URS (2002) were adjusted for radioactive decay to a base year of 2000. The Task 1.1 technical memorandum (ECS 2016) compared the URS (2002) inventory estimate to eight previous SDA estimates and found, with one exception, that URS (2002) provides the best estimate of the SDA inventory for use in the Phase I studies. This conclusion is consistent with Garrick et al. (2009, page 4-4), which identified URS (2002) as the "most comprehensive and detailed" effort to "identify and characterize the inventories of wastes that are buried in the 14 SDA trenches."

The one exception was that the SDA Sr-90 activity estimate in URS (2002) had to be revised to specifically include the 1966–1967 waste shipments from the Martin Marietta, Quehanna, Pennsylvania facility. This correction is discussed in more detail in Subsection III.B and has been incorporated into the SDA inventory used for this study. Table III-1 presents a summary of the adjusted URS (2002) SDA radionuclide inventory estimate incorporating the Quehanna Sr-90 shipment disposed in Trench 4. Only those radionuclides that have a total SDA inventory of 1 Ci or greater are explicitly shown in Table III-1, while those with less than 1 Ci are grouped as "All Others." URS (2002) provides detailed breakdowns by 50-foot segments of each of the 14 SDA trench inventories, and should be consulted if that level of detail is desired.

**Table III-1: SDA 2000 Radionuclide Inventory Summary – Source: URS 2002, Adjusted for Sr-90 in Trench 4**

| Nuclide | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | Trench 9 | Trench 10 | Trench 11 | Trench 12 | Trench 13 | Trench 14 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H-3 | 8.7E+00 | 7.9E+01 | 9.1E+02 | 2.8E+03 | 3.8E+03 | 2.7E+03 | 3.7E+00 | 6.9E+03 | 3.9E+03 | 7.1E+03 | 8.6E+03 | 2.3E+03 | 1.4E+03 | 8.1E+02 | 4.1E+04 |
| Pu-238 | 4.4E-01 | 9.2E-01 | 2.3E+00 | 2.3E+01 | 1.7E+02 | 0.0E+00 | 1.9E-01 | 4.2E+03 | 4.3E+03 | 1.2E+04 | 5.5E+03 | 2.1E+01 | 4.2E+00 | 4.3E-01 | 2.7E+04 |
| Ni-63 | 1.7E+01 | 3.6E+01 | 8.0E+01 | 1.5E+03 | 2.7E+03 | 1.5E+04 | 7.3E+00 | 1.6E+02 | 1.3E+02 | 8.5E+00 | 7.4E+01 | 4.2E+02 | 1.3E+01 | 5.9E+01 | 2.1E+04 |
| Cs-137 | 2.4E+02 | 8.0E+02 | 9.6E+02 | 6.3E+03 | 1.2E+03 | 9.8E-01 | 1.0E+02 | 3.3E+02 | 1.9E+03 | 6.3E+01 | 3.6E+02 | 1.8E+02 | 1.3E+02 | 2.6E+02 | 1.3E+04 |
| Sr-90 | 1.8E+00 | 4.1E+00 | 4.8E+00 | 7.5E+03 | 5.3E+00 | 3.0E-01 | 8.1E-01 | 5.1E+00 | 1.6E+01 | 1.4E+01 | 8.1E+00 | 2.3E+01 | 1.9E+01 | 1.8E+01 | 7.7E+03 |
| Co-60 | 2.6E+00 | 1.9E+01 | 2.4E+01 | 1.8E+02 | 4.0E+02 | 4.3E+03 | 8.3E-01 | 3.4E+01 | 2.8E+01 | 1.5E+01 | 2.0E+01 | 1.5E+02 | 3.6E+01 | 2.2E+01 | 5.2E+03 |
| Pu-241 | 3.2E+00 | 6.0E+00 | 3.2E+01 | 3.4E+02 | 1.8E+02 | 0.0E+00 | 1.5E+00 | 5.8E+02 | 1.9E+03 | 3.3E+00 | 8.2E+00 | 6.5E+02 | 1.3E+02 | 4.9E+00 | 3.8E+03 |
| Ni-59 | 1.5E-01 | 1.2E+00 | 1.4E+00 | 4.6E+01 | 1.1E+02 | 6.1E+02 | 4.2E-02 | 5.6E+00 | 6.6E-01 | 3.4E-02 | 4.6E-01 | 1.6E+01 | 1.2E-01 | 1.4E+00 | 8.0E+02 |

**Table III-1: SDA 2000 Radionuclide Inventory Summary – Source: URS 2002, Adjusted for Sr-90 in Trench 4**

| Nuclide | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | Trench 9 | Trench 10 | Trench 11 | Trench 12 | Trench 13 | Trench 14 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Am-241 | 8.6E-01 | 1.6E+00 | 5.4E+00 | 6.3E+01 | 2.3E+01 | 0.0E+00 | 3.6E-01 | 6.3E+01 | 1.9E+02 | 1.1E+01 | 9.7E+00 | 5.4E+01 | 1.1E+01 | 7.9E-01 | 4.3E+02 |
| C-14 | 2.7E+00 | 3.8E+00 | 1.2E+01 | 8.4E+01 | 2.5E+01 | 6.8E+00 | 1.0E+00 | 2.1E+01 | 3.4E+01 | 4.1E+01 | 4.1E+01 | 2.1E+01 | 3.8E+00 | 6.9E+00 | 3.0E+02 |
| U-238 | 2.1E-02 | 7.6E-02 | 5.1E-01 | 5.9E+01 | 9.4E+00 | 0.0E+00 | 3.5E-03 | 4.0E+01 | 1.1E+01 | 1.4E+01 | 1.2E+01 | 1.1E+01 | 1.3E+01 | 2.1E+01 | 1.9E+02 |
| Pu-239 | 4.0E-01 | 1.8E+00 | 1.0E+01 | 2.5E+01 | 2.0E+01 | 0.0E+00 | 1.7E-01 | 2.1E+01 | 5.8E+01 | 2.8E+00 | 4.8E-01 | 2.7E+01 | 1.1E+01 | 3.5E-01 | 1.8E+02 |
| Pu-240 | 6.6E-04 | 1.6E-03 | 9.3E-01 | 9.3E+00 | 5.5E+00 | 0.0E+00 | 2.7E-04 | 1.8E+01 | 5.5E+01 | 5.6E-02 | 5.4E-02 | 1.7E+01 | 3.4E+00 | 4.1E-03 | 1.1E+02 |
| Ra-226 | 1.7E-01 | 2.1E-01 | 4.3E-01 | 1.2E+01 | 2.8E+00 | 0.0E+00 | 1.6E-11 | 1.3E+00 | 7.0E-01 | 7.7E-01 | 1.6E+00 | 2.7E+00 | 1.1E+00 | 3.9E+00 | 2.7E+01 |
| Th-230 | 5.2E-05 | 2.4E-05 | 1.8E-04 | 9.8E+00 | 2.0E+00 | 0.0E+00 | 3.3E-09 | 5.0E-03 | 1.3E-03 | 1.8E-03 | 1.4E-03 | 1.2E-03 | 1.3E-03 | 2.1E-03 | 1.2E+01 |
| Th-232 | 6.3E-01 | 5.3E-03 | 7.3E-02 | 2.5E-02 | 6.2E-01 | 0.0E+00 | 9.6E-20 | 3.4E+00 | 6.6E-02 | 5.4E-01 | 1.2E-01 | 1.5E-01 | 9.7E-02 | 9.2E-01 | 6.6E+00 |
| U-235 | 1.1E-02 | 6.5E-03 | 3.3E-02 | 1.4E+00 | 2.2E-01 | 0.0E+00 | 4.4E-04 | 6.2E-01 | 1.7E-01 | 2.3E-01 | 1.8E-01 | 1.8E-01 | 2.0E-01 | 3.0E-01 | 3.5E+00 |
| I-129 | 6.0E-02 | 1.9E-01 | 2.2E-01 | 1.5E+00 | 2.6E-01 | 0.0E+00 | 2.4E-02 | 7.1E-02 | 4.0E-01 | 1.0E-02 | 7.0E-02 | 3.2E-02 | 2.4E-02 | 4.9E-02 | 2.9E+00 |
| Tc-99 | 2.1E-02 | 6.8E-02 | 8.0E-02 | 5.3E-01 | 1.4E-01 | 2.5E-01 | 8.2E-03 | 2.7E-02 | 1.4E-01 | 4.8E-03 | 2.6E-02 | 1.9E-02 | 8.8E-03 | 1.8E-02 | 1.3E+00 |
| All Others | 1.7E+00 | 5.6E-01 | 1.5E+00 | 5.2E+01 | 1.7E+01 | 1.7E+02 | 4.0E-02 | 2.7E+01 | 1.5E+01 | 9.3E+00 | 8.8E+00 | 1.2E+01 | 6.9E+00 | 8.4E+01 | 4.0E+02 |
| Total | 2.8E+02 | 9.6E+02 | 2.0E+03 | 1.9E+04 | 8.6E+03 | 2.3E+04 | 1.2E+02 | 1.2E+04 | 1.3E+04 | 2.0E+04 | 1.5E+04 | 3.9E+03 | 1.8E+03 | 1.3E+03 | 1.2E+05 |

## B. Martin-Marietta – Quehanna Adjustment

As indicated in the Task 1.1 technical memorandum (ECS 2016), the URS (2002) SDA inventory estimate mischaracterized the waste shipped from the Martin Marietta – Quehanna facility by assuming that all the waste from the Quehanna facility had the Special Purpose Reactor, deactivation and decommissioning (D&D) waste profile. However, according to the SDA Integrated Database, the waste was composed of Sr-90. Profiling the waste as Sr-90 is consistent with the Quehanna Facility Design and Safety Evaluation Report (Martin Marietta Corporation [MMC] 1964). Table III-2 compares the Special Purpose Reactor, D&D waste profile to the Sr-90 profile.

**Table III-2: Waste Profile Versus Shipping Manifest**

| Nuclide | Special Purpose Reactor, D&D | | Sr-90 |
|---|---|---|---|
| | Table 2-13 (Ci/m$^3$) | (%) | |
| Sr-90 | 0.011 | 0.028% | 100% |
| Fe-55 | 10.7 | 27.4% | 0% |
| Co-60 | 17.9 | 45.8% | 0% |
| Cs-137 | 9.35 | 23.9% | 0% |
| All Others | 1.04 | 2.66% | 0% |
| **Total** | **39.0** | **—** | **—** |

The SDA Integrated Database was consulted as part of this study to identify when and how much of the Quehanna Sr-90 waste was disposed in the SDA. The mischaracterized inventory was then removed and replaced with the Sr-90 inventory value. Table III-3 shows that 21 waste shipments were received from the Quehanna facility over an approximate one-year period from May 1966 to May 1967, totaling 11,945 cubic feet (ft$^3$) and 16,602 Ci. All of the Quehanna facility waste was disposed in nine 50-foot segments of Trench 4, as identified in Table III-3.

| Table III-3: Martin-Marietta – Quehanna Waste Shipments | | | | | |
|---|---|---|---|---|---|
| Shipment No. | Disposal Date | Distance (ft)[1] | Trench 4 Segment | Volume ($ft^3$) | Activity (Ci) |
| 66-E-5005 | May 4, 1966 | 175 | 150-200 | 389.55 | 1,673 |
| 66-E-5010 | May 11, 1966 | 175 | 150-200 | 352.8 | 1,647 |
| 66-E-5013 | May 16, 1966 | 175 | 150-200 | 404.25 | 2,036 |
| 66-E-5021 | May 25, 1966 | 175 | 150-200 | 455.7 | 1,272 |
| 66-F-6015 | June 15, 1966 | 225 | 200-250 | 323.4 | 1,837 |
| 66-F-6019 | June 20, 1966 | 225 | 200-250 | 288.05 | 2,730 |
| 66-H-6002 | August 3, 1966 | 275 | 250-300 | 602.7 | 1,468 |
| 66-J-6001 | October 3, 1966 | 325 | 300-350 | 996.62 | 190 |
| 66-J-6006 | October 5, 1966 | 325 | 300-350 | 840.1 | 58 |
| 66-K-6003 | November 3, 1966 | 375 | 350-400 | 829.35 | 784 |
| 66-K-6006 | November 4, 1966 | 375 | 350-400 | 683.6 | 237 |
| 66-K-6019 | November 30, 1966 | 375 | 350-400 | 124.95 | 22 |
| 66-L-6020 | December 19, 1966 | 425 | 400-450 | 565.95 | 35 |
| 66-L-6023 | December 21, 1966 | 425 | 400-450 | 607.95 | 1,060 |
| 67-A-7023 | January 24, 1967 | 475 | 450-500 | 628.05 | 233 |
| 67-B-7014 | February 17, 1967 | 475 | 450-500 | 573.3 | 1,137 |
| 67-C-7028 | March 30, 1967 | 525 | 500-550 | 690.9 | 27 |
| 67-C-7029 | March 31, 1967 | 525 | 500-550 | 514.6 | 129 |
| 67-E-7019 | May 16, 1967 | 525 | 500-550 | 705.6 | 0.14 |
| 67-E-7023 | May 18, 1967 | 525 | 500-550 | 919.3 | 24 |
| 67-E-7040 | May 29, 1967 | 675 | 650-700 | 448.38 | 0.07 |
| — | **Total** | — | — | **11,945** | **16,602** |

[1] Distance = Feet from permanent marker at beginning of trench to midpoint of trench segment.

Table III-4 compares the activity of the Quehanna facility waste both at the time of disposal and at January 1, 2000, using both the Special Purpose Reactor, D&D waste profile and the Sr-90 profile. Although not shown in Table III-4, Y-90 was also assumed to be present in the adjusted activity in an amount equal to the Sr-90 activity.

| Table III-4: Adjusted Martin-Marietta – Quehanna Activity | | | | |
|---|---|---|---|---|
| Nuclide | Martin-Marietta – Quehanna Activity (Ci) | | | |
| | At Disposal | | At Year 2000 | |
| | URS 2002 | Adjusted | URS 2002 | Adjusted |
| Sr-90 | 4.7 | 16,602 | 2.1 | 7,490 |
| Fe-55 | 4,550 | 0.0 | 0.9 | 0.0 |
| Co-60 | 7,611 | 0.0 | 94 | 0.0 |
| Cs-137 | 3,976 | 0.0 | 1,836 | 0.0 |
| All Others | 461 | 0.0 | 175 | 0.0 |
| **Total** | **16,602** | **16,602** | **2,108** | **7,490** |

The activities shown in Table III-4 were then prorated between the nine Trench 4 segments that received the Quehanna facility waste using the Table III-3 Activity column. It was then a simple matter of subtracting out the URS (2002) activities and adding in the Sr-90 adjusted activity for each Trench 4 segment. The results of this correction are reflected in the Trench 4 column of Table III-1.

## C. Decayed SDA Inventory

Using the methodology described in Section II, the adjusted URS (2002) Year 2000 SDA inventory was decayed to 2020 (the new base year) and to 2050, 2080, 2110, and 2140.

The resulting decayed inventories are provided along with the adjusted 2000 inventory in a format similar to URS (2002), Appendix C (i.e., by radionuclide, trench, and 50-foot trench segment) in six accompanying Excel files (i.e., *SDA Inventory – 2000.xlsx*, *SDA Inventory – 2020.xlsx*, *SDA Inventory – 2050.xlsx*, *SDA Inventory – 2080.xlsx*, *SDA Inventory – 2110.xlsx*, *SDA Inventory – 2140.xlsx*).

To show the overall impact of radiological decay on the total SDA inventory, Table III-5 shows the SDA decayed total inventory at each of the six decay times.

**Table III-5: SDA Decayed Total Inventory**

| Nuclide | SDA Decayed Inventory (Ci) | | | | | |
|---|---|---|---|---|---|---|
| | 2000 | 2020 | 2050 | 2080 | 2110 | 2140 |
| H-3 | 4.1E+04 | 1.3E+04 | 2.5E+03 | 4.5E+02 | 8.3E+01 | 1.5E+01 |
| Pu-238 | 2.7E+04 | 2.3E+04 | 1.8E+04 | 1.4E+04 | 1.1E+04 | 8.8E+03 |
| Ni-63 | 2.1E+04 | 1.8E+04 | 1.4E+04 | 1.2E+04 | 9.3E+03 | 7.5E+03 |
| Cs-137 | 1.3E+04 | 8.1E+03 | 4.1E+03 | 2.0E+03 | 1.0E+03 | 5.1E+02 |
| Sr-90 | 7.7E+03 | 4.7E+03 | 2.3E+03 | 1.1E+03 | 5.3E+02 | 2.6E+02 |
| Co-60 | 5.2E+03 | 3.8E+02 | 7.3E+00 | 1.4E-01 | 2.7E-03 | 5.3E-05 |
| Pu-241 | 3.8E+03 | 1.5E+03 | 3.5E+02 | 8.1E+01 | 1.9E+01 | 4.5E+00 |
| Ni-59 | 8.0E+02 | 8.0E+02 | 7.9E+02 | 7.9E+02 | 7.9E+02 | 7.9E+02 |
| Am-241 | 4.3E+02 | 5.0E+02 | 5.1E+02 | 4.9E+02 | 4.7E+02 | 4.5E+02 |
| C-14 | 3.0E+02 | 3.0E+02 | 3.0E+02 | 3.0E+02 | 3.0E+02 | 3.0E+02 |
| U-238 | 1.9E+02 | 1.9E+02 | 1.9E+02 | 1.9E+02 | 1.9E+02 | 1.9E+02 |
| Pu-239 | 1.8E+02 | 1.8E+02 | 1.8E+02 | 1.8E+02 | 1.8E+02 | 1.8E+02 |
| Pu-240 | 1.1E+02 | 1.1E+02 | 1.1E+02 | 1.1E+02 | 1.1E+02 | 1.1E+02 |
| Ra-226 | 2.7E+01 | 2.7E+01 | 2.7E+01 | 2.7E+01 | 2.7E+01 | 2.6E+01 |
| Th-230 | 1.2E+01 | 1.2E+01 | 1.2E+01 | 1.2E+01 | 1.2E+01 | 1.2E+01 |
| Th-232 | 6.6E+00 | 6.6E+00 | 6.6E+00 | 6.6E+00 | 6.6E+00 | 6.6E+00 |
| U-235 | 3.5E+00 | 3.5E+00 | 3.5E+00 | 3.5E+00 | 3.5E+00 | 3.5E+00 |
| I-129 | 2.9E+00 | 2.9E+00 | 2.9E+00 | 2.9E+00 | 2.9E+00 | 2.9E+00 |
| Tc-99 | 1.3E+00 | 1.3E+00 | 1.3E+00 | 1.3E+00 | 1.3E+00 | 1.3E+00 |
| All Others | 4.0E+02 | 7.9E+02 | 7.8E+02 | 7.8E+02 | 7.8E+02 | 7.8E+02 |
| **Total** | **1.2E+05** | **7.1E+04** | **4.4E+04** | **3.2E+04** | **2.5E+04** | **2.0E+04** |

Figure III-1 is a graphical representation of Table III-5 for the eight radionuclides with the highest activity in the 2000 SDA inventory. As shown, after about 2020, Pu-238 and nickel-63 (Ni-63) dominate the SDA inventory and, as time passes, become more dominant due to the decay of Cs-137 and Sr-90, which have shorter half-lives.

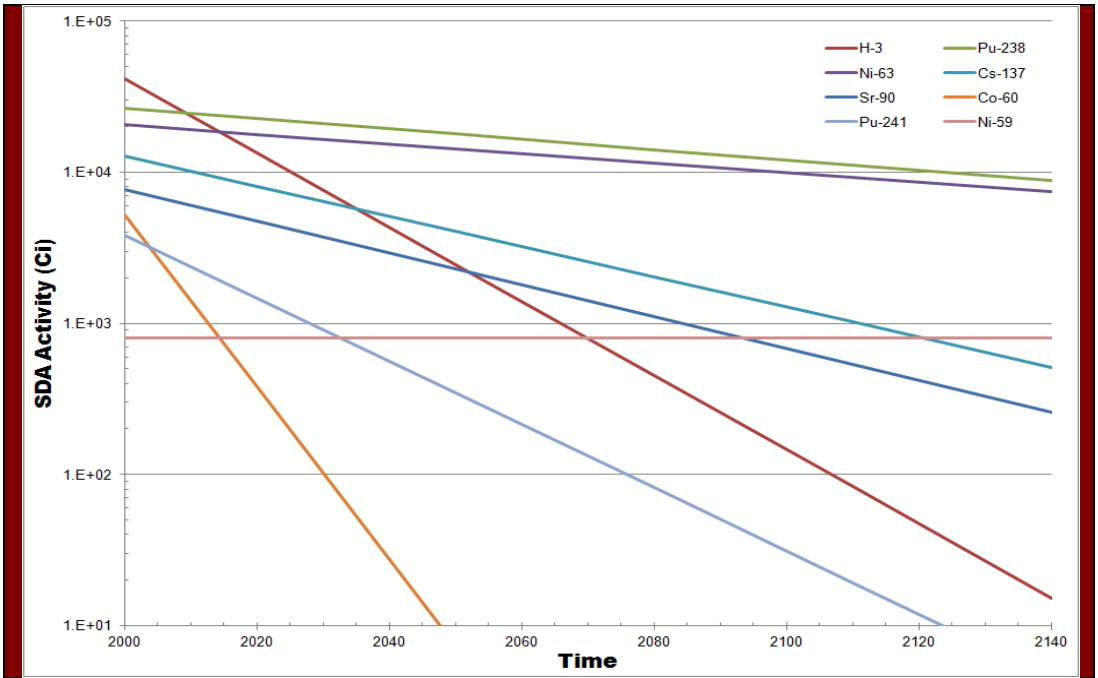


**Figure III-1 – SDA Decayed Inventory – Eight Largest Radionuclides**

Of the eight radionuclides with the highest SDA 2000 activities, only cobalt-60 (Co-60) and Cs-137 present a direct dose concern. Each disintegration of Co-60 emits 1.17 and 1.33 mega-electron volt (MeV) gammas, while Cs-137 emits a 0.66 MeV gamma. In comparison, the other six radionuclides either do not emit gammas (i.e., tritium [H-3], Ni-63, and Sr-90) or emit very weak gammas (i.e., Ni-59, 0.0024 MeV; Pu-238, 0.00168 MeV; and Pu-241, <0.001 MeV).

Title 10 of the *Code of Federal Regulations* (10 CFR) §61.55, Table 2 gives the upper limit for Class A low-level radioactive waste for Co-60 as 700 curies per cubic meter ($Ci/m^3$), and the Class A, B, and C limits for Cs-137 as 1, 44, and 4,600 $Ci/m^3$, respectively.

Figure III-2 shows what the dose rate would be for a 55-gallon drum full of each of these wastes (with a density of 2.35 gallons per cubic centimeter) at the 10 CFR §61.55 upper limit activity concentrations as a function of the thickness of concrete shielding. The black dashed line in Figure III-2 is the 10 CFR §1201 occupational dose rate limit (i.e., 5 rem per year [rem/yr], or with an annual exposure of 2,000 hours, 2.5 millirem per hour [mrem/hr]). The point at which each of the four curves crosses the 2.5 mrem/hr line indicates the thickness of concrete shielding to achieve an acceptable occupational dose rate.[1]

[1] This Technical Memorandum uses 2.5 mrem/hr as the divide between contact and remote operations, but recognizes that this could change. For comparison, the West Valley site utilizes a 0.25 mrem/hr administrative dose limit, DOE's divide between contact and remote waste (DOE 1997) is 200 mrem/hr, and NRC is considering reducing the occupational limit to from 5 rem/yr (2.5 mrem/hr) to 2 rem/yr (1.0 mrem/hr) (FR 2014).

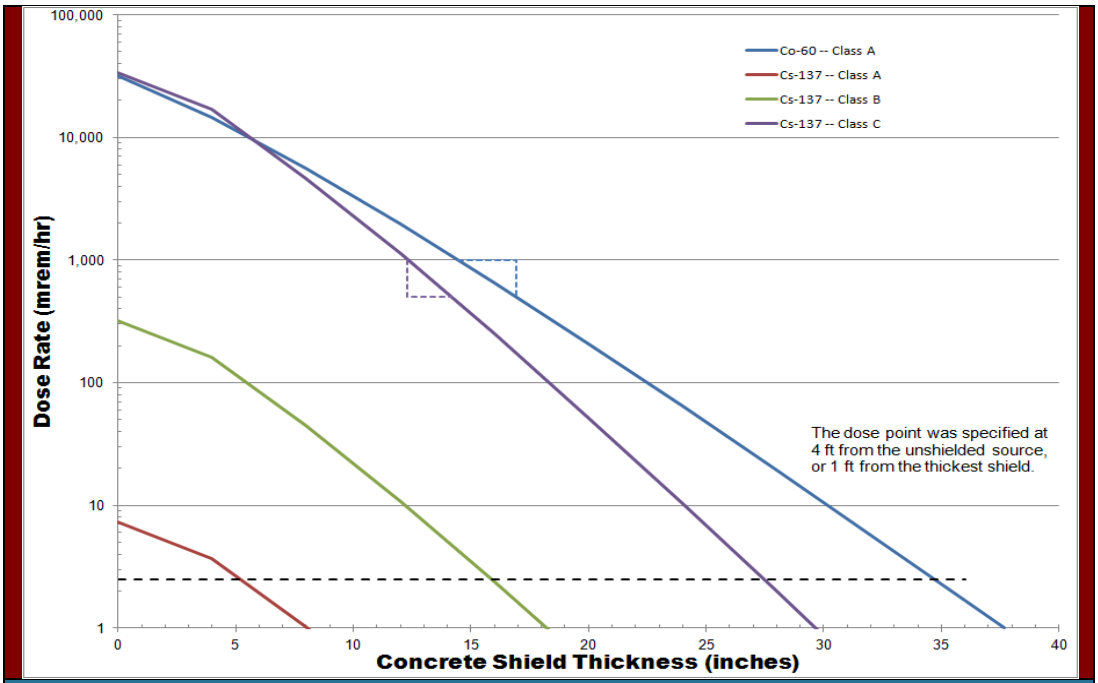


**Figure III-2 – Co-60 and Cs-137 Shielding Requirements**

In Figure III-2, the dashed triangles indicate the change in concrete thickness to reduce the dose rate from 1,000 mrem/hr to 500 mrem/hr, or a reduction of 50% in dose rate. In other words, these triangles represent the concrete "half-value thicknesses," or the thickness of concrete necessary to reduce the dose rate by half. It was determined that the Co-60 and Cs-137 half-value thicknesses are 2.5 and 1.8 inches, respectively. Because of the linear relationship between dose rate and activity, both the half-value thicknesses and the half-life represent a 50% reduction in the dose rate and activity. This allows the development of a relationship between the thickness of concrete and the time required to reach an acceptable occupational dose rate as a result of radiological decay (Figure III-3). The time at which each respective curve crosses the horizontal axis (equals 0 concrete thickness) represents the time required to enable work to be performed at an acceptable occupational dose rate without any shielding.

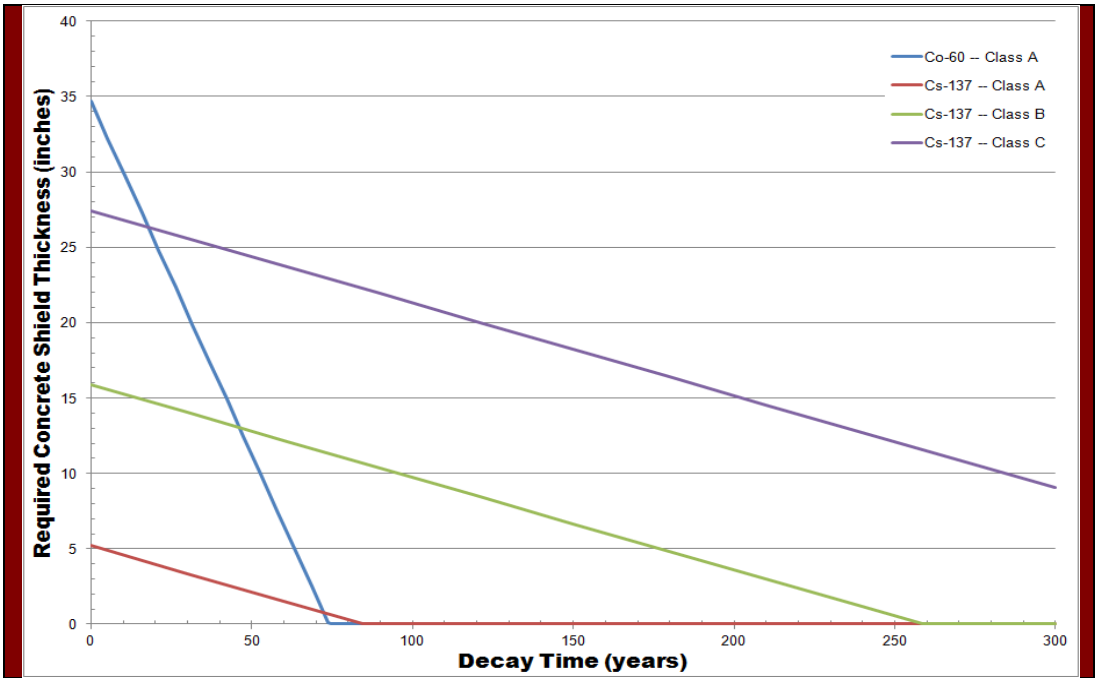


**Figure III-3 – Co-60 and Cs-137 Unshielded Decay Times**

URS (2002), Table S-1 indicates that 93.8% of all waste disposed within the SDA could be classified as Class A waste, implying Co-60 and Cs-137 concentrations at or below (sometimes substantially below) the 10 CFR §61.55, Table 2 Class A limits. Assuming that the disposed waste was at the Class A limits, Figure III-3 shows that no shielding is required for Co-60 waste after about 75 years, and after about 85 years for Class A Cs-137 waste. Therefore, considering that URS (2002) used January 1, 2000, as its characterization date, this means that about 94% of the SDA could be exhumed from within an unshielded enclosure after 2090.

It is also of interest to perform a similar calculation based on the various types/profiles of wastes disposed in the SDA. Table III-6 shows the URS (2002) waste profiles that have the largest activity concentrations within the SDA. Five of the seven waste profiles have large contributions from Co-60 and/or Cs-137.

**Table III-6: Co-60 and Cs-137 Waste Profile Contribution**

| Primary | Secondary | Concentration ($Ci/m^3$) | Contribution | |
|---|---|---|---|---|
| | | | Co-60 | Cs-137 |
| Special Purpose Reactor | Internals | 12,340 | 42% | 0.0% |
| Isotope Production | Large Tritium | 1,678 | 0.0% | 0.0% |
| Power Reactor | Internals | 1,115 | 42% | 0.0% |
| Isotope Production | Reactor Targets | 561 | 0.0% | 0.6% |
| Institutional | Bioresearch | 96 | 8.2% | 4.5% |
| Power Reactor | BWR | 83 | 43% | 30% |
| Special Purpose Reactor | Naval | 48 | 14% | 64% |

The SDA Integrated Database shows that 16 waste shipments were identified as having the Special Purpose Reactor, Internals waste profile. A cumulative distribution curve of those 16 shipments versus their total activity concentration from Co-60 is shown in Figure III-4. The point on the curve corresponding to the Co-60 Class A limit of 700 $Ci/m^3$

is 1,667 Ci/m$^3$ (i.e., 700 Ci/m$^3$ at 42% Co-60 = 700/0.42 = 1,667 Ci/m$^3$), which is shown in Figure III-4. Figure III-4 indicates that there were 10 waste shipments, totaling about 40 ft$^3$, that characterized as Special Purpose Reactor, Internals and exceeded the Co-60 Class A limit.

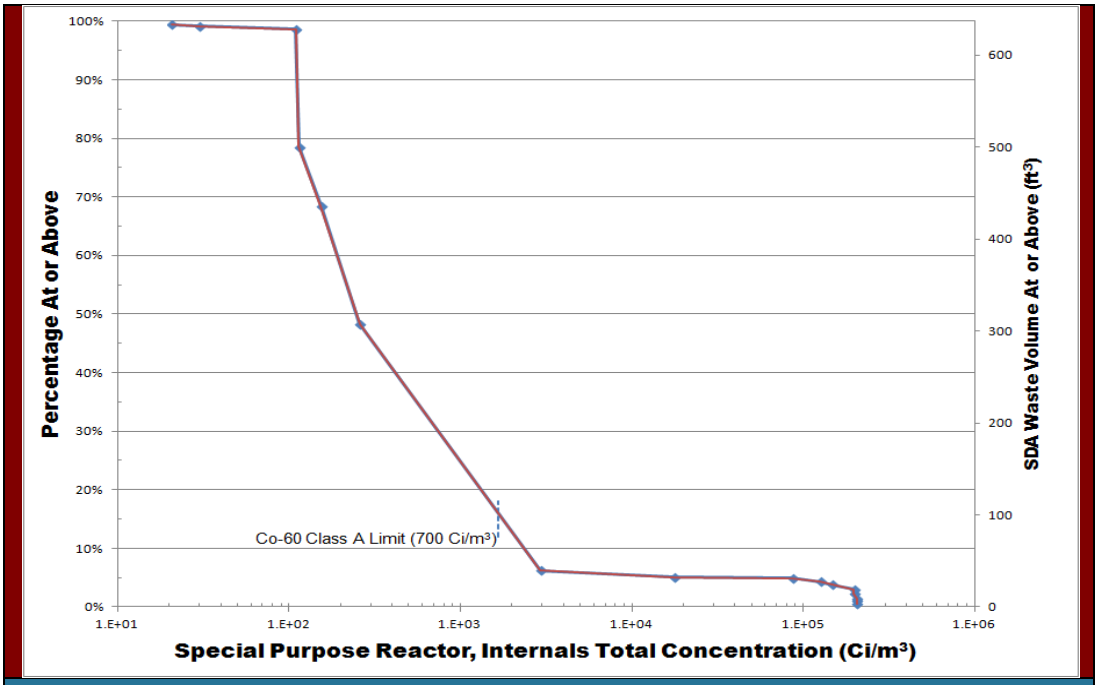


**Figure III-4 – Special Purpose Reactor, Internals Total Concentration**

Likewise, the SDA Integrated Database shows that 19 waste shipments were identified as having the Power Reactor, Internals waste profile. A cumulative distribution curve of those 19 shipments versus their total radionuclide concentration is shown in Figure III-5. The total concentration of Co-60 that results in the Class A limit (i.e., 700 Ci/m$^3$ / 0.42 = 1,667 Ci/m$^3$) is also shown in Figure III-5, which indicates that there were nine waste shipments, totaling about 575 ft$^3$, that characterized as Power Reactor, Internals and exceeded the Co-60 Class A limit.

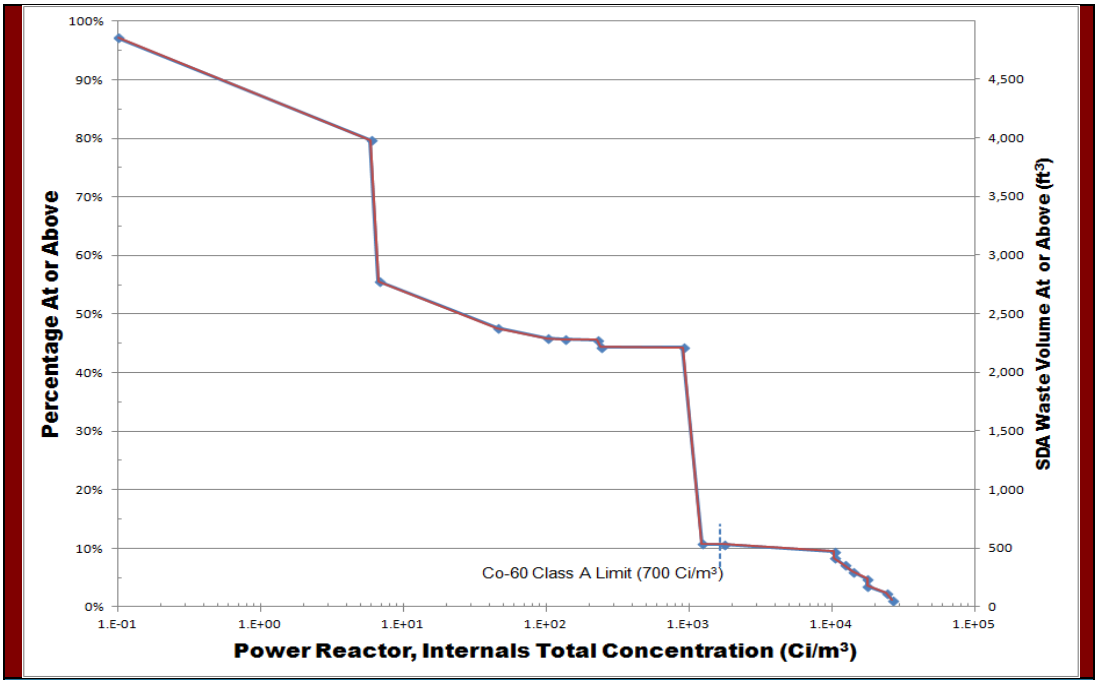


**Figure III-5 – Power Reactor, Internals Total Concentration**

Table III-7 is a summary of the 10 Special Purpose Reactor and 9 Power Reactor, Internal waste shipments that exceeded the Co-60 Class A limit. Of these, 14 of the shipments were disposed in the Trench 6 special purpose holes and could be fully removed by exhuming the Trench 6 special holes. The shipments shown in Table III-7 include the 15 waste shipments with the largest radionuclide concentrations disposed in the SDA, and 18 of the 20 largest concentration shipments. The volume of waste associated with the largest 15 shipments is about 390 $ft^3$, while the total volume of all 19 Table III-7 shipments is about 520 $ft^3$. The two right columns of Table III-7 show the dates when the Co-60 Class A concentration limit (700 $Ci/m^3$) and a 2.5 mrem/hr single drum dose rate would be reached, based on the SDA Integrated Database burial date for each respective shipment.

**Table III-7: Reactor Internal Greater than Class A Waste Shipments**

| Shipment No. | Source of Waste | Volume ($ft^3$) | Concentration ($Ci/m^3$) | Disposal Location | | Date to Reach | |
|---|---|---|---|---|---|---|---|
| | | | | Trench | Location | Class A | 2.5 mR/hr* |
| 73-K-036 | Fort Belvoir SM-1 Reactor | 3.1 | 2.1E+05 | 6 | SPH-16 | May-2010 | Mar-2082 |
| 73-K-040 | Fort Belvoir SM-1 Reactor | 3.1 | 2.1E+05 | 6 | SPH-17 | Jun-2010 | Mar-2082 |
| 73-K-057 | Fort Belvoir SM-1 Reactor | 3.1 | 2.1E+05 | 6 | SPH-19 | Jun-2010 | Mar-2082 |
| 73-B-001 | Saxton | 5 | 2.0E+05 | 6 | SPH-05 | May-2009 | Feb-2081 |
| 73-B-004 | Saxton | 5 | 2.0E+05 | 6 | SPH-06 | May-2009 | Feb-2081 |
| 73-B-007 | Saxton | 5 | 1.5E+05 | 6 | SPH-07 | Mar-2007 | Dec-2078 |
| 73-K-045 | Fort Belvoir SM-1 Reactor | 3.1 | 1.3E+05 | 6 | SPH-18 | Sep-2006 | Jun-2078 |
| 70-G-9002 | Pratt & Whitney Aircraft | 4.08 | 8.7E+04 | 6 | SPH-01 | Jun-2000 | Apr-2072 |
| 73-J-010 | Yankee Rowe | 60 | 2.6E+04 | 6 | SPH-12 | Sep-1994 | Jul-2066 |
| 73-J-018 | Yankee Rowe | 60 | 2.4E+04 | 6 | SPH-13 | Jan-1994 | Nov-2065 |
| 74-I-033-02 | Naval Research Laboratory | 1 | 1.8E+04 | 14 | 125 | Aug-1992 | May-2064 |
| 73-C-013 | Yankee Rowe | 60 | 1.8E+04 | 6 | SPH-08 | Feb-1991 | Nov-2062 |
| 73-C-016 | Yankee Rowe | 60 | 1.8E+04 | 6 | SPH-09 | Feb-1991 | Nov-2062 |
| 73-C-025 | Yankee Rowe | 60 | 1.4E+04 | 6 | SPH-11 | May-1989 | Feb-2061 |

**Table III-7: Reactor Internal Greater than Class A Waste Shipments**

| Shipment No. | Source of Waste | Volume ($ft^3$) | Concentration ($Ci/m^3$) | Disposal Location | | Date to Reach | |
|---|---|---|---|---|---|---|---|
| | | | | Trench | Location | Class A | 2.5 mR/hr* |
| 67-E-7001 | Yankee Rowe | 58 | 1.2E+04 | 4 | 525 | Jun-1982 | Mar-2054 |
| 73-C-019 | Yankee Rowe | 60 | 1.0E+04 | 6 | SPH-10 | Jan-1987 | Nov-2058 |
| 67-E-7010 | Yankee Rowe | 58 | 1.0E+04 | 5 | 0 | Mar-1981 | Dec-2052 |
| 73-F-048 | Brookhaven National Lab | 7.26 | 2.9E+03 | 12 | 325 | Sep-1977 | Jul-2049 |
| 67-B-7006 | Big Rock Point | 58 | 1.7E+03 | 4 | 475 | Jun-1967 | Mar-2039 |

* Based on the unshielded dose rate to activity relationship. Operator shielding and/or long reach excavators could be used to shorten the time periods.

Table III-6 shows two waste profiles with large contributions from both Cs-137 and Co-60: Power Reactor, boiling-water reactor (BWR) and Special Purpose Reactor, Naval. The SDA Integrated Database shows 183 waste shipments with the Power Reactor, BWR profile, and 779 waste shipments with the Special Purpose Reactor, Naval profiles. Figure III-6 and Figure III-7 are cumulative distribution plots of the BWR and Naval waste profiles disposed in the SDA as a function of the total radionuclide concentration in the waste.

Also shown on Figures III-6 and III-7 is the Cs-137 Class A concentration limit at the time of disposal; i.e., volume to the left of the Cs-137 Class A limit is Class A waste, while volume to the right is greater than Class A. At the time of disposal, the volumes of waste with BWR and Naval profiles exceeding the Class A limit are shown on these figures to be approximately 4,300 $ft^3$ and 30,000 $ft^3$, respectively. These volumes have decreased over time as the result of radioactive decay. Figure III-8 shows the volume of waste with these two waste profiles that is greater than Class A at various times.

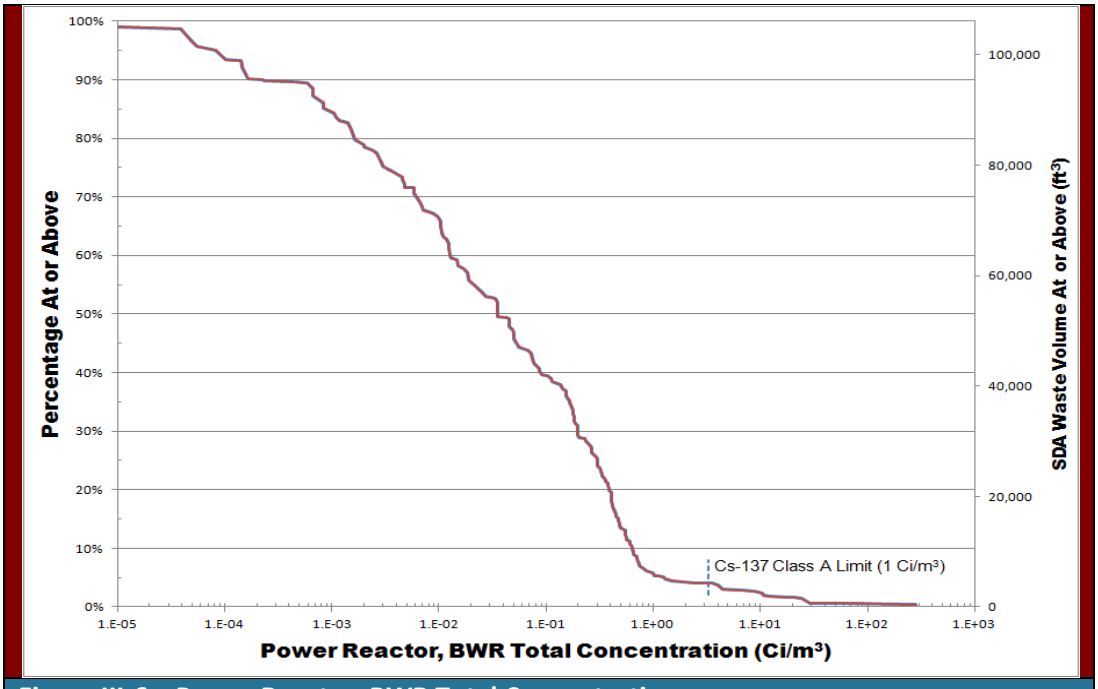


**Figure III-6 – Power Reactor, BWR Total Concentration**

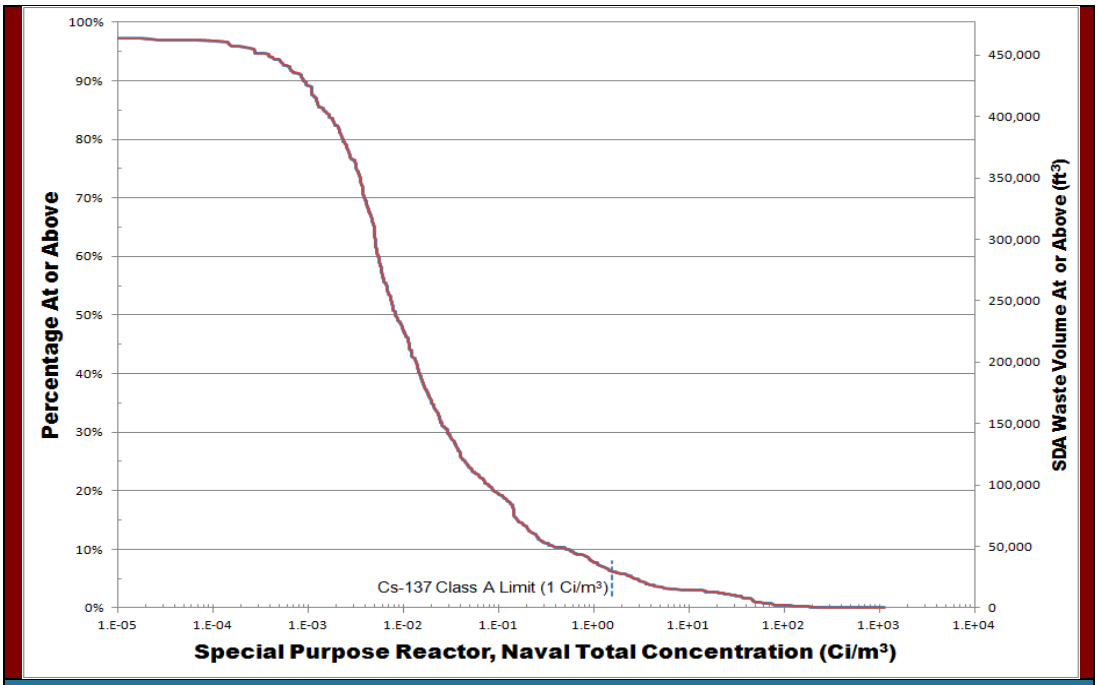


**Figure III-7 – Special Purpose Reactor, Naval Total Concentration**

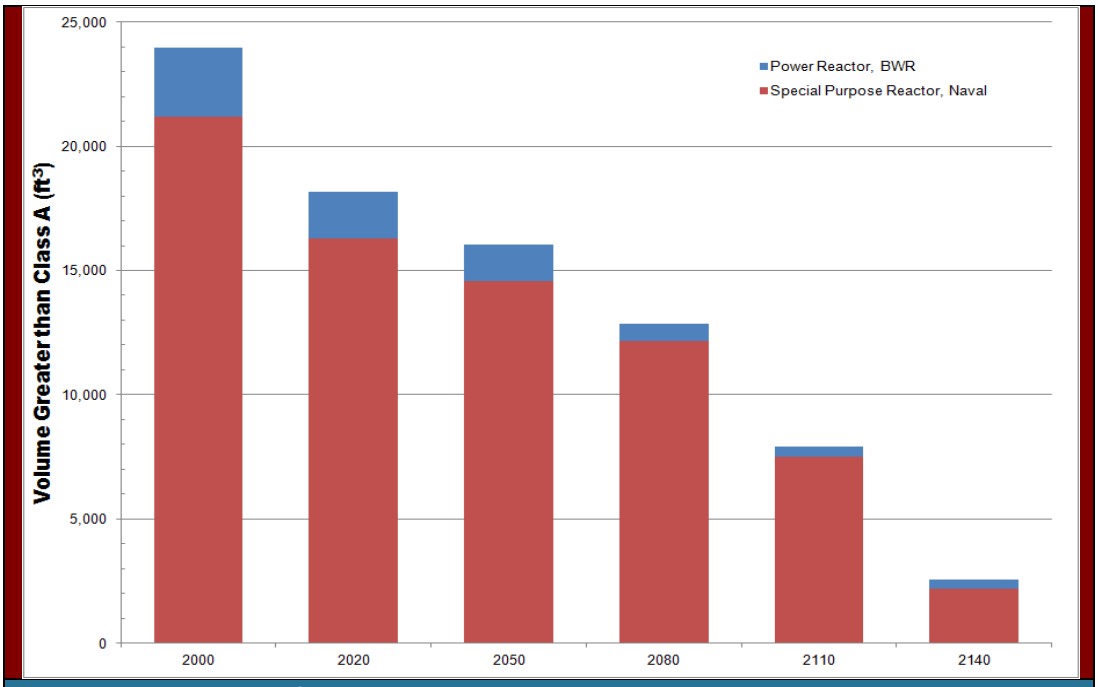


**Figure III-8 – Volume of Waste with Cs-137 Greater Than Class A**

# IV. NRC-Licensed Disposal Area

The NDA was operated by Nuclear Fuels Services, Inc. (NFS), under license from the Atomic Energy Commission (now U.S. Nuclear Regulatory Commission [NRC]), for disposal of solid radioactive waste generated from onsite fuel reprocessing operations. Beginning in 1966, solid radioactive waste materials from the nearby Main Plant Process Building exceeding 200 milliroentgen per hour (mR/hr), as well as other materials for which disposal in the SDA was not permitted, were buried by NFS in disposal holes in the NDA and backfilled with earth. From 1982-1986, the WVDP buried approximately 200,000 $ft^3$ of waste in twelve trenches in the NDA. For this study, the NDA has been divided into the following three distinct areas: (1) the NFS deep holes, (2) the NFS special holes, and (3) the WVDP disposal trenches. A more complete description of the NDA, including a figure, is provided in the Task 1.1 Technical Memorandum (ECS 2016).

## A. URS (2000) Inventory Estimate

URS (2000) provided NDA radionuclide inventory estimates for base year 2000. The Task 1.1 technical memorandum (ECS 2016) compared the URS (2000) inventory estimate to seven previous NDA estimates, and from these comparisons the continued use of the URS (2000) inventory estimate was recommended. Specific concerns had been previously expressed regarding the NDA plutonium inventory due to differences with the plutonium activities provided in DOE and NYSERDA (1996), Table C-9. The Task 1.1 technical memorandum concluded that the plutonium activities provided in DOE and NYSERDA (1996), Table C-9 are in error, and that there is substantial agreement between the URS (2000) inventory and other NDA plutonium activity and/or mass estimates. For this reason, the URS (2000) inventory was recommended for use in the Phase I studies without adjustment.

Table IV-1 presents a summary of the URS (2000) NDA radionuclide inventory estimates as of the 2000 base year used for that study. URS (2000) provides detailed breakdowns of the NDA inventories by waste unit, and should be consulted if that level of detail is desired.

**Table IV-1: NDA 2000 Radionuclide Inventory Summary – Source: URS 2000**

| Nuclide | Activity (1/1/2000) (Ci) | Percentage |
|---|---|---|
| Ni-63 | 116,407 | 39.1% |
| Cs-137 | 36,819 | 12.4% |
| Ba-137m | 34,831 | 11.7% |
| Co-60 | 29,723 | 10.0% |
| Y-90 | 28,814 | 9.7% |
| Sr-90 | 28,806 | 9.7% |
| Pu-241 | 15,372 | 5.2% |
| Fe-55 | 1,823 | 0.61% |
| Am-241 | 1,783 | 0.60% |
| Ni-59 | 1,110 | 0.37% |
| Pu-239 | 579 | 0.19% |
| C-14 | 517 | 0.17% |
| Pu-240 | 399 | 0.13% |

| Table IV-1: NDA 2000 Radionuclide Inventory Summary – Source: URS 2000 | | |
|---|---|---|
| **Nuclide** | **Activity (1/1/2000) (Ci)** | **Percentage** |
| Pu-238 | 379 | 0.13% |
| H-3 | 64.9 | 0.02% |
| Nb-94 | 14.5 | 0.005% |
| Zr-93 | 13.2 | 0.004% |
| U-233 | 11.3 | 0.004% |
| Tc-99 | 10.2 | 0.003% |

## B. Decayed NDA Inventory

Using the methodology described in Section II, the URS (2000) NDA inventory was decayed to 2020 (the new base year) and to 2050, 2080, 2110, and 2140. The resulting decayed inventories are provided in the accompanying Excel file (i.e., *NDA Inventory by Hole – Decayed.xlsx*) for each NDA NFS deep hole, NFS special hole, and WVDP trench. To show the overall impact of radiological decay, Table IV-2 shows the NDA decayed total inventory at each of the six decay times.

| Table IV-2: NDA Decayed Inventory | | | | | | |
|---|---|---|---|---|---|---|
| **Nuclide** | **NDA Decayed Inventory (Ci)** | | | | | |
| | **2000** | **2020** | **2050** | **2080** | **2110** | **2140** |
| Ni-63 | 1.2E+05 | 1.0E+05 | 8.1E+04 | 6.5E+04 | 5.3E+04 | 4.2E+04 |
| Cs-137 | 3.7E+04 | 2.3E+04 | 1.2E+04 | 5.9E+03 | 2.9E+03 | 1.5E+03 |
| Co-60 | 3.0E+04 | 2.1E+03 | 4.1E+01 | 8.0E-01 | 1.6E-02 | 3.0E-04 |
| Sr-90 | 2.9E+04 | 1.8E+04 | 8.6E+03 | 4.1E+03 | 2.0E+03 | 9.7E+02 |
| Pu-241 | 1.5E+04 | 5.9E+03 | 1.4E+03 | 3.3E+02 | 7.7E+01 | 1.8E+01 |
| Fe-55 | 1.8E+03 | 1.1E+01 | 4.9E-03 | 2.2E-06 | 9.9E-10 | 4.5E-13 |
| Am-241 | 1.8E+03 | 2.0E+03 | 2.1E+03 | 2.0E+03 | 1.9E+03 | 1.8E+03 |
| Ni-59 | 1.1E+03 | 1.1E+03 | 1.1E+03 | 1.1E+03 | 1.1E+03 | 1.1E+03 |
| Pu-239 | 5.8E+02 | 5.8E+02 | 5.8E+02 | 5.8E+02 | 5.8E+02 | 5.8E+02 |
| C-14 | 5.2E+02 | 5.2E+02 | 5.1E+02 | 5.1E+02 | 5.1E+02 | 5.1E+02 |
| Pu-240 | 4.0E+02 | 4.0E+02 | 4.0E+02 | 4.0E+02 | 3.9E+02 | 3.9E+02 |
| H-3 | 6.5E+01 | 2.1E+01 | 3.9E+00 | 7.1E-01 | 1.3E-01 | 2.4E-02 |
| Tc-99 | 1.0E+01 | 1.0E+01 | 1.0E+01 | 1.0E+01 | 1.0E+01 | 1.0E+01 |
| U-238 | 1.5E+00 | 1.5E+00 | 1.5E+00 | 1.5E+00 | 1.5E+00 | 1.5E+00 |
| U-235 | 1.2E-01 | 1.2E-01 | 1.2E-01 | 1.2E-01 | 1.2E-01 | 1.2E-01 |
| I-129 | 2.1E-02 | 2.1E-02 | 2.1E-02 | 2.1E-02 | 2.1E-02 | 2.1E-02 |
| Th-232 | 8.9E-03 | 8.9E-03 | 8.9E-03 | 8.9E-03 | 8.9E-03 | 8.9E-03 |
| Th-230 | 3.7E-04 | 4.8E-04 | 6.4E-04 | 8.1E-04 | 9.9E-04 | 1.2E-03 |
| Ra-226 | 4.1E-06 | 7.7E-06 | 1.5E-05 | 2.4E-05 | 3.5E-05 | 4.9E-05 |
| All Others | 4.6E+02 | 3.7E+02 | 3.0E+02 | 2.5E+02 | 2.0E+02 | 1.7E+02 |
| Total | 3.0E+05 | 1.9E+05 | 1.3E+05 | 9.0E+04 | 6.7E+04 | 5.2E+04 |

Figure IV-1 is a graphical representation of Table IV-2 for the eight radionuclides with the largest activity in the 2000 NDA inventory. As shown, Ni-63 dominates the NDA inventory over this entire time period, and as time passes becomes more dominant due to the decay of the Cs-137 and Sr-90, which have shorter half-lives. Notice the slight increase in the Am-241 inventory, which is due to the decay of Pu-241, as indicated in Figure II-6.

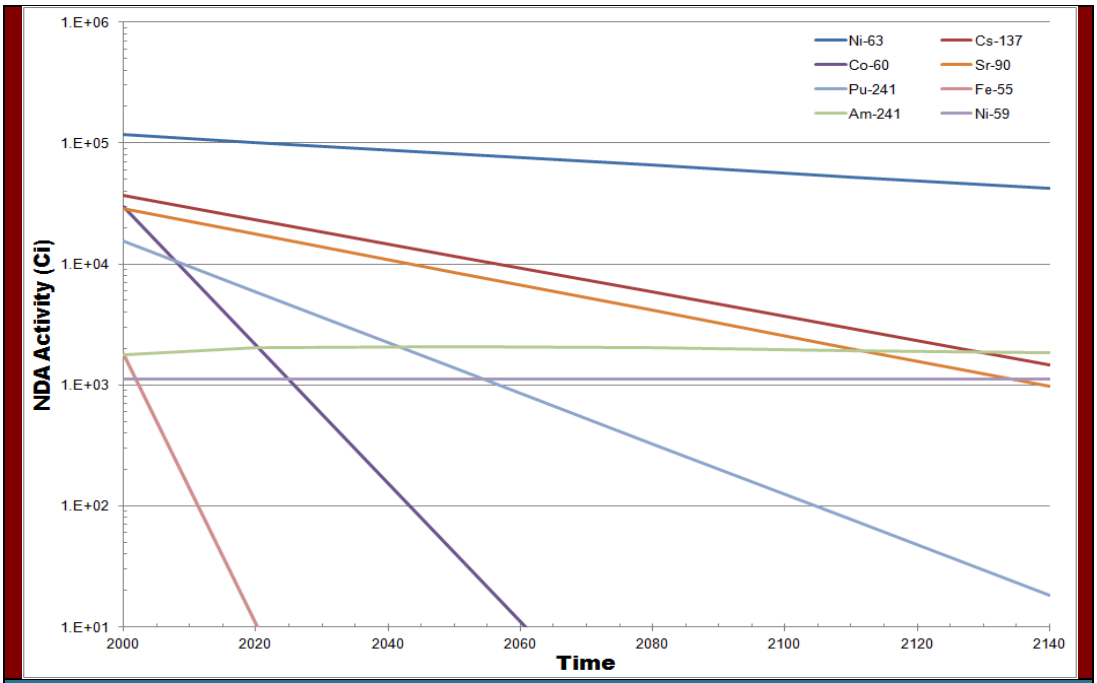


**Figure IV-1 – NDA Decayed Inventory – Eight Largest Radionuclides**

Figure IV-2 provides a series of plots that show the changing radionuclide composition of the waste in individual NDA disposal holes over time. (Note that, for clarity, only the five radionuclides and 49 holes with the largest 2000 inventory are shown. Even so, it is recognized that it may be difficult to read specific hole identifiers and/or activities off of Figure IV-2. That information may be found in the Excel file *NDA Inventory by Hole – Decayed.xlsx*, that accompanies and is a part of this report.) Figure IV-2 shows the almost complete domination of the NDA activity by Ni-63 by 2140, and that the Co-60 and Pu-241 activities have almost completely decayed away by 2050 and 2140, respectively. This same observation can also be made from the decay curves for all NDA waste units shown in Figure IV-1.

With reference to the second (2020) plot in Figure IV-2, NDA Hole 7-1 is shown to have the largest total activity in the new base year of 2020. Using the volume of waste in Hole 7-1 (i.e., 344.2 $ft^3$) and the 2020 distribution of radionuclides and their activities shown in Figure IV-2, MicroShield®'s internal radiological decay capability was used to extend the calculation beyond 2140 to 2700. The results of this analysis are shown in Figure IV-3. The solid curves on Figure IV-3 are the Total (dark blue), Co-60 (light blue), Cs-137 (red), Ni-59 (green), carbon-14 (C-14) (purple), and niobium-94 (Nb-94) (orange) activities, while the dashed curves are the Total (dark blue), 1.5 MeV (light blue), 0.6 MeV (red), and 0.8 MeV (orange) dose rates.

Initially, the Total dose rate follows the 1.5 MeV (or Co-60) curve until about 2060, then it transitions to the 0.6 MeV (or Cs-137) curve until about 2180, when it transitions to the 0.8 MeV (or Nb-94) curve. Since Nb-94 has a 20,300 year half-life, no further reduction of the dose rate occurs beyond that point, as shown in Figure IV-3. Nb-94 is formed by the neutron activation of naturally occurring, stable Nb-93 that is added to stainless steel and Inconel to increase their strength.

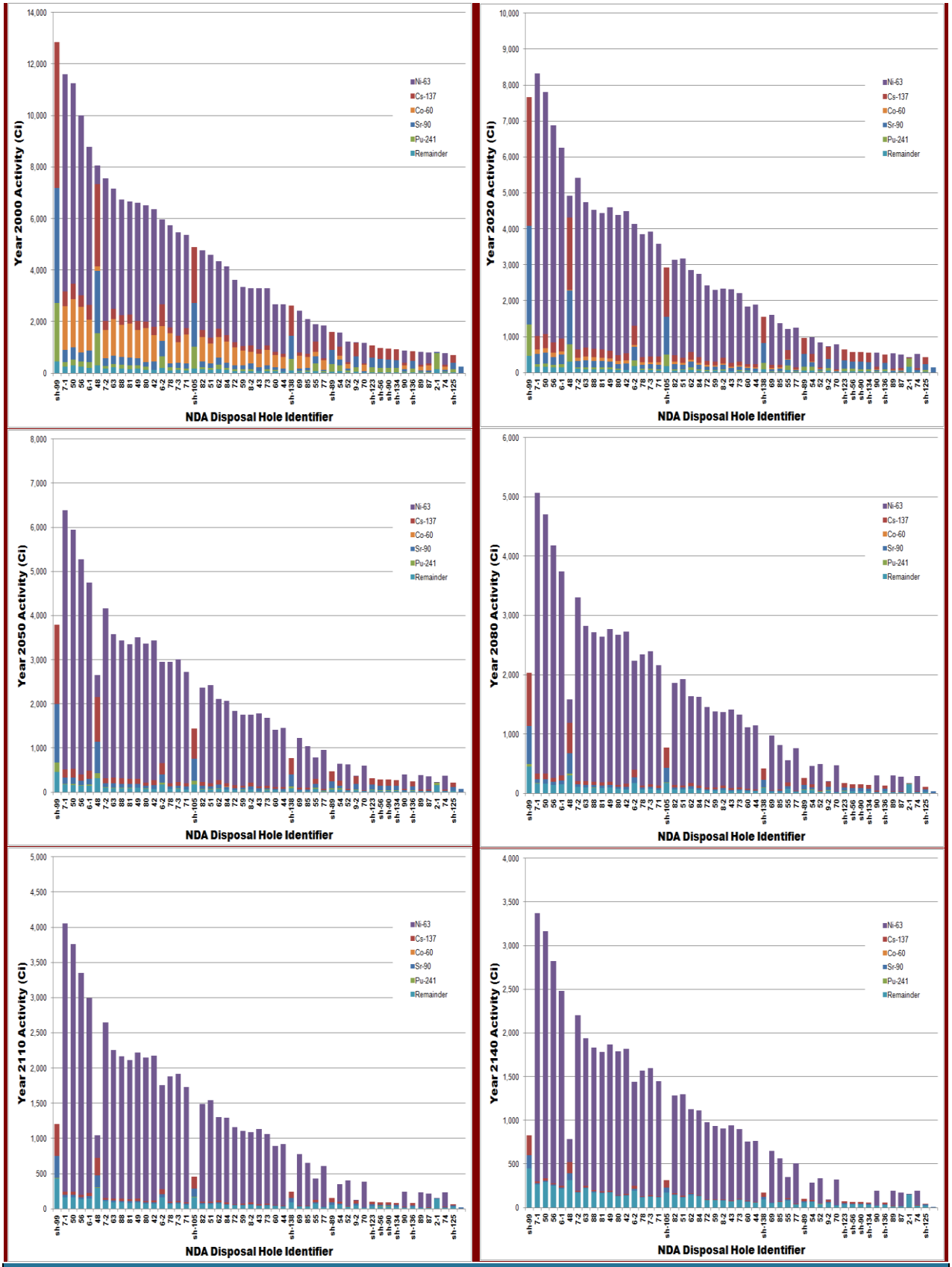


**Figure IV-2 – NDA Five Largest Radionuclide Distributions**

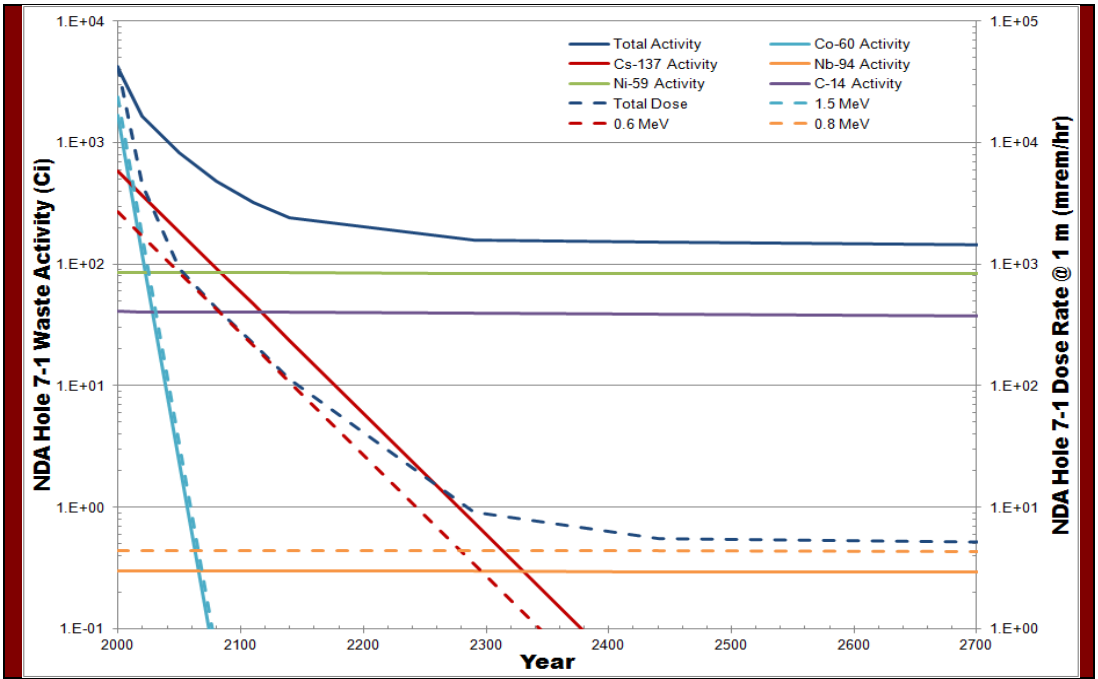


**Figure IV-3 – NDA Hole 7-1 Activity and Dose Rate**

With reference to Figure IV-3, Cs-137 would dominate the NDA dose over most of the next 200 years. Figure IV-4 shows the distribution of the Cs-137 concentration in NDA waste based on the 2020 inventory. By applying the same MicroShield model used to develop Figure IV-3, it was determined that a Cs-137 concentration of approximately 0.05 Ci/$m^3$ would be the level corresponding to an unshielded dose rate of 2.5 mrem/hr at a distance of 1 meter from the waste. As shown on Figure IV-4, about half (47.9%) of the NDA waste would have an unshielded dose rate larger than 2.5 mrem/hr, or larger than 5 rem/yr to a fulltime worker.

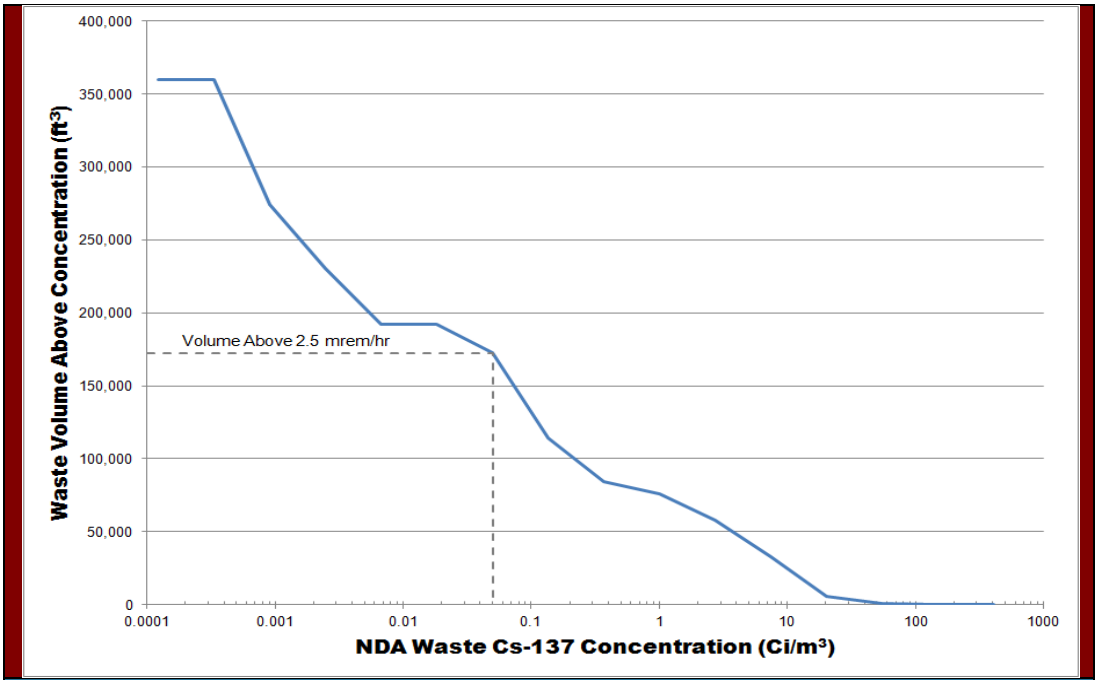


**Figure IV-4 – Distribution of Cs-137 in NDA Waste**

A number of approaches could be utilized to reduce the amount of NDA waste that required shielding, including: 1) increasing the allowable dose rate, by limiting exposure duration; 2) delaying the exhumation operations, thereby allowing for radiological decay; and 3) performing operations with long-reach tools. Figure IV-5 demonstrates the effects that each of these approaches would have on the amount of NDA waste that could be exhumed unshielded. The starting base case for Figure IV-5 is the 2.5 mrem/hr point on the shown curve in Figure IV-4 (i.e., 47.9% of the waste volume is above the 2.5 mrem/hr dose rate in 2020), based on the assumption that the dose point is 1 meter from the waste.

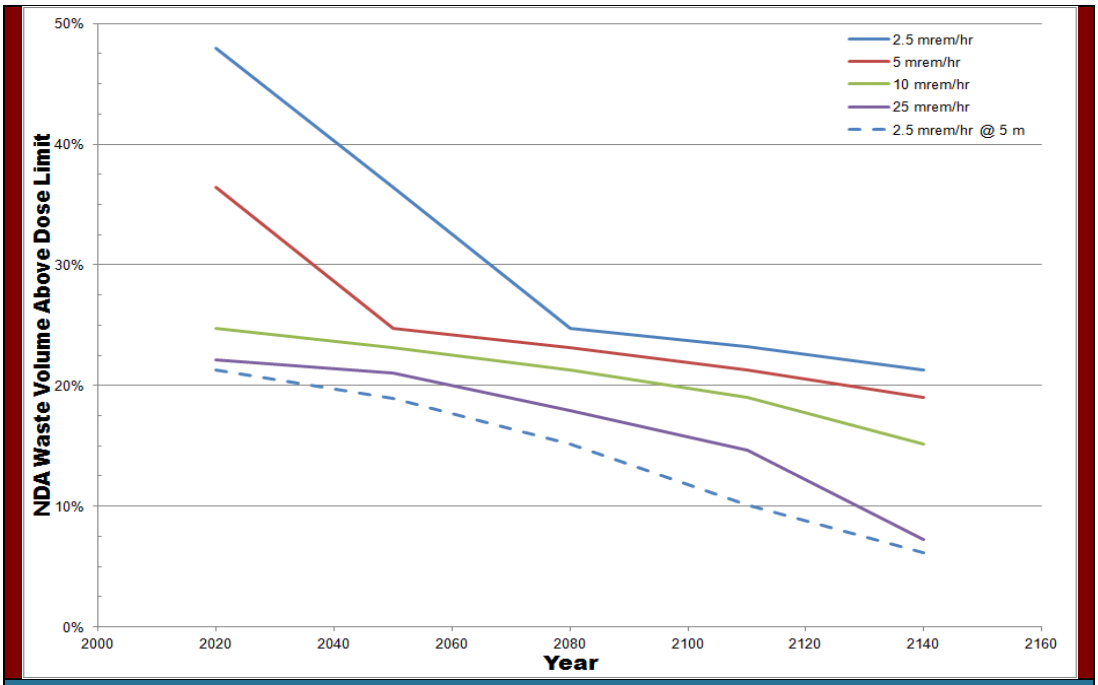


**Figure IV-5 – Effect of Radiological Decay on NDA Waste Unshielded Dose Rate**

As indicated above in Section IV.A, plutonium disposed in the NDA is of particular interest. Figure IV-6 shows the time-dependent NDA activity for the four main plutonium isotopes: Pu-238, Pu-239, Pu-240, and Pu-241. Because Pu-241 has a short half-life of 14.4 years and its activity is reduced by almost three orders of magnitude over the time period of interest, and because it decays by beta emission to Am-241 (see Figure II-6) without significant gamma emission,[2] Pu-241 will not be included in the following discussion.

[2] Note: Table IV-2 and Figure IV-1 both show the slight increase in Am-241 activity until about 2050 due to Pu-241 decay.

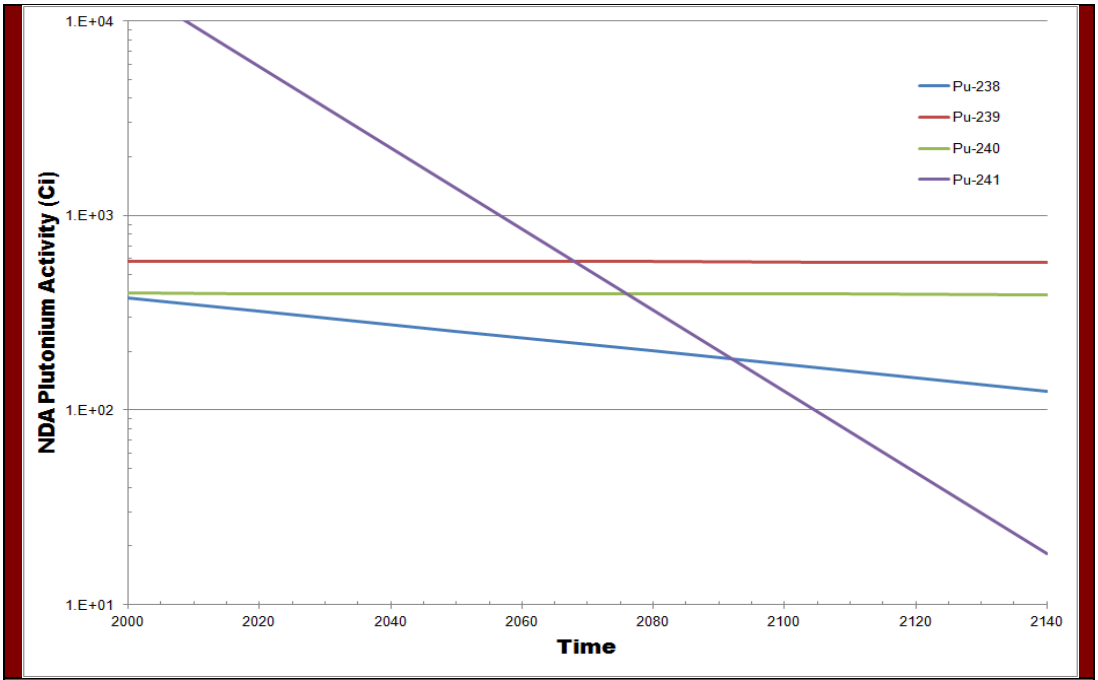


**Figure IV-6 – NDA Plutonium Activity**

Figure IV-7 shows the 2020 distribution within the NDA of the three alpha-emitting plutonium isotopes, Pu-238, Pu-239, and Pu-240, based upon the URS (2000) estimate. With the exception of about six holes, Figure IV-7 shows that the alpha-emitting plutonium inventory is spread more or less uniformly throughout the NDA.

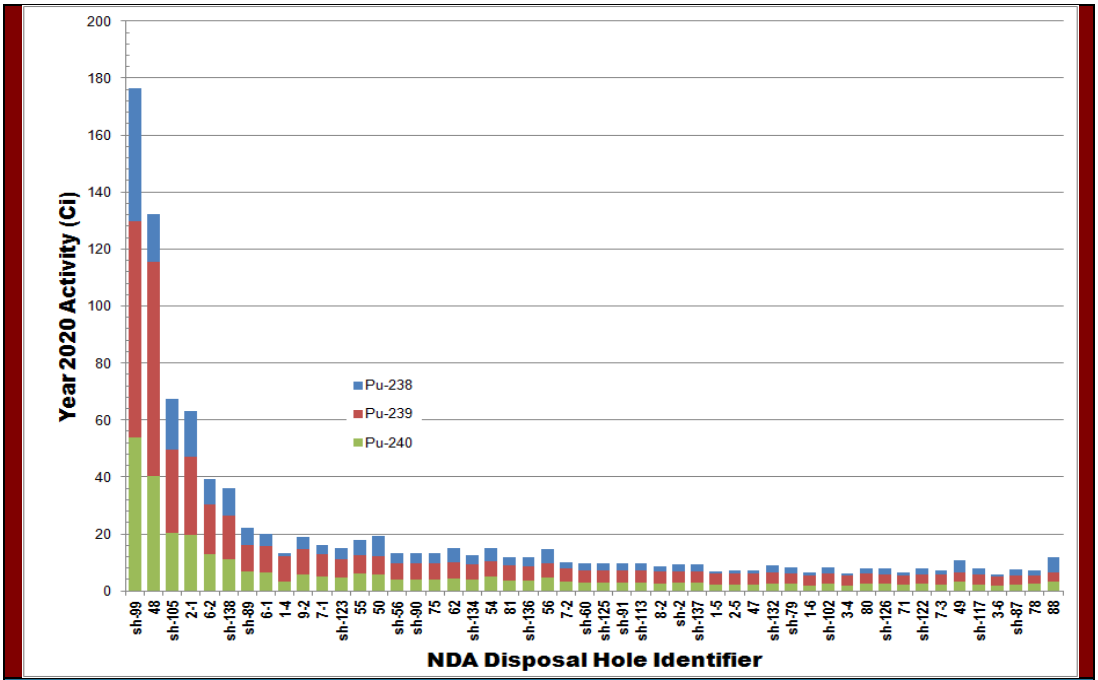


**Figure IV-7 – NDA Plutonium Distribution by Disposal Hole**

Figure IV-7 shows that Special Hole sh-99 contains about 47, 76, and 54 Ci of Pu-238, Pu-239, and Pu-240, respectively, while the spent fuel disposed in Hole 48 contains about 17, 75, and 40 Ci of Pu-238, Pu-239, and Pu-240, respectively. Together, these two holes contain about 23.6% of the NDA alpha-emitting plutonium activity, while the six holes with the largest alpha-emitting plutonium isotopes contain about 40% of the total NDA activity.

Figure IV-8 is an alternative presentation of the NDA alpha-emitting plutonium isotope distribution. Figure IV-8 again shows that the plutonium is spread fairly uniformly over the NDA (e.g., about 60% of all holes have from 0 to 2 Ci, and only six to eight holes have more than 20 Ci). It also shows that, due to the relative long half-lives of the alpha-emitting plutonium isotopes, there is not much change in the NDA plutonium distribution over this study's time period of interest.

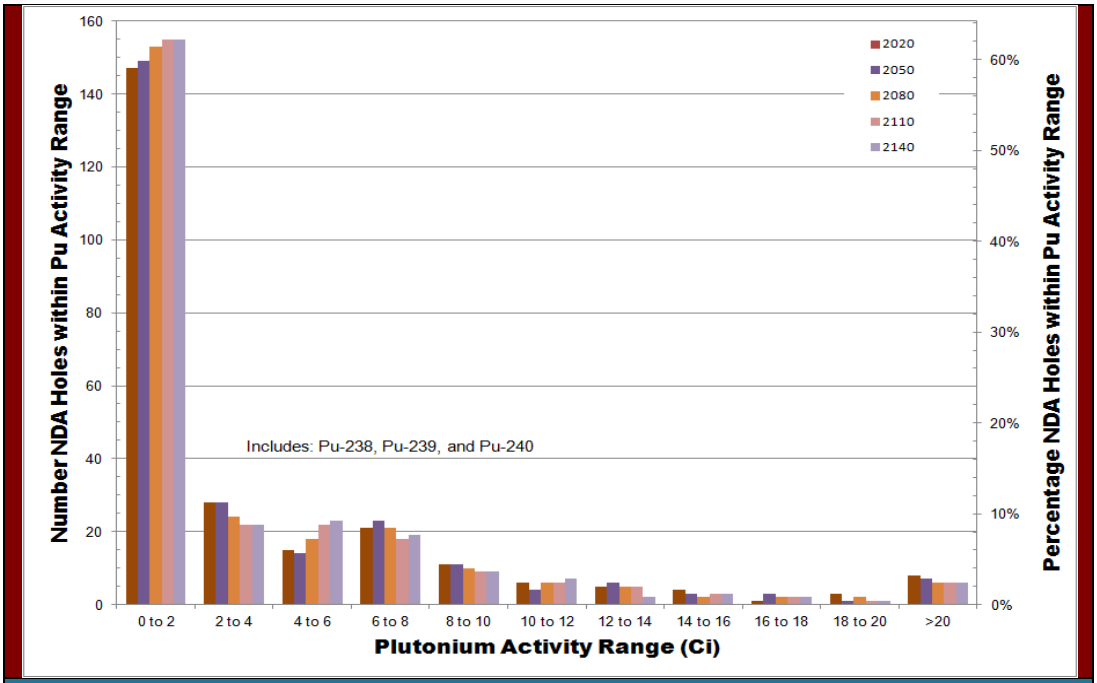


**Figure IV-8 – NDA Alpha-Emitting Plutonium Distribution Over Time**

# V. Waste Tank Farm

For purposes of this study, the primary components of the WTF are the four underground waste storage tanks: 8D-1, 8D-2, 8D-3, and 8D-4. During reprocessing, HLW from the plant was sent to Tanks 8D-2 and 8D-4. Tank 8D-4 held the acidic THOREX waste produced during Campaign 11, while the PUREX waste from all of the other campaigns was held in Tank 8D-2. The WVDP used Tank 8D-1 to house ion exchange columns that were part of the Supernatant Treatment System, with the spent resins dumped to the bottom of Tank 8D-1. Tank 8D-3 was mostly kept as a spare to Tank 8D-4.

As shown in Figure V-1, much of the HLW that had been stored in the tanks was removed and vitrified in the 5-year period from 1996 to 2001. In particular, about 98% and >99.9% of the Cs-137 and Sr-90 activity, respectively, have already been removed from the tanks.

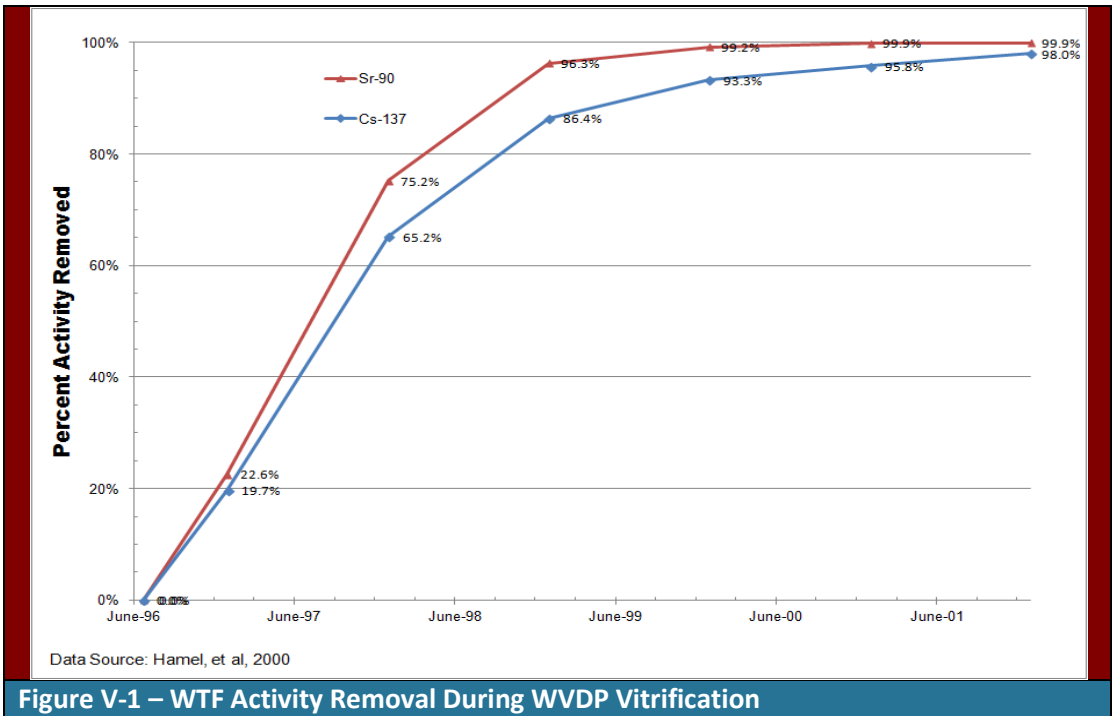


**Figure V-1 – WTF Activity Removal During WVDP Vitrification**

## A. WVNSCO and Gemini (2005) Inventory Estimate

WVNSCO and Gemini (2005) provided WTF radionuclide inventory estimates for year 2005. The Task 1.1 technical memorandum (ECS 2016) compared the WVNSCO and Gemini (2005) inventory estimate to a previous WTF estimate and recommended the continued use of the WVNSCO and Gemini (2005) inventory estimates for Tanks 8D-1 and 8D-2. In the case of Tank 8D-4, sampling was performed of the liquid, sludge, and internal walls in 2012 to characterize the radiological and hazardous contents of the tank following a reduction in the liquid levels. The revised inventory (CH2M Hill BWXT West Valley, LLC [CHBWV] 2012) was recommended for use in the Phase I studies for Tank 8D-4. Due to the small amount of activity WVNSCO and Gemini (2005) estimated to remain in Tank 8D-3, the Task 1.1 technical memorandum made no specific recommendation about that tank. Instead, it was assumed that any exhumation

approach used to remove Tank 8D-4 would also be used for Tank 8D-3, since they are both contained within the same vault.

Table V-1 presents a summary of the WVNSCO and Gemini (2005) radionuclide inventory estimates for Tanks 8D-1 and 8D-2, and the CHBWV (2012) inventory for Tank 8D-4. The inventories, as reported in these two documents, had base years of 2005 and 2012, respectively. WVNSCO and Gemini (2005) and CHBWV (2012) provide more detailed breakdowns of the WTF inventories and should be consulted if that level of detail is desired.

**Table V-1: WTF 2005/2012 Radionuclide Inventory Summary (Ci) – Sources: WVNSCO & Gemini (2005) & CHBWV (2012)**

| Nuclide | Tank 8D-1 | Tank 8D-2 | Tank 8D-4 | Total |
|---|---|---|---|---|
| C-14 | 2.0E-02 | 2.7E-03 | 9.3E-03 | 3.2E-02 |
| Sr-90 | 2.3E+03 | 3.4E+04 | 2.1E+03 | 3.8E+04 |
| Tc-99 | 5.4E+00 | 2.9E+00 | 1.1E+00 | 9.4E+00 |
| I-129 | 6.8E-03 | 3.8E-03 | 1.4E-02 | 2.4E-02 |
| Cs-137 | 2.5E+05 | 8.6E+04 | 1.3E+04 | 3.5E+05 |
| U-232 | 6.0E-01 | 1.2E-01 | 1.5E-02 | 7.3E-01 |
| U-233 | 2.6E-01 | 5.9E-02 | 1.2E-02 | 3.3E-01 |
| U-234 | 1.0E-01 | 2.2E-02 | | 1.3E-01 |
| U-235 | 3.4E-03 | 1.1E-03 | 1.8E-04 | 4.7E-03 |
| U-238 | 3.1E-02 | 5.2E-03 | 8.3E-04 | 3.7E-02 |
| Np-237 | 2.3E-02 | 5.0E-01 | 1.5E-02 | 5.4E-01 |
| Pu-238 | 5.6E+00 | 1.5E+02 | 2.2E+01 | 1.8E+02 |
| Pu-239 | 1.5E+00 | 3.6E+01 | 6.6E+00 | 4.1E+01 |
| Pu-240 | 1.1E+00 | 2.6E+01 | | 3.0E+01 |
| Pu-241 | 4.4E+01 | 7.4E+02 | N.P. | 7.8E+02 |
| Am-241 | 3.8E-01 | 3.8E+02 | 5.5E+01 | 4.4E+02 |
| Cm-243 | 1.1E-03 | 3.6E+00 | 5.3E+00 | 3.8E+00 |
| Cm-244 | 5.0E-02 | 8.0E+01 | | 8.5E+01 |

## B. Decayed WTF Inventory

Using the methodology described in Section II, the WVNSCO and Gemini (2005) and CHBWV (2012) WTF inventories were decayed to 2020 (the new base year) and to 2050, 2080, 2110, and 2140. The resulting decayed inventories are provided in the accompanying Excel file (i.e., *WTDF Inventory – Decayed.xlsx*). To show the overall impact of radiological decay, Table V-2 shows the WTF decayed total inventory at each of the six decay times.

**Table V-2: WTF Decayed Inventory**

| Nuclide | WTF Decayed Inventory (Ci) | | | | | |
|---|---|---|---|---|---|---|
| | 2005/12* | 2020 | 2050 | 2080 | 2110 | 2140 |
| Cs-137 | 3.49E+05 | 2.49E+05 | 1.25E+05 | 6.27E+04 | 3.15E+04 | 1.58E+04 |
| Sr-90 | 3.84E+04 | 2.70E+04 | 1.30E+04 | 6.30E+03 | 3.04E+03 | 1.47E+03 |
| Pu-241 | 7.84E+02 | 3.81E+02 | 8.99E+01 | 2.12E+01 | 5.00E+00 | 1.18E+00 |
| Pu-238 | 1.78E+02 | 1.59E+02 | 1.25E+02 | 9.89E+01 | 7.80E+01 | 6.16E+01 |
| Tc-99 | 9.40E+00 | 9.40E+00 | 9.40E+00 | 9.40E+00 | 9.40E+00 | 9.40E+00 |
| Pu-239 | 4.41E+01 | 4.41E+01 | 4.40E+01 | 4.40E+01 | 4.40E+01 | 4.39E+01 |
| Pu-240 | 2.71E+01 | 2.71E+01 | 2.70E+01 | 2.69E+01 | 2.68E+01 | 2.67E+01 |
| Am-241 | 4.35E+02 | 4.39E+02 | 4.28E+02 | 4.10E+02 | 3.91E+02 | 3.73E+02 |

**Table V-2: WTF Decayed Inventory**

| Nuclide | WTF Decayed Inventory (Ci) | | | | | |
|---|---|---|---|---|---|---|
| | 2005/12* | 2020 | 2050 | 2080 | 2110 | 2140 |
| U-233 | 3.19E-01 | 3.19E-01 | 3.19E-01 | 3.19E-01 | 3.19E-01 | 3.19E-01 |
| U-234 | 1.34E-01 | 1.41E-01 | 1.53E-01 | 1.62E-01 | 1.70E-01 | 1.76E-01 |
| U-238 | 3.70E-02 | 3.70E-02 | 3.70E-02 | 3.70E-02 | 3.70E-02 | 3.70E-02 |
| Np-237 | 5.38E-01 | 5.40E-01 | 5.44E-01 | 5.48E-01 | 5.52E-01 | 5.56E-01 |
| C-14 | 3.20E-02 | 3.19E-02 | 3.18E-02 | 3.17E-02 | 3.16E-02 | 3.15E-02 |
| I-129 | 2.46E-02 | 2.46E-02 | 2.46E-02 | 2.46E-02 | 2.46E-02 | 2.46E-02 |
| U-235 | 4.68E-03 | 4.68E-03 | 4.68E-03 | 4.68E-03 | 4.68E-03 | 4.69E-03 |
| All Others | 0.00E+00 | 6.19E-01 | 6.23E-01 | 6.27E-01 | 6.31E-01 | 6.35E-01 |
| Total | 3.89E+05 | 5.39E+05 | 2.70E+05 | 1.35E+05 | 6.79E+04 | 3.42E+04 |

* For Tanks 8D-1 and 8D-2 WVNSCO and Gemini (2005) estimated the inventory at 2005; for Tank 8D-4 CHBWV (2012) estimated the inventory at 2012. For this summary table they have been added together, however, they were kept separate when the decay calculations were performed, as shown in the accompanying Excel file, *WTDF Inventory – Decayed.xlsx*.

Figure V-2 is a graphical representation of Table V-2 for the eight radionuclides with the largest activities in the tanks, as reported in the 2005/2012 column of Table V-2. To generate Figure V-2, it was necessary to decay correct the Tank 8D-4 2012 inventory back to 2005. As shown, Cs-137 and Sr-90 dominate the WTF inventory over this entire time period. Figure V-2 also shows that, with the exception of Cs-137, Sr-90, Pu-241, and Pu-238, the WTF activity is approximately unchanged over the entire time period of interest.

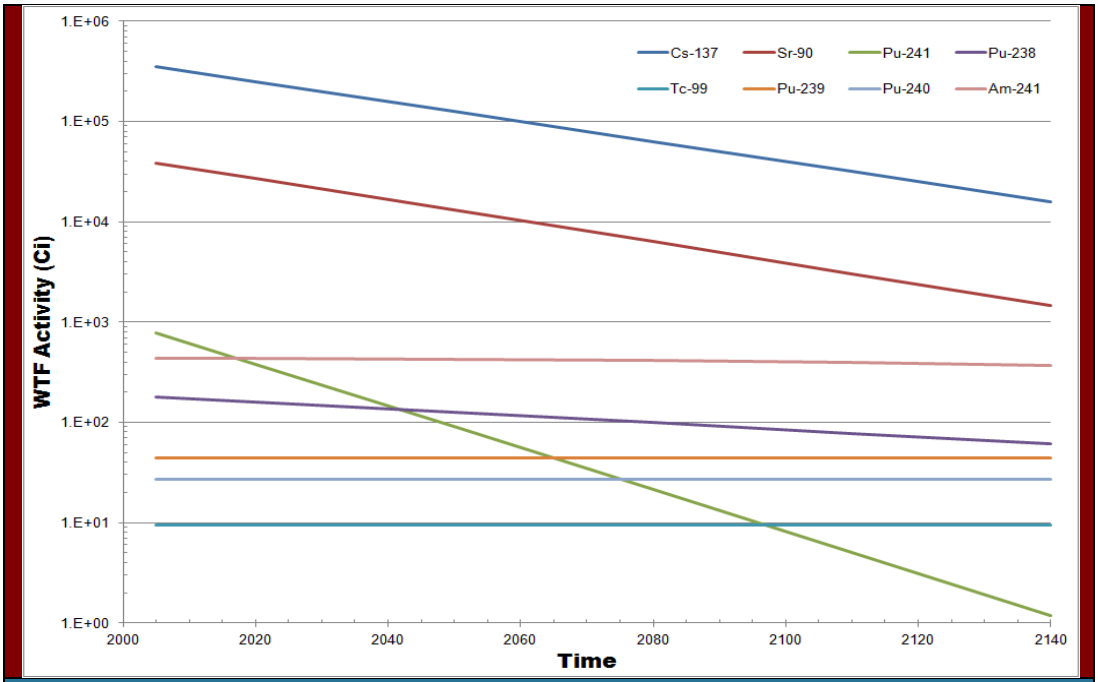


**Figure V-2 – WTF Decayed Inventory – Eight Largest Radionuclides**

Table V-1 provides a breakdown of the dominant Cs-137 inventory into specific sources within each tank. In both Tanks 8D-1 and 8D-2, more than half of the Cs-137 inventory remains associated with the zeolite in the tanks, even though 98% of the Cs-137 activity

in zeolite had been removed between 1996 and 2001. The sludge in the bottom of the tank is the dominant source of Cs-137 in Tank 8D-4.

**Table V-3: WTF Cs-137 Distribution**

| Tank | Area | 2005/12* | 2020 | 2050 | 2080 | 2110 | 2140 |
|---|---|---|---|---|---|---|---|
| Tank 8D-1 | Sludge** | 9.8E+02 | 6.9E+02 | 3.5E+02 | 1.7E+02 | 8.8E+01 | 4.4E+01 |
| | Zeolite | 1.5E+05 | 1.1E+05 | 5.3E+04 | 2.7E+04 | 1.3E+04 | 6.7E+03 |
| | Fixed | 5.5E+03 | 3.9E+03 | 2.0E+03 | 9.8E+02 | 4.9E+02 | 2.5E+02 |
| | STS IX | 9.4E+04 | 6.7E+04 | 3.3E+04 | 1.7E+04 | 8.4E+03 | 4.2E+03 |
| | STS Equip | 2.8E+03 | 2.0E+03 | 1.0E+03 | 5.0E+02 | 2.5E+02 | 1.3E+02 |
| | **Total** | **2.5E+05** | **1.8E+05** | **8.9E+04** | **4.5E+04** | **2.2E+04** | **1.1E+04** |
| Tank 8D-2 | Sludge* | 3.4E+03 | 2.4E+03 | 1.2E+03 | 6.0E+02 | 3.0E+02 | 1.5E+02 |
| | Zeolite | 4.8E+04 | 3.4E+04 | 1.7E+04 | 8.6E+03 | 4.3E+03 | 2.2E+03 |
| | Fixed | 3.5E+04 | 2.5E+04 | 1.2E+04 | 6.2E+03 | 3.1E+03 | 1.6E+03 |
| | **Total** | **8.6E+04** | **6.1E+04** | **3.1E+04** | **1.5E+04** | **7.7E+03** | **3.9E+03** |
| Tank 8D-4 | Sludge* | 1.4E+04 | 1.1E+04 | 5.7E+03 | 2.8E+03 | 1.4E+03 | 7.1E+02 |
| | Fixed | 4.4E+00 | 3.7E+00 | 1.8E+00 | 9.2E-01 | 4.6E-01 | 2.3E-01 |
| | **Total** | **1.4E+04** | **1.1E+04** | **5.7E+03** | **2.8E+03** | **1.4E+03** | **7.1E+02** |

* For Tanks 8D-1 and 8D-2 WVNSCO and Gemini (2005) estimated the inventory at 2005; for Tank 8D-4 CHBWV (2012) estimated the inventory at 2012.

** WVNSCO and Gemini 2005 and CHBWV 2012 identified inventory in the tank's liquid, however Tanks 8D-1 and 8D-2 are currently dry and Tank 8D-4 will be emptied in the future. For this table, it has been assumed that the Cs-137 liquid inventory remains in the sludge once the liquid has been removed.

The last zeolite transfer out of Tank 8D-1 occurred on February 6, 2001. From February 4–6, 2001, dose rate measurements reflective of the residual radionuclide inventory were taken at the Tank 8D-1 M-4 and M-7 risers as the water level was increased in the tank prior to zeolite transfer (WVNSCO and Gemini 2005). The radiation detection probe was located 20 feet 9.5 inches off the tank floor for both risers. Figure V-3 shows the February 2001 dose rate measurements as a function of the Tank 8D-1 water level. In order to extrapolate the dose rate back to a zero water level, trend lines were fitted to the measured dose rates. An exponential equation provided the best fit for the M-7 dose rates, while a second order polynomial provided the best fit for the M-4 dose rates.

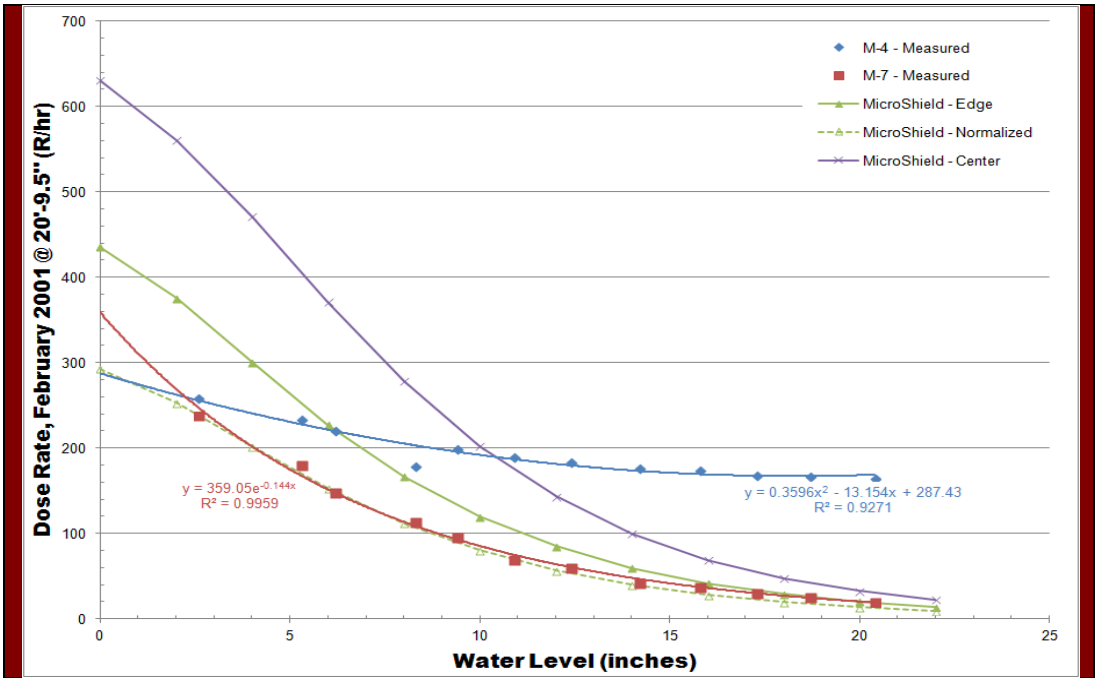


**Figure V-3 – Tank 8D-1 Dose Rates; Measured and Calculated**

Comparing the measured dose rates for the two risers, the M-4 dose rates do not reduce as much as the M-7 dose rates with increasing water level. This observation perhaps indicates that radiation from a source located above the water level is responsible for a portion of the M-4 measured dose rates. Thus, the M-7 measured dose rates were used for the additional analysis performed in this study.

In order to compare the dose rate that would result from the Table V-3 Tank 8D-1 inventory to the measured dose rates, the Table V-3 Tank 8D-1 Cs-137 zeolite inventory was decayed to February 2001, assumed to be uniformly spread over the entire bottom of Tank 8D-1, and entered into the MicroShield computer program. In order to approximate the location of the M-7 riser, the dose rate was calculated 5 feet from the edge of the tank. Two source geometries were assumed: a simple disk (i.e., zero thickness) and a 1-centimeter-high cylinder. A 35-foot radius was assumed for both geometries. There was no significant difference between the results from these two geometries.

The results are shown in Figure V-3, and indicate modeled dose rates about 50% larger than the measured dose rates at the M-7 riser. Given that the MicroShield analysis assumed uniform distribution of the Cs-137 inventory on the bottom of Tank 8D-1, when in reality the distribution is very irregular, the level of agreement is considered quite good.

The MicroShield results were then normalized to the 6.2-inch dose rate measurement (i.e., the MicroShield dose rate at 6.2 inches was adjusted to be the same as the measured dose rate at this depth, and the same adjustment was made to all of the other MicroShield dose rates). The results of this normalization are shown by the dashed line in Figure V-3, which shows that the normalized MicroShield results and the

measured M-7 dose rates have almost exactly the same curve. This is confirmation that the M-7 measured dose rates are due to Cs-137.

A final MicroShield run was made to calculate the dose rate at the center of Tank 8D-1, where it would be the largest. The results of this run are also shown in Figure V-3 by the uppermost blue line, and indicate that the dose rate at the center of Tank 8D-1 could be almost 50% larger than what was measured at the M-7 riser.

Figure V-3 and all of the above discussion are based on the Tank 8D-1 inventory as it was in February 2001. Using the Figure V-3 February 2001 dose rates as a starting point, Figure V-4 shows what the dose rate inside Tank 8D-1 would be over the time period of interest. As of 2140, the dose rate remains greater than 10 roentgen per hour (R/hr), more than three orders of magnitude greater than the 2.5 mrem/hr occupational exposure limit that would allow for contact-handled operations (based on an annual limit of 5 rem divided by 2,000 work hours per year).

To determine the date at which the 2.5 mrem/hr dose rate would be achieved, the decay calculations were extended beyond 2140. The results of this analysis are shown by the same set of curves in Figure V-4, but using the right and top axes as the points of reference. The point of intersection of each curve with the dash-dot line at 2.5 mrem/hr (on the right axis) gives the year (on the top axis) at which the occupational exposure limit would be satisfied. As shown, it would be necessary to wait until about 2510 before the Tank 8D-1 dose rate decayed sufficiently to allow for contact-handled operation.

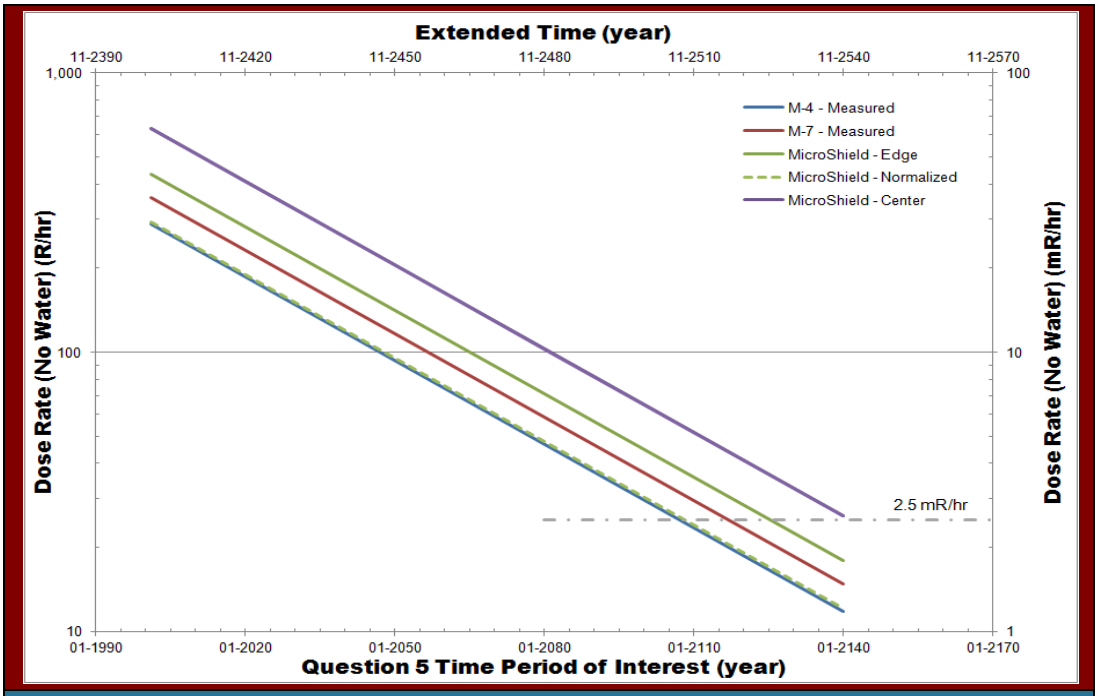


**Figure V-4 – Tank 8D-1 Dose Rates Over Time**

A higher dose rate could be allowed if additional protective measures are taken (e.g., long-reach tools, limiting exposure time); conversely, a lower dose could be imposed by site policy, which often aims to limit occupational exposures to 10% of the limit. It is also noted that only the Cs-137 contribution from zeolite on the tank floor was considered in

this analysis. There are other sources of radiation within Tank 8D-1 (e.g., the Supernatant Treatment System ion exchange columns) that would result in dose rates greater than those shown in Figure V-4.

# VI. Summary of Results

This technical memorandum has been prepared as a response to the following question previously prepared by DOE and NYSERDA to help the EXWG focus on those areas for which further analysis may facilitate interagency consensus related to exhumation alternatives:

> ***Question 5:*** Would answers to any of the above questions change if we waited for 30, 60, 90, or 120 years before undertaking the action? For example, could the action go from a remote action to a contact-handled action?

Using the methodology described in Section II, the SDA, NDA, and WTF inventory estimates selected for use in the Phase I Studies were decayed to 2020 (the new base year) and to 2050, 2080, 2110, and 2140. Summaries of the resulting decayed inventories are provided in Table III-5 for the SDA, Table IV-2 for the NDA, and Table IV-2 for the WTF. Detailed decayed inventories are provided in a set of accompanying Excel files. Excel files are being used to transmit the detailed results of this effort for two reasons: first, to provide a more detailed level of information consistent with that included in previous reports (e.g., URS 2000, URS 2002, WVNSCO and Gemini 2005); and second, to ensure that the decayed inventories are readily available in electronic format if others wish to utilize them in their calculations.

Additionally, Question 5 asked whether exhumation could "go from a remote action to a contact-handled action" if one was to wait for the specified times. The answer to that part of Question 5 is specific to each disposal area. As Section III.C discusses, by waiting approximately 90 years from the time of waste disposal, all the Class A waste that was disposed in the SDA (i.e., 93.8% of the total volume) could be exhumed using contact-handled operations. Since the last SDA disposal occurred in 1975, contact-handled exhumation could begin as early as 2065. Additionally, Table III-7 shows that most (but not all) of the waste potentially requiring remote exhumation after 2065 is located in the special holes of Trench 6.

For the NDA, Section IV.B indicated that about 52.1% of the disposed waste could be exhumed using contact-handled operations in 2020, and that that percentage would increase to about 78.7% by waiting until 2140 (see Figure IV-5). Although most of the dose rate at the NDA is controlled by the decay of Cs-137 (similar to both the SDA and WTF), Section IV.B discussed that there is a small volume of NDA waste (about 2.3%) that contains sufficient Nb-94 to always require shielded, remote-handled actions.

Section IV.B also looked into the question of the plutonium distribution within the NDA and found that, with the exception of about six holes, the alpha-emitting plutonium inventory is spread more or less uniformly throughout the NDA (Figure IV-7). The spent fuel disposed in Deep Hole 48 and the waste in Special Hole sh-99 represent about 23.6% of the NDA alpha-emitting plutonium inventory and four other holes contain a total of 16.4%, which leaves about 60% of the alpha-emitting plutonium activity spread throughout the remainder of the NDA. For example, each of the 12 WVDP trenches is estimated to contain a total of 0.7% of the NDA alpha-emitting plutonium inventory. Figure IV-8 shows the NDA alpha-emitting plutonium distribution over time.

For the WTF, Section V.B shows that the dose rate associated with the residual inventory in Tanks 8D-1 and 8D-2 would remain large enough to require shielding and remote-handled operations for almost 400 years past the time period of interest of this study (see Figure V-4).

This conclusion was not only based on the WVNSCO and Gemini (2005) inventory estimates, but also on the actual Tank 8D-1 radiation measurements that were taken in February 2001 (see Figure V-3).

# VII. References

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