Task 1.3: Technical Memorandum – Selective Removal Scenarios

Revision 1

West Valley Demonstration Project and
Western New York Nuclear Service Center

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Prepared By:

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Enviro Compliance Solutions, Inc. (ECS)

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WEST VALLEY DEMONSTRATION PROJECT AND WESTERN NEW YORK NUCLEAR SERVICE CENTER

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Task 1.3: Technical Memorandum – Selective Removal Scenarios
Revision 1

TABLE OF CONTENTS

Page

Contents

Exhibits

Tables

Acronyms and Abbreviations

BWR	boiling-water reactor
C	carbon
CFR	*Code of Federal Regulations*
Ci	curie
Co	cobalt
Cs	cesium
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)
ft^3	cubic foot/feet
HLW	high-level waste
hr	hour(s)
m	meter(s)
MeV	mega-electron volt
min	minute(s)
mR/hr	milliroentgen per hour
mrem/hr	millirem per hour
NDA	NRC-Licensed Disposal Area
NFS	Nuclear Fuels Services, Inc.
Ni	nickel
Np	neptunium
NRC	United States Nuclear Regulatory Commission
NYSERDA	New York State Energy Research and Development Authority
Pu	plutonium
R/hr	roentgen per hour
Ra	radium
rem/yr	rem per year
SDA	State-Licensed Disposal Area
sec	second(s)
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.
yr	year(s)

Executive Summary

A. Overview of Approach

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 the 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 U.S. Department of Energy (DOE) and the New York State Energy Research and Development Authority (NYSERDA) (the agencies) in reaching consensus on waste exhumation alternatives that may eventually be selected for final analysis as part of the Phase 2 decision process.

The EXWG performed Task 1.3 to provide DOE and NYSERDA with supplemental information on the comparative value of proposed selective removal scenarios for the State-Licensed Disposal Area (SDA) and the U.S. Nuclear Regulatory Commission (NRC)-Licensed Disposal Area (NDA) through an evaluation of waste inventories and exhumation volumes for a variety of scenarios. Three categories of exhumation scenarios were analyzed: 1) exhumation of the 'long-lived' radionuclides 2) exhumation of Greater Than Class C (GTCC) waste; and 3) exhumation of the waste disposal areas most prone to erosion or slope failure. The EXWG also analyzed a trench by trench exhumation scenario for the SDA. Each scenario was defined by an exhumation target (e.g., radiological activity) and an exhumation standard (e.g., 100% of GTCC waste, 75% of all I-129 activity, 90% of transuranic activity, etc.). Consideration was also given to the level of reduction that would be achieved in the higher-activity, short-lived radionuclides that were not specifically targeted under the various exhumation scenarios examined.

The SDA and NDA waste inventories used for this study were those originally reported in URS (2002) and URS (2000), respectively, and subsequently corrected and updated in EXWG Task 1.2 to account for radioactive decay from the base year of 2000 used in the URS reports to a new base year of 2020 (ECS 2016b).

The SDA inventories are reported for each 50-foot segment of each disposal trench (except for Trench 6, which is a series of special disposal holes). Therefore, under a given selective exhumation scenario, exhumation was assumed to occur first in the 50-foot segment with the greatest amount of the target, then in the 50-foot segment with the next highest amount of the target, and so on until the exhumation standard was met. For each selective exhumation scenario, plots of the percentage of target removed versus the percentage of waste removed were prepared. Plots of the SDA showing which 50-foot segments would be preferentially exhumed to meet a given standard are also provided in this Technical Memorandum.

For the NDA, the inventory was broken down into individual waste units as defined by each of the 99 Deep Holes, 136 Special Holes, 12 WVDP trenches, and 3 caissons, based on a spreadsheet prepared by Dr. Ralph Wild that is more detailed than the inventory that he presented in URS (2000). An approach similar to that used for the SDA was then applied to determine the amount of NDA material required to be exhumed to meet the selective exhumation target and standard under each scenario (i.e., the NDA waste units with the largest activities would be exhumed first).

This Task 1.3 Technical Memorandum does not provide cost estimates for any particular selective exhumation scenario. Instead, the EXWG uses the volume of waste material removed as a surrogate for project cost for comparative purposes. The underlying assumption is that the percent of the volume of material removed provides a first-cut measure of the relative cost for the different scenarios. While recognizing a degree of non-linearity in the related costs, removing 5% of the volume to achieve a certain exhumation standard should cost about 5% as much as removing the total volume as a rough order of magnitude (ROM) estimate for comparative purposes.

B. Summary of Results

The following sections provide a summary of the results for the SDA and NDA selective exhumation analyses, including an estimate of the removal efficiency of each selective exhumation scenario. For this analysis, "removal efficiency" is defined as the amount of activity removed versus the volume exhumed, with cost assumed to be directly related to volume exhumed as explained above.

1. State-Licensed Disposal Area

Below is a summary of the principal results of the SDA selective exhumation analysis:

1) Removal of the long-lived fission products (e.g., I-129, Tc-99, and C-14) would require exhumation of primarily Trench 4, followed by 50-foot segments from Trench 9, and then certain segments from Trenches 5, 2, and 3.
2) Removal of the long-lived fission products is initially quite cost effective, e.g., 50% of the I-129 activity can be removed by exhuming only 5% of the SDA volume—a 10 to 1 removal efficiency. As more long-lived fission products are removed the efficiency decreases, e.g., exhumation of 28% of the SDA volume is required to remove 90% of the I-129 activity—a 3.2 to 1 removal efficiency.
3) Long-lived fission products are generally located in trenches containing Cs-137; therefore, while a complementary removal of high-activity Cs-137 would be realized, removal of long-lived fission products would generally require either additional dose radiation protection measures or delaying exhumation to allow for decay of the short-lived Cs-137.
4) Removal of transuranic (TRU) waste would require exhumation of certain 50-foot segments primarily from Trench 10, followed by segments of Trenches 11, 8, and 9.
5) Removal of TRU is initially quite cost effective, e.g., 50% of the TRU activity can be removed by exhuming 2.8% of the SDA volume—an 18 to 1 removal efficiency. As more long-lived TRU waste is removed, the efficiency decreases only slightly, e.g., 90% of the TRU activity can be achieved by exhuming only 7.1% of the SDA volume—still almost a 13 to 1 removal efficiency.
6) The direct dose rates for the trench segments associated with TRU exhumation are generally less than 2.5 mrem/hr; therefore, less robust measures to protect workers from radiation exposure would be required if targeting TRU waste removal.
7) Uranium-234 is spread out over much of the SDA, including Trench 4 (south end), Trench 5, and Trenches 8 through 14. Removal of U-234 is initially quite cost effective, e.g., 50% of the U-234 activity can be removed by exhuming 7% of the SDA volume—a 7 to 1 removal efficiency. As more U-234 is removed the efficiency decreases, e.g., exhumation of 28% of the SDA volume is required to remove 90% of the U-234 activity—a 3.2 to 1 removal efficiency. Targeting the removal of U-234 would also effectively remove U-235 and U-238, but would not be an effective strategy for removing long-lived fission products or TRU.

8) The direct dose rates for many of the trench segments associated with U-234 exhumation are generally less than 2.5 mrem/hr. However, a few of the segments contain high dose rates (e.g., in Trenches 4 and 9) that would result in requiring additional dose radiation protection measures.

9) Targeting a combination of long-lived fission products, TRU, and U-234 would require exhumation of segments from Trench 4, and then from Trenches 5 and Trenches 8 through 11, and a few others.

10) Removal of a combination of radionuclides is initially quite cost effective, e.g., exhumation of 10% of the SDA volume would remove 60%, 53%, and 18% of the I-129, TRU, and U-234 activity, respectively. Exhumation of 50% of the SDA volume would remove 91%, 97%, and 88% of the I-129, TRU, and U-234 activity, respectively. Since these removal percentages are so high, exhumation of the SDA beyond 50% would not be cost-effective for these radionuclides. Of course, for any one radionuclide, these efficiencies are not as effective as targeting that radionuclide, e.g., when TRU is targeted, exhumation of only 7.1% of the SDA volume is required to remove 90% of the TRU activity.

11) Targeting GTCC waste would initially target the same trench segments as targeting TRU, which accounts for nearly 90% of the GTCC volume. Next, specific 50-foot segments from Trench 4 would be targeted, likely due to the presence of Cs-137, and finally Trench 6 holes would be targeted, due to the presence of Ni-63 and Nb-94.

12) No advantage has been identified for targeting the GTCC waste when compared to targeting either TRU or a combination of radionuclides.

13) Targeting the segments commonly believed to be most prone to erosion (i.e., the SDA's northern and eastern edges) would remove waste from the area within 50 feet of the edge of the SDA, thereby decreasing the potential and delaying the time when an erosion gully could/would expose the waste. However, this selective exhumation scenario is not effective at removing activity from the SDA, i.e., exhumation of 21% of the SDA volume to protect against erosion would remove only 30%, 16%, and 20% of the I-129, TRU, and U-234 activity, respectively.

14) For the trench by trench removal scenario, Trench 4 would be the most effective target and Trench 6 the least effective for the analyzed radionuclides. Removing six complete trenches under an optimum scheme would require exhuming 52% of the SDA volume and would remove 80%, 100%, and 79% of the I-129, TRU, and U-234 activity, respectively.

15) Lastly, if it is desired to only exhume 10% of the SDA (implying a 90% cost reduction), then the exhumation should occur in Trench 4 and several other 50-foot segments in other trenches. The specific non-Trench 4 segments would depend on the secondary goal of the exhumation (e.g., TRU removal, long-lived fission product removal, or erosion protection).

2. NRC-Licensed Disposal Area

Below is a summary of the principal results of the NDA selective exhumation analysis:

1) The NDA's Deep Holes and Special Holes each contain about 50% of the NDA's activity, while the WVDP trenches contain <1% of the activity. Thus, selectively exhuming the WVDP trenches would not be an effective means of reducing the NDA's activity, and was not further investigated.

2) Fission products and TRU radionuclides have very similar profiles across the NDA's Deep Holes and Special Holes. For example, the percentage amount of Cs-137 (representing fission products) in any one hole or group of holes is nearly the same as the percentage of Pu-238 (representing TRU) in the same hole or group of holes. As a result, targeting specific radionuclides for exhumation is not beneficial for the NDA, since the same holes would be targeted to remove a given percentage of Cs-137 as would be targeted to remove the same percentage of Pu-238 (or any other TRU or fission product).

3) Activation products are an exception to the condition reported in the previous paragraph. The activation products do not appear in the Special Holes, only in the Deep Holes. The Deep Holes contain fuel rod cladding and other fuel assembly hardware, which contain activation products generated in the upstream head end in the reprocessing plant, whereas the Special Holes contain waste from further downstream in the reprocessing plant, after the cladding and hardware had been removed. Within the Deep Holes only, the condition cited in the previous bullet would also apply to the activation products.

4) Because of differences in location and depth between the Deep Holes and Special Holes, which could result in a difference in exhumation approach and technologies, it makes sense to analyze the selective exhumation of the Deep Holes separate from the exhumation of the Special Holes.

5) Exhuming the Top 10, Top 25, and Top 50 most radioactive Deep Holes would remove about 45%, 75%, and 90% of the Deep Hole radioactivity, respectively, while removing approximately 10%, 25%, and 47% of the volume, respectively. For the Top 10 Deep Holes the removal efficiency is 4.5 to 1; for the Top 25 the removal efficiency drops to 3 to 1; and for the Top 50 the removal efficiency is <2 to 1.

6) The dose rate for 24 of the Top 25 activity Deep Holes is greater than 25 mrem/hr until the year 2110. In the year 2140, the dose rate from 24 of the Top 24 Deep Holes remains greater than the 2.5 mrem/hr dose rate goal, implying that some form of direct dose radiation protection would be required for waste removal from the Deep Holes regardless of when the work was performed.

7) When all 99 of the NDA Deep Holes are looked at, the dose rates would exceed 25 mrem/hr in 75 holes in 2020, 54 holes in 2050, 40 holes in 2080, 17 holes in 2110, and 3 holes in 2140. By 2140, the dose rate from 61 of the Deep Holes (62%) would still be greater than the 2.5 mrem/hr dose rate goal.

8) Exhuming the Top 10, Top 25, and Top 50 most radioactive Special Holes would remove about 63%, 82%, and 96% of the Special Hole radioactivity, respectively, while removing less than 22%, 33%, and 57% of the volume, respectively. For the Top 10 Special Holes,

the removal efficiency is 2.9 to 1; for the Top 25 the removal efficiency drops to 2.5 to 1; and for the Top 50 the removal efficiency is <2 to 1.

9) The dose rate for all Top 25 activity Special Holes is greater than 2.5 mrem/hr until the year 2110, at which time only one Special Hole falls below that level. There are a significant number of Special Holes with dose rates below 2.5 mrem/hr (50 holes in 2020, increasing to 100 holes in 2110). Unfortunately, most of these Special Holes do not contain a significant amount of activity. For example, the 40 Special Holes that have the least activity cumulatively contain <0.1% of the total activity of the Special Holes. From an activity reduction point of view, the exhumation of these 40 Special Holes would not have a significant effect of the amount of residual radioactivity if selectively removed.

10) For both the NDA Deep Holes and Special Holes, it may be more effective to target specific areas for removal, rather than specific holes. For example, most of the Special Holes with the highest activity are located on the western side of the NDA. Therefore, it may be more effective to exhume the entire western side of the NDA. Likewise, the Deep Holes with the highest activity are located throughout a 130 foot by 160 foot area. Therefore, it may be more effective to exhume the entire area than attempt to locate and exhume a series of specific Deep Holes.

11) For both the Deep Holes and Special Holes, targeting GTCC waste for removal would not result in any substantial benefit when compared to targeting activity removal. Essentially all the Deep Holes and Special Holes would need to be removed to remove all the GTCC waste, which would be classified as complete removal rather than a selective removal scenario. On the other hand, partial removal that targets GTCC waste would result in leaving behind holes that contain a large portion of the NDA activity.

12) Targeting the NDA holes that are commonly believed to be most prone to erosion (i.e., the NDA’s northern edges) to prevent or delay the time when an erosion gully could/would expose the NDA waste would remove waste from 78 Special Holes. These 78 Special Holes represent about 57% of the 136 NDA Special Holes, but contain only about 21% of the Special Hole activity, resulting in a negative removal efficiency of about 1 to 2.7.

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 the 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 U.S. Department of Energy (DOE) and the New York State Energy Research and Development Authority (NYSERDA) (the agencies) in reaching consensus on waste exhumation alternatives that may eventually be selected for final analysis as part of the Phase 2 decision process. The EXWG is concentrating on three onsite areas: 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 1.3

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 in response to the following topical question:

> ***Question 1:*** Can the long-lived inventory in the SDA, NDA, and WTF be somehow selectively removed to reduce the time that these facilities will pose a hazard? If so, at what cost?

The EXWG performed Task 1.3 to provide DOE and NYSERDA with supplemental information on the comparative value of selective removal scenarios through an evaluation of waste inventories and exhumation volumes for a variety of scenarios. Three categories of exhumation scenarios were analyzed: 1) exhumation of the 'long-lived' radionuclides (i.e., 10CFR 61, Table 2); 2) exhumation of Greater Than Class C (GTCC) waste; and 3) exhumation of the waste disposal areas most prone to erosion or slope failure. The EXWG also analyzed a trench by trench exhumation scenario for the SDA. Each scenario was defined by an exhumation target (e.g., radiological activity) and an exhumation standard (e.g., 100% of GTCC waste, 75% of all I-129 activity, 90% of transuranic activity, etc.). Consideration was also given to the level of reduction that would be achieved in the higher-activity, short-lived radionuclides that were not specifically targeted under the various exhumation scenarios examined.

The SDA and NDA waste inventories used for this study were those reported in URS (2002) and URS (2000), respectively, as recommended by the EXWG in Task 1.1 based on a comparative evaluation of previously reported inventories. The EXWG made corrections to individual inventory quantities for reasons explained in the Task 1.1 technical memorandum (2016a), and subsequently updated the SDA and NDA inventories in Task 1.2 to account for radioactive decay from the base year of 2000 used in the URS reports to a new base year of 2020 (ECS 2016b).

The SDA inventories are reported for each 50-foot segment of each disposal trench (except for Trench 6, which is a series of special disposal holes). The EXWG has kept this level of detail in its evaluation of the selective exhumation scenarios. Therefore, under a given selective exhumation scenario, exhumation was assumed to occur first in the 50-foot segment with the greatest amount of the target, then in the 50-foot segment with the next highest amount of the target, and so on until the exhumation standard was met. For each selective exhumation scenario, plots of the percentage of target removed versus the percentage of waste removed were prepared.

Plots of the SDA showing which 50-foot segments would be preferentially exhumed to meet a given standard are provided in this Technical Memorandum. These segments were superimposed on a plan view of the SDA to better depict the relative geographic positioning of the trench segments being proposed for removal, as well as whether removal of a certain segment or group of segments would address multiple exhumation targets.

For the NDA, the inventory was broken down into individual waste units as defined by each of the 99 Deep Holes, 136 Special Holes, 12 WVDP trenches, and 3 caissons, based on a spreadsheet prepared by Dr. Ralph Wild that is more detailed than the inventory that he presented in URS (2000). An approach similar to that used for the SDA was then applied to determine the amount of NDA material required to be exhumed to meet the selective exhumation target and standard under each scenario (i.e., the NDA waste units with the largest activities would be exhumed first).

The WTF was not included in the Task 1.3 analysis. Essentially all the WTF waste is contained within the sludge at the bottom of the tanks or within the 'bathtub ring' on the sidewall of Tank 8D-2. Therefore, the location of each of these potentially removable items is already well known, and it would not be of value to target specific radionuclides or to determine what percentage of a particular radionuclide would be selectively removed under various scenarios similar to what is being proposed for the SDA and NDA.

The final part of Question 1 was "at what cost" could the selective exhumation be performed. This Task 1.3 Technical Memorandum does not provide cost estimates for any particular selective exhumation scenario. Instead, the EXWG uses the volume of waste material removed as a surrogate for project cost for comparative purposes. The underlying assumption is that the percent of the volume of material removed provides a first-cut measure of the relative cost for the different scenarios. While recognizing a degree of non-linearity in the related costs, removing 5% of the volume to achieve a certain exhumation standard should cost about 5% as much as removing the total volume as a rough order of magnitude (ROM) estimate for comparative purposes.

There are two potential volumes that could be used for this purpose: the waste volume or the empty trench/hole volume that would include any backfill soil. Arguments can be made for using either (e.g., the trench/hole must be emptied during exhumation, or the waste would be more difficult to remove). If all trenches/holes are equally filled with waste (e.g., 75%), then both volumes would have the same percentage removed. However, this is not the case. For the SDA, while not all SDA trenches are equally filled (URS, 2002), the differences are not large and the decision as to which volume to use will not have a material effect on the comparative results of the study. In this case, the trench volume was selected for use to provide a common comparative value across all 50-foot trench segments of the SDA. The situation is different for the NDA due to the disposal of waste in three very different configurations – Deep Holes, Special Holes, and Trenches – with the holes containing a relatively large quantity of soil overlying the waste. Therefore, for the NDA, the waste volume was selected as the metric for comparison of exhumation efficiencies.

B. Report Organization

This Technical Memorandum is organized into the following four sections in addition to the introductory section (Section 0:

Introduction and Background):

- Section II: State-Licensed Disposal Area
- Section III: NRC-Licensed Disposal Area
- Section IV: Summary of Results
- Section V: References

Within each of the two main sections (Sections II and III), a brief description of the inventory for each of the respective waste areas, as presented in URS (2002) and URS (2000), is first provided. This is followed by a description of the selective exhumation scenarios evaluated and the corresponding results. A summary of the results of the various selective exhumation scenarios that were studied is presented in Section IV. Section V provides a list of the references that were consulted for this study.

II. State-Licensed Disposal Area

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 exhibits, is provided in the Task 1.1 Technical Memorandum (ECS 2016a). 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 on-site operations; and waste disposal and decontamination companies.

A. Methodology

For each selective exhumation scenario, the trench segments with the largest inventory of the targeted radionuclide are removed first, followed by those trench segments with increasingly smaller inventories. Any trench segments without a targeted radionuclide inventory are not removed. The results are presented as a function of the percentage of the targeted radionuclide removed versus the percentage of the SDA trench volume removed. By presenting the results as percentages, the results generally apply to any analysis time (e.g., 2020, 2050, 2080, etc.). An exception to this is when multiple radionuclides are targeted. However, since the focus of this study is on long-lived radionuclides, this does not greatly affect the results. Another potential exception is if there is a large inventory of the parent radionuclide of a targeted radionuclide in some, but not all, trench segments. However, as shown in the Task 1.2 Technical Memorandum (ECS 2016b), the contribution to the inventory of a given radionuclide inventory due to in-growth from its parent is generally very small, so in practice this potential exception does not significantly affect the results of the study.

It is not possible to selectively excavate only the target radionuclide (i.e., I-129). Other radionuclides that are present in the waste will be excavated along with the target radionuclide (see the waste profiles discussed in URS (2002), Section 2.3). In this Technical Memorandum, the non-targeted radionuclides that are removed along with the target radionuclide are referred to as “tag along” radionuclides.

The results of the analyses are mainly presented in a series of exhibits, with each exhibit composed of three parts – a chart, a table, and a schematic. The chart is a plot of the percentage of the target and “tag along” radionuclides that are removed versus the SDA volume that is exhumed. The table shows the percentage of SDA trench volume removed for the targeted radionuclide removal goals of 50%, 75%, 80%, 90%, and 95%, as well as the percentages of “tag along” radionuclides removed. Note, because the study is based on removing entire trench segments, it was not possible to remove exactly the goal amount of the targeted radionuclide. Thus, the table also shows the actual percentage removed of the targeted radionuclide. Finally, the SDA schematic shows which SDA segments would be removed to achieve each of the targeted radionuclide’s removal goals. In the SDA schematic, exhumed SDA segments are shown in various shades of blue, ranging from the darkest blue for 50% removal (i.e., the trench segments with the highest activity of the target radionuclide) to the lightest blue for 95% removal. Segments that do not contain any waste are shown in green, while waste-containing segments that would not be exhumed are shown in tan.

B. Selective Exhumation Scenarios

1. Long-Lived Radionuclides

For purposes of this evaluation of selective removal scenarios, it is desired to focus the removal on those radionuclides that are the "risk drivers" for the SDA, thereby reducing the overall long-term risk potential. At this time, the probabilistic performance assessment (PPA) is in its early stages and the radionuclides that are the "risk drivers" have not yet been identified. The EXWG, therefore, used the following sources of information to develop an initial list of radionuclides for inclusion in the evaluation of selective removal scenarios:

- The Final Environmental Impact Statement (FEIS) (DOE 2010), Appendix H deterministic performance assessment identified those radionuclides that controlled the calculated dose (i.e., "Controlling Nuclides") for releases from the SDA. Tables H-30, H-37, H-51, and H-58 in the FEIS identified C-14 and U-234 as the "Controlling Nuclides" for the SDA.
- Potential intruder exposures following the loss of institutional control were also analyzed in the FEIS, Section H.2.2.3.2. Three scenarios were analyzed: Intruder Worker, Resident Farmer with Waste Material in His Garden, and Resident Farmer Using Contaminated Groundwater. The last scenario was not considered to be applicable to the SDA due to "the low hydraulic conductivity of the unweathered Lavery till and the unsaturated conditions in the Kent recessional sequence." For the two scenarios that are applicable to the SDA, Cs-137 was identified as the radionuclide "contributing the greatest portion of dose."
- A quantitative risk assessment was also performed for the SDA following the FEIS (Garrick, et al 2009). Depending on the scenario being analyzed, Garrick's quantitative risk assessment identified several major radionuclide contributors to dose, specifically I-129, Cs-137, Pu-238, and actinide nuclides.

The EXWG also referenced 10 CFR §61.55 to ensure completeness in the radionuclides to be considered in this study. Eight long-lived radionuclides are identified in 10 CFR §61.55, Table 1, including C-14, Ni-59, Nb-94, Tc-99, I-129, alpha emitting transuranics, Pu-241, and Cm-242. Five short-lived radionuclides are also identified in 10 CFR §61.55, Table 2, including H-3, Ni-63, Co-60, Sr-90, and Cs-137. Four of the radionuclides, H-3, C-14, Tc-99, and I-129, are included in Part 61 due to their groundwater migration potential (NRC 1982, pp 4-17, 5-25, and 5-43) and resulting potential human exposure. Other radionuclides are included to protect the inadvertent intruder over the short term (i.e., <500 years, Cs-137) and over the long term (e.g., Pu-239, a transuranic) (NRC 1982, p 4-29). With the exception of Cm-242, all the radionuclides specifically identified in both Tables 1 and 2 of 10 CFR §61.55 are included in the SDA inventory estimates. For this study, C-14, Tc-99, I-129, and transuranics (with Pu-238 and/or Pu-239 representing alpha emitting transuranics) from Table 1 were included, as well as Cs-137 from Table 2. The other radionuclides from Tables 1 and 2, including Ni-59, Nb-94, and Pu-241, were not included because they are not present in significant quantities in the SDA and have not been identified as major dose drivers for the SDA.

It is anticipated that targeting one or more of the long-lived radionuclides will also target one or more of the short-lived radionuclides. For example, if the long-lived fission product I-129 is targeted, then the short-lived fission product Cs-137 will also be removed.

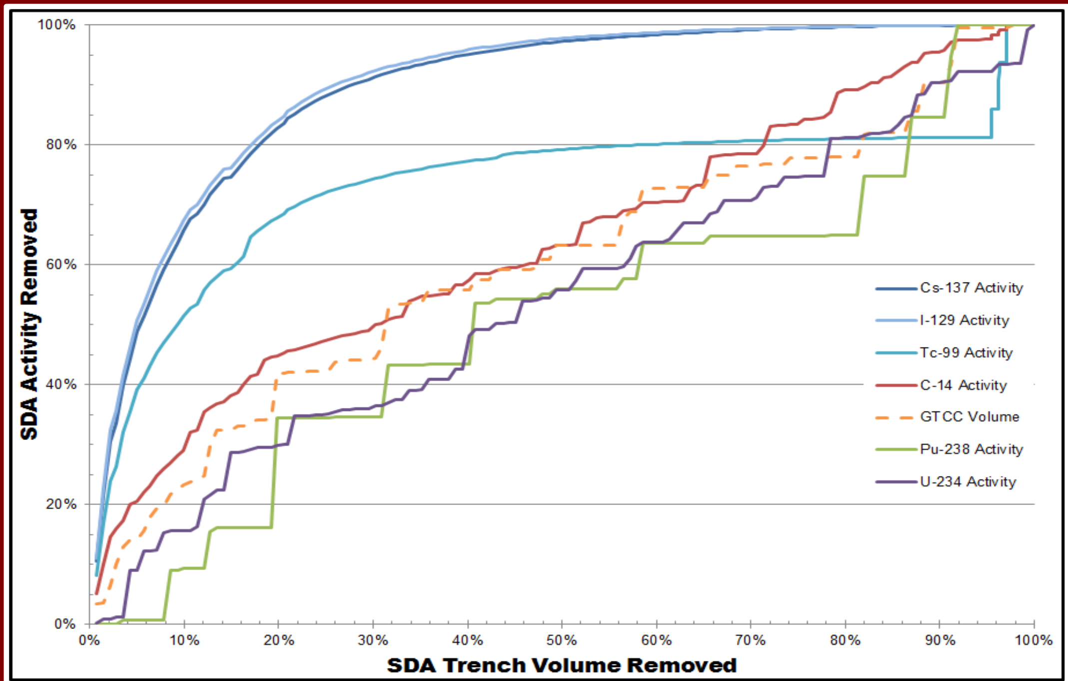
Target Radionuclides: Iodine-129/Cesium-137

Iodine-129 is a fission product, with a U-235 thermal fission cumulative yield of 0.706% (IAEA 2008, Table C-3.3). The 15.7 million year half-life of I-129 (resulting in a very low specific activity), when combined with a low-energy beta particle (0.150 MeV) and minimal gamma radiation, makes I-129 difficult to measure. For that reason, I-129 in radioactive waste is usually estimated by using a Cs-137 based scaling factor. Cesium-137 is also a U-235 fission product that is easy to measure due to the strong gamma radiation emission from its daughter product Ba-137m.

URS 2002 obtained most of its waste profiles from NUREG/CR-1759, Vol 2 (D&M 1981). In NUREG/CR-1759, the concentrations of a number of radionuclides (including I-129) were “scaled” from the concentration of an appropriate basic radionuclide (e.g., Cs-137). Thus, I-129 can only appear in the SDA inventory estimate when Cs-137 appears, and is always proportional to the I-129 to Cs-137 scaling factors reported in NUREG/CR-1759, Tables B-23 and B-24. Thus, for this study, there is no reason to present separate selective exhumation curves for I-129 and Cs-137.The Exhibit II-1 chart below illustrates this point by showing that the selective exhumation curves for I-129 and Cs-137 are nearly identical. This is due to the use of the NUREG/CR-1759 scaling factors. The curves are not identical because Cs-137 appears in five URS (2002) waste streams without I-129. These five waste streams (Industrial Biomedical, LSA Trash, Institutional Bioresearch, Medical, and Non-Bioresearch) contribute only about 1.2% of the total Cs-137 activity.

The Exhibit II-1 table shows that a substantial amount of the Cs-137 and I-129 inventory can be removed by selectively exhuming a small portion of the SDA. For example, about 50% of the Cs-137 / I-129 inventory can be removed by exhuming only about 5% of the SDA volume—a 10 to 1 removal efficiency. About 90% of the Cs-137 / I-129 inventory can be removed by exhuming about 28% of the SDA volume—a 3.2 to 1 removal efficiency.

For the selective exhumation of Cs-137 and I-129, Exhibit II-1 also includes data for four “tag along” radionuclides: Tc-99, C-14, Pu-238, and U-234, as well as for GTCC waste. The Tc-99 curve in the Exhibit II-1 chart generally follows the Cs-137 curve because (as described in the following section) fission-produced Tc-99 is generally scaled from Cs-137. The “step” increases at the far right of the Exhibit II-1 Tc-99 curve are due to the exhumation of activation product Tc-99 from the Trench 6 Special Holes. No discernable correlations are apparent from the Exhibit II-1 chart between the exhumation of Cs-137/I-129 and the other “tag along” radionuclides (i.e., C-14, Pu-238 and U-234).



Target: Cs-137 / I-129			SDA Volume	Tc-99 Activity	C-14 Activity	GTCC Volume	Pu-238 Activity	U-234 Activity
Goal	Cs-137	I-129						
50%	48.8%	50.8%	5.0%	39.1%	20.5%	14.1%	0.7%	9.0%
75%	74.6%	76.1%	14.9%	59.3%	38.2%	32.5%	16.2%	28.6%
80%	80.9%	82.1%	18.4%	66.4%	44.1%	34.1%	16.2%	29.5%
90%	90.2%	91.2%	28.1%	73.5%	48.4%	44.1%	34.5%	35.9%
95%	95.2%	95.9%	40.1%	77.3%	57.4%	55.8%	43.4%	48.2%

SDA Trench Segments to Exhume to Remove Cs-137 Activity

Trench Segment Distance (feet)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	Remain	Remain	Ex: 90%	Ex: 95%	Ex: 95%	No Waste	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 2	Ex: 50%	Ex: 95%	Remain	Remain	Remain	Ex: 95%	Ex: 90%	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 3	Ex: 80%	Ex: 90%	Remain	Ex: 95%	Ex: 90%	Ex: 90%	Ex: 90%	Remain	Remain	Remain	Ex: 95%	Ex: 75%	Ex: 80%	Ex: 95%
Trench 4	Ex: 50%	Ex: 50%	Ex: 75%	Ex: 50%	Ex: 50%	Ex: 75%	Ex: 50%	Ex: 75%	Ex: 75%	Ex: 75%	Ex: 75%	Remain	Remain	Ex: 90%
Trench 5	Ex: 50%	Remain	Remain	Remain	Remain	Remain	Ex: 95%	Ex: 80%	Ex: 80%	Remain	Remain	Remain	No Waste	No Waste
Trench 7	Ex: 90%	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 8	Ex: 95%	Ex: 90%	Ex: 95%	Remain	Remain	Remain	Ex: 95%	Remain	Ex: 95%	Remain	Ex: 90%	No Waste	No Waste	No Waste
Trench 9	Ex: 90%	Ex: 75%	Remain	Ex: 75%	Ex: 75%	Ex: 75%	Ex: 75%	Ex: 75%	Remain	Ex: 75%	Remain	Remain	No Waste	No Waste
Trench 10	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 11	Remain	Ex: 90%	Remain	Remain	Ex: 95%	Remain	Remain	Remain	Ex: 80%	Remain	Remain	Remain	No Waste	No Waste
Trench 12	Ex: 95%	Remain	Remain	Remain	Remain	Ex: 95%	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 13	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Ex: 95%	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 14	Remain	Remain	Remain	Ex: 90%	Remain	Remain	Remain	Remain	Remain	Remain	Ex: 90%	Ex: 95%	Remain	No Waste
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain					

Exhibit II-1: SDA Selective Exhumation of Cs-137 and I-129

The above analysis assumes that the Cs-137 and I-129 behave similarly once in the ground, and that both remain in the deposited waste forms. However, once in the ground, I-129 is expected to behave differently than Cs-137 because iodine is one of the more mobile elements in soil and can move with groundwater, whereas cesium is generally one of the less mobile elements in the environment and preferentially adheres to soil or waste (ANL 2007). The iodine and cesium partition coefficients (K_d) reflect these behaviors. The K_d is defined as the ratio of the radionuclide concentration associated with the solid (pCi/g) to the radionuclide concentration in the surrounding water (pCi/mL). The larger the K_d the more radioactivity remains with the solid, while the smaller the K_d the more radioactivity is in the water and available to travel with the groundwater. For clay soil, such as is found at the SDA, the iodine K_d ranges from 1 to 123 mL/g, with a geometric mean of 6 mL/g, and the cesium K_d ranges from 566 to 375,000 mL/g, with a geometric mean of 5,500 mL/g (ANL 2015, Table 2.13.3).

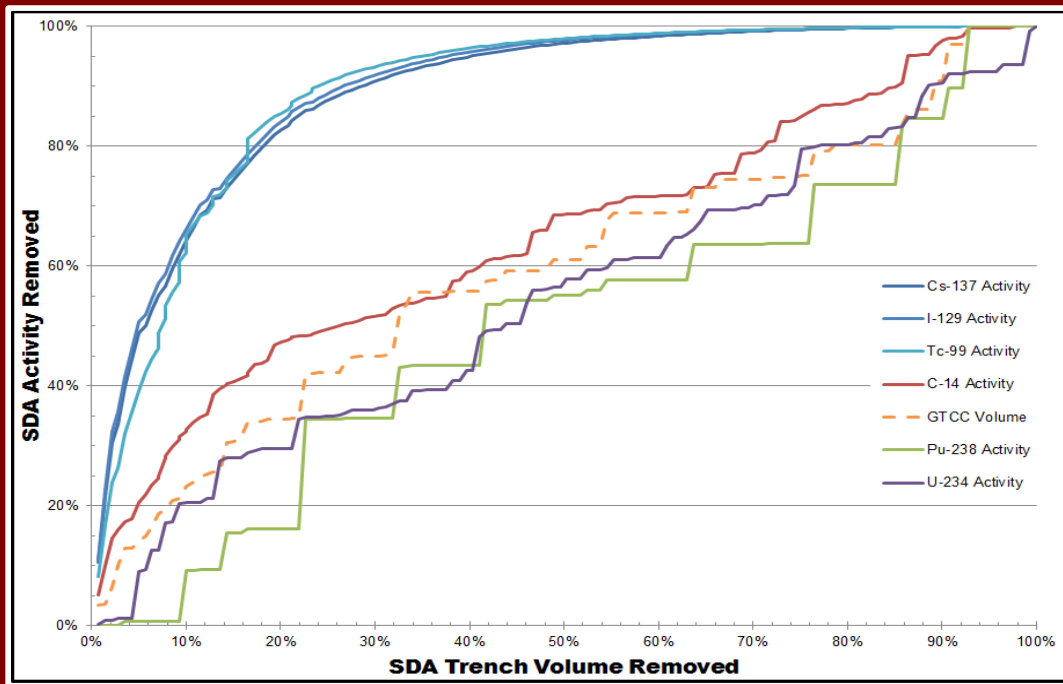
Thus, if groundwater contacts the waste, as has happened in the SDA, it is likely that the I-129 will leave the waste with the groundwater, while the Cs-137 will remain with the waste. Presently there is not enough information on the I-129 concentration within the SDA trenches to allow for the modeling of this phenomenon. However, a simplified analysis performed by the EXWG based on historic leachate pumpout rates and leachate concentration data indicates the potential for nearly all of the I-129 to have already been removed from the SDA trenches via dissolution into the leachate and the pumping of over 2 million gallons of leachate from the trenches in the late 1970s and early 1980s (E&E 1994, Table 3-1). Before any decision is made to selectively exhume I-129, a sampling program should be undertaken to ensure that the I-129 has not been re-distributed within the trenches or already removed from the trenches with the leachate.

Target Radionuclide: Technetium-99

Like I-129, Tc-99 is a fission product, with a U-235 thermal fission cumulative yield of 6.132% (IAEA 2008, Table C-3.3). The 212,000 year half-life of Tc-99 (resulting in a low specific activity), when combined with its low energy beta particle (0.292 MeV, maximum), makes Tc-99 difficult to measure. For that reason, Tc-99 in radioactive waste is usually estimated by using a Cs-137 based scaling factor.

However, unlike I-129, Tc-99 can be produced by neutron activation of the molybdenum that is present in minute quantities in steel, e.g., 304 stainless steel contains about 0.05% molybdenum (PNL 1980, Table E.1-5). About 24% of molybdenum is Mo-98, which by neutron capture produces Mo-99, which in turn decays to Tc-99. Thus, in addition to being present in the URS (2002) fission product waste profiles, Tc-99 is also present in the Power Reactor and Special Purpose Reactor Internals waste streams.

The Exhibit II-2 chart shows that the Tc-99 selective exhumation curve is similar to the Cs-137 and I-129 curves. However, the Exhibit II-2 SDA schematic indicates that a number of Trench 6 Special Holes that contain Reactor Internals waste would need to be exhumed to meet the Tc-99 removal goals, while no exhumation of Trench 6 is required to meet the Cs-137/I-129 removal goals. The Exhibit II-2 table indicates that slightly less SDA volume would need to be exhumed to remove 90% of the Tc-99 than would be required to remove 90% of Cs-137/I-129, i.e., about 24% versus about 28%, with the associated less cost. However, the cost saving due to less exhumation volume may be offset by the increased cost due to the higher dose rates and need for additional shielding in the Trench 6 Special Holes. This is due to the fact that Tc-99 occurs in the Trench 6 Special Holes, which are much smaller than the 50-foot trench segments that contain Cs-137/I-129.



Target: Tc-99		SDA	Cs-137	I-129	C-14	GTCC	Pu-238	U-234
Goal	Activity	Volume	Activity	Activity	Activity	Volume	Activity	Activity
50%	51.1%	7.8%	56.6%	58.7%	28.0%	19.3%	0.7%	17.2%
75%	75.3%	15.0%	74.4%	75.9%	40.7%	30.7%	15.5%	28.0%
80%	80.3%	16.5%	77.2%	78.6%	42.1%	33.9%	16.2%	28.9%
90%	90.1%	24.0%	86.8%	88.0%	49.0%	42.2%	34.5%	34.8%
95%	95.2%	35.4%	93.4%	94.2%	54.6%	55.7%	43.4%	39.3%

SDA Trench Segments to Exhume to Remove Tc-99 Activity

Trench Segment Distance (feet)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	Remain	Remain	Ex: 90%	Ex: 95%	Remain	No Waste	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 2	Ex: 50%	Remain	Remain	Remain	Remain	Remain	Ex: 90%	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 3	Ex: 90%	Ex: 90%	Remain	Ex: 95%	Ex: 95%	Ex: 95%	Ex: 95%	Remain	Remain	Remain	Ex: 95%	Ex: 75%	Ex: 80%	Ex: 95%
Trench 4	Ex: 50%	Ex: 50%	Ex: 75%	Ex: 50%	Ex: 50%	Ex: 50%	Ex: 50%	Ex: 50%	Ex: 75%	Ex: 75%	Ex: 50%	Remain	Remain	Ex: 90%
Trench 5	Ex: 50%	Remain	Remain	Remain	Remain	Remain	Ex: 95%	Ex: 90%	Ex: 50%	Remain	Remain	Remain	No Waste	No Waste
Trench 7	Ex: 90%	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 8	Ex: 95%	Ex: 95%	Remain	Remain	Remain	Remain	Ex: 95%	Remain	Ex: 95%	Remain	Ex: 95%	No Waste	No Waste	No Waste
Trench 9	Ex: 95%	Ex: 75%	Remain	Ex: 75%	Ex: 80%	Ex: 75%	Ex: 75%	Ex: 75%	Remain	Ex: 75%	Remain	Remain	No Waste	No Waste
Trench 10	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 11	Remain	Ex: 90%	Remain	Remain	Remain	Remain	Remain	Remain	Ex: 90%	Remain	Remain	Remain	No Waste	No Waste
Trench 12	Remain	Ex: 90%	Remain	Remain	Remain	Ex: 95%	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 13	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 14	Remain	Remain	Remain	Ex: 90%	Remain	Remain	Remain	Remain	Remain	Remain	Ex: 95%	Remain	Remain	No Waste
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
	Ex: 90%	Remain	Remain	Remain	Ex: 75%	Ex: 75%	Ex: 75%	Ex: 75%	Ex: 75%	Ex: 80%				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	Ex: 75%	Ex: 50%	Ex: 75%	Remain	Remain	Ex: 80%	Ex: 80%	Ex: 90%	Ex: 90%					

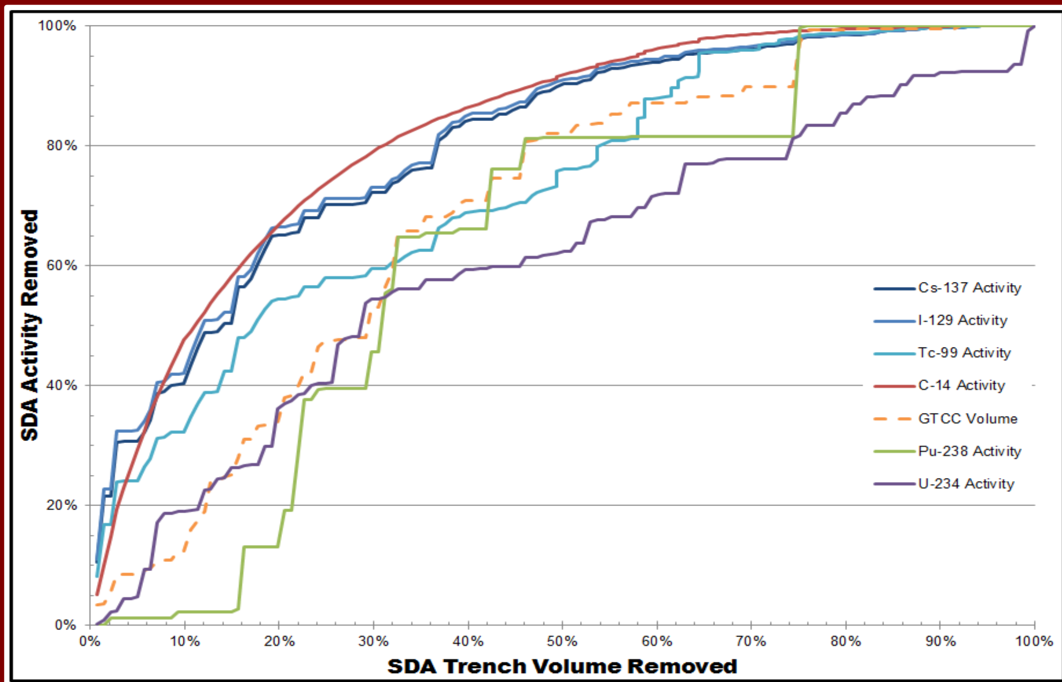
Exhibit II-2: SDA Selective Exhumation of Tc-99

Similar to iodine, technetium is very mobile in the environment, and has a K_d in clay soil that ranges from 0.02 to 1 mL/g with a geometric mean of 0.09 mL/g (ANL 2015, Table 2.13.3). Thus, before any decision is made to selectively exhume Tc-99, a sampling program should be undertaken to ensure that the Tc-99 has not been re-distributed within the trench, or has not already been removed from the trenches when the leachate was pumped out in the late 1970s and early 1980s.

Target Radionuclide: Carbon-14

Like I-129 and Tc-99, C-14 is a low energy beta emitter (0.156 MeV), with no other radiations produced. This makes field detection of C-14 difficult, e.g., a thin-window G-M survey meter must be within 1 cm of the source (MSU 2013). Carbon-14 is not a fission product. It is produced in a reactor primarily when nitrogen-14 absorbs a neutron and emits a proton, and other similar neutron activation reactions (Davis 1977). Nevertheless, NUREG/CR-1759, Vol 2 (D&M 1981), and likewise URS (2002), uses Cs-137 (a fission product) as a scaling factor to estimate the amount of C-14 present in waste. The only exception to this in URS (2002) is the Isotope Production Large Tritium waste stream that includes C-14, but not Cs-137 (URS 2002, Table 2-8), which is responsible for approximately 23% of the total C-14 inventory in the SDA.

As a result of largely being based on Cs-137 scaling, the Exhibit II-3 chart shows that the C-14 selective exhumation curve approximates the Cs-137/I-129 curves. However, the Exhibit II-3 table shows that almost 47% of the SDA waste would have to be exhumed to achieve 90% removal of C-14, which is substantially larger than the 28% required to remove 90% of the Cs-137/I-129 (Exhibit II-1). The Exhibit II-3 SDA schematic shows that many more segments of Trenches 10 through 14 would need to be exhumed to achieve 90% C-14 removal than Exhibit II-1 shows for removal of Cs-137/I-129. It is likely that much of the Isotope Production Large Tritium waste stream was buried in these additional segments.



Target: C-14		SDA	Cs-137	I-129	Tc-99	GTCC	Pu-238	U-234
Goal	Activity	Volume	Activity	Activity	Activity	Volume	Activity	Activity
50%	50.7%	11.4%	46.3%	48.2%	36.9%	17.5%	2.1%	19.3%
75%	75.2%	26.2%	70.2%	71.2%	58.0%	47.7%	39.6%	46.8%
80%	80.3%	31.2%	72.3%	73.2%	59.5%	56.5%	55.4%	54.7%
90%	90.0%	46.8%	87.9%	88.8%	71.7%	80.9%	81.3%	61.4%
95%	95.1%	57.9%	93.5%	94.2%	82.9%	87.1%	81.5%	69.6%

SDA Trench Segments to Exhume to Remove C-14 Activity

Trench Segment Distance (feet)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	Remain	Remain	Ex: 90%	Remain	Remain	No Waste	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 2	Ex: 90%	Remain	Remain	Remain	Remain	Remain	Ex: 90%	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 3	Ex: 95%	Ex: 90%	Ex: 95%	Ex: 90%	Ex: 90%	Ex: 90%	Ex: 95%	Remain	Remain	Remain	Ex: 95%	Ex: 90%	Ex: 90%	Ex: 90%
Trench 4	Ex: 50%	Ex: 50%	Ex: 50%	Ex: 50%	Ex: 50%	Ex: 75%	Ex: 50%	Ex: 75%	Ex: 90%	Ex: 75%	Ex: 50%	Remain	Remain	Remain
Trench 5	Ex: 75%	Remain	Ex: 75%	Ex: 90%	Remain	Ex: 75%	Ex: 75%	Ex: 75%	Ex: 75%	Remain	Remain	Remain	No Waste	No Waste
Trench 7	Ex: 95%	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 8	Ex: 90%	Ex: 95%	Ex: 80%	Ex: 75%	Ex: 75%	Ex: 75%	Remain	Ex: 90%	Ex: 95%	Ex: 80%	Ex: 95%	No Waste	No Waste	No Waste
Trench 9	Remain	Ex: 80%	Ex: 50%	Ex: 75%	Ex: 90%	Ex: 75%	Ex: 75%	Ex: 50%	Remain	Ex: 75%	Remain	Remain	No Waste	No Waste
Trench 10	Ex: 75%	Ex: 80%	Ex: 90%	Ex: 75%	Ex: 90%	Ex: 50%	Ex: 80%	Ex: 80%	Remain	Ex: 50%	Remain	Remain	No Waste	No Waste
Trench 11	Ex: 75%	Remain	Ex: 90%	Ex: 50%	Ex: 50%	Ex: 75%	Remain	Ex: 90%	Ex: 50%	Remain	Ex: 50%	Ex: 95%	No Waste	No Waste
Trench 12	Ex: 75%	Ex: 95%	Ex: 80%	Remain	Remain	Ex: 95%	Ex: 50%	Remain	Remain	Ex: 95%	Remain	Remain	No Waste	No Waste
Trench 13	Remain	Remain	Ex: 90%	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 14	Ex: 90%	Remain	Ex: 95%	Ex: 90%	Remain	Ex: 95%	Ex: 95%	Remain	Remain	Remain	Ex: 95%	Remain	Remain	No Waste
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Ex: 95%	Remain	Remain				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	Remain	Ex: 95%	Ex: 95%	Remain	Remain	Remain	Remain	Remain	Remain					

Exhibit II-3: SDA Selective Exhumation of C-14

Target Radionuclides: Transuranics (Pu-238)

Transuranic radionuclides are defined as any element with an atomic number higher than that of uranium (atomic number 92). Specifically, for waste characterization purposes, transuranics are defined as alpha-emitting TRU radionuclides with half-lives greater than 20 years. Table II-1 presents a list of TRU radionuclides (NNSS 2013), along with their half-lives, and the URS (2002) SDA inventory.

Table II-1: SDA Transuranic Radionuclides

TRU Nuclide	Half-Life (yrs)	SDA 2000 Activity (Ci)	
		(Ci)	Percentage
Pu-238	87.7	26,513.	97.4%
Am-241	432.2	431.6	1.6%
Pu-239	24,065	178.4	0.7%
Pu-240	6,537	109.4	0.4%
Am-243	7,380	1.38	0.0%
Pu-242	376,000	0.20	0.0%
Cm-243	28.5	0.01	0.0%
Np-237	2,140,000	2.9E-03	0.0%
Am-242m	152.0	5.0E-04	0.0%
Cm-245	8,500	4.7E-07	0.0%
Cm-246	4,730	4.0E-08	0.0%
Pu-244	82,600,000	3.0E-12	0.0%
Cf-249	350.6	2.7E-13	0.0%
Cm-247	15,600,000	4.9E-14	0.0%
Cm-248	339,000	4.9E-14	0.0%
Cf-251	898.0	3.6E-15	0.0%
Bk-247	1,380	Not Analyzed	0.0%

As Table II-1 shows, Pu-238, Am-241, Pu-239, and Pu-240 contribute essentially all the TRU activity, and Pu-238 is by far the dominant TRU radionuclide disposed in the SDA. URS (2002), Table S-2 indicates that the Fuel Cycle SNAP waste stream contains 26,218 Ci, and Section 2.3.1.7 says that all the SNAP activity is due to Pu-238. Thus, the majority Pu-238 activity reported in Table II-1 is from the Fuel Cycle SNAP waste stream. The SDA database contains 40 SNAP records, with each SNAP record containing both the mass of Pu-238 in grams (entered as an Add-In [URS 2002, Section 2.4.1]) and the total activity (Curies). Exhibit II-4 plots the Pu-238 activity versus its mass for these 40 SNAP records. The fitted trend line has a slope of 17.1 Ci/g, which is the Pu-238 specific activity. SNAP record 71-G-9003-1 is shown in Exhibit II-4. The manifest for this shipment shows that 79 30-gallon and three 55-gallon drums were shipped with a total special nuclear material (SNM) weight of 168.8 grams and activity of 2,900 Ci, or 17.2 Ci/g, indicating that the SNM was essentially all Pu-238.

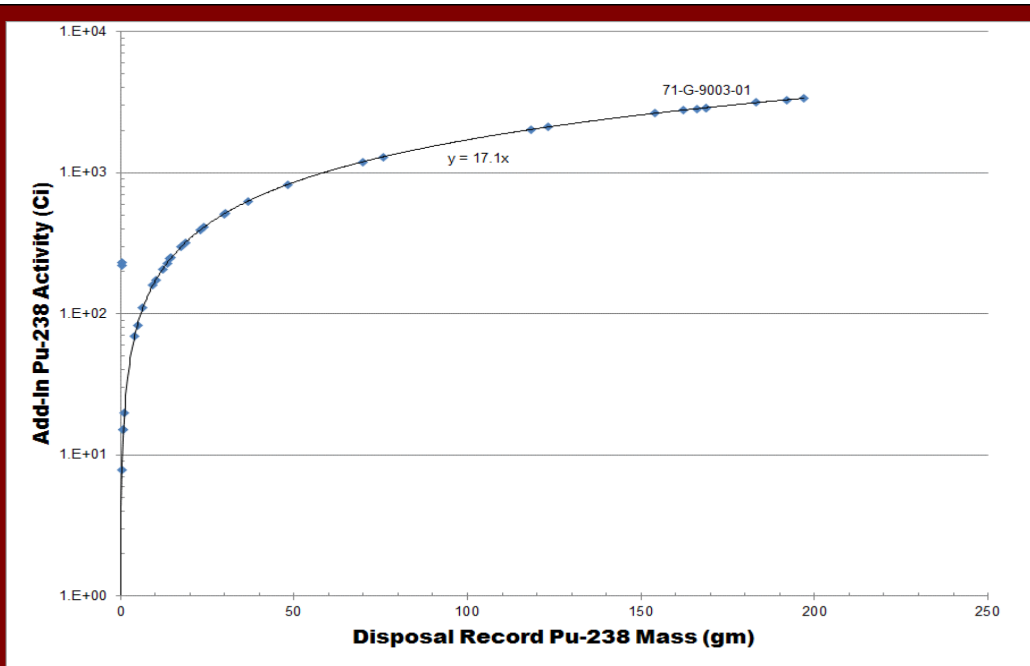
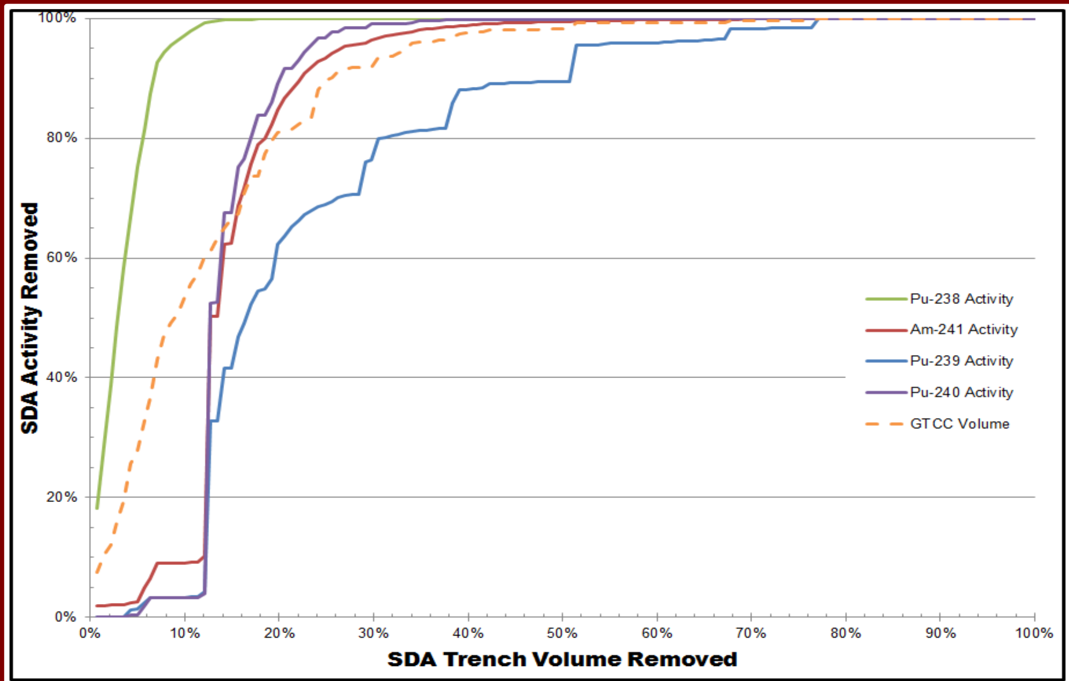


Exhibit II-4: URS 2000 "Add-In" Pu-238 Activity

Using Pu-238 as a surrogate for TRU, Exhibit II-5 shows the results of the selective exhumation of TRU waste from the SDA. The Exhibit II-5 table shows that over 90% of the Pu-238 (TRU) activity can be removed by exhuming only about 7% of the SDA volume (13 to 1 removal efficiency), or only ten 50-foot trench segments, as shown in the Exhibit II-5 SDA schematic, i.e., two segments each from Trenches 8 and 9, five segments from Trench 10, and a single segment from Trench 11. To remove over 95% of the Pu-238 (TRU) activity, only two additional 50-foot segments would need to be exhumed, i.e., one each from Trenches 10 and 11.

In addition to Pu-238, Exhibit II-5 shows the results for Am-241, Pu-239, and Pu-240 as "tag along" radionuclides, as well as the GTCC volume results. The Exhibit II-5 chart shows that a large quantity of Pu-238 is initially removed, but very little Am-241, Pu-239, or Pu-240 is removed. This result reflects the initial removal of the 12 segments to remove 95% of the Pu-238, which contain Pu-238 only as SNAP waste. Of the next nine segments that would be preferentially removed, only seven contain SNAP waste and the "tag along" radionuclides start to come into play. The removal of the GTCC volume approximates the removal of the TRU radionuclides. However, as is discussed in Section II.B.2, there are other non-TRU sources of GTCC waste, so the correlation between GTCC volume removed and TRU removed is only approximate.

As indicated above, the Exhibit II-5 results are based on using Pu-238 as a surrogate for all TRU waste. As Table II-1 shows, Am-241, Pu-239, and Pu-240 make small, but non-negligible contributions to the TRU activity. A correlation analysis was performed to determine the relationship (if any) between how the four TRU radionuclides were deposited in the SDA. Table II-2 shows the numerical results of the TRU radionuclide correlation analysis, as well as descriptive interpretation of the numerical results.



Target: Pu-238		SDA	Am-241	Pu-239	Pu-240	GTCC
Goal	Activity	Volume	Activity	Activity	Activity	Volume
50%	48.6%	2.8%	2.0%	0.1%	0.0%	15.8%
75%	75.3%	5.0%	2.6%	1.4%	0.4%	27.8%
80%	81.4%	5.7%	5.0%	2.5%	1.9%	32.8%
90%	92.6%	7.1%	9.0%	3.3%	3.2%	42.9%
95%	95.5%	8.5%	9.0%	3.3%	3.3%	49.3%

SDA Trench Segments to Exhume to Remove Pu-238 Activity

Trench Segment Distance (feet)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	Remain	Remain	Remain	Remain	Remain	No Waste	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 2	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 3	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain
Trench 4	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain
Trench 5	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 7	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 8	Ex: 75%	Remain	Remain	Remain	Remain	Ex: 90%	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste	No Waste
Trench 9	Remain	Ex: 80%	Remain	Remain	Remain	Remain	Ex: 75%	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 10	Ex: 50%	Ex: 75%	Ex: 90%	Ex: 50%	Ex: 50%	Ex: 95%	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 11	Ex: 95%	Ex: 50%	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 12	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 13	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 14	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain					

Exhibit II-5: SDA Selective Exhumation of Pu-238, as TRU Surrogate

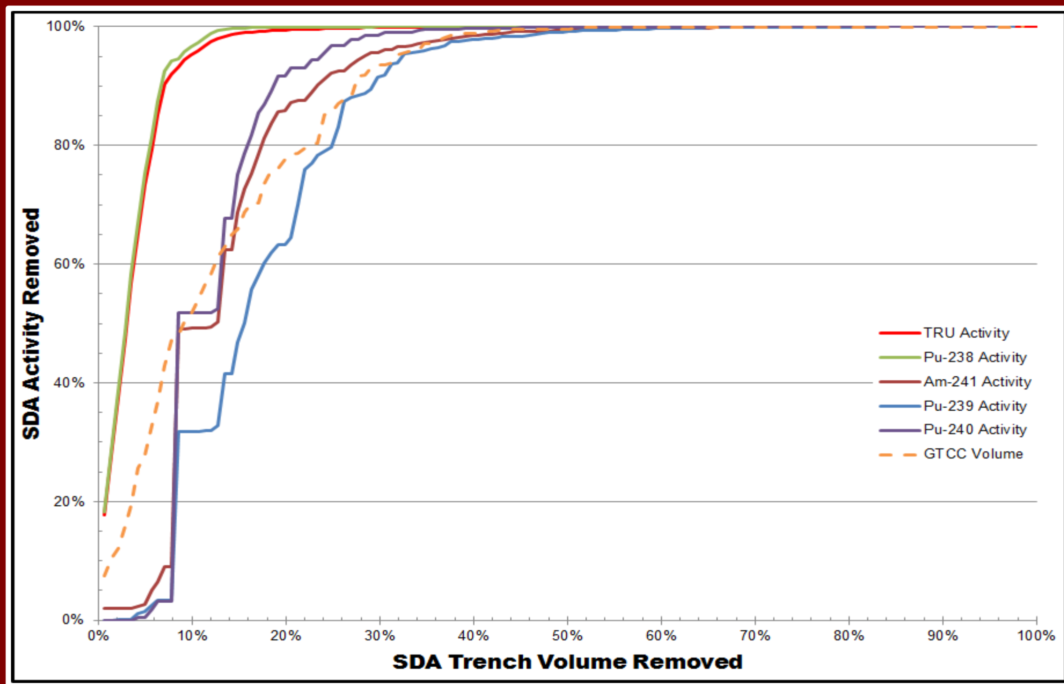
Table II-2 shows a Strong correlation between the Pu-238 activity and the GTCC volume, and Very Weak correlations between Pu-238 activity and the other three TRU activities (Am-241, Pu-239, and Pu-240). However, there are Very Strong correlations among the Am-241, Pu-239, and Pu-240. Given the Exhibit II-5 chart results, the Table II-2 results of the TRU radionuclide correlation analysis is not surprising.

Table II-2: SDA TRU Radionuclide Correlation—Numerical

Radionuclide	Pu-238 Activity	Am-241 Activity	Pu-239 Activity	Pu-240 Activity	GTCC Volume
Pu-238 Activity	1.0	—	—	—	—
Am-241 Activity	0.022	1.0	—	—	—
Pu-239 Activity	-0.030	0.939	1.0	—	—
Pu-240 Activity	-0.017	0.995	0.940	1.0	—
GTCC Volume	0.716	0.138	0.103	0.076	1.0
SDA TRU Correlation—Descriptive					
Pu-238 Activity	Exact	—	—	—	—
Am-241 Activity	VW	Exact	—	—	—
Pu-239 Activity	-VW	VS	Exact	—	—
Pu-240 Activity	-VW	VS	VS	Exact	—
GTCC Volume	Strong	Weak	Weak	VW	Exact

Correlation Coefficient Lower	Correlation Coefficient Upper	Descriptor
1.0		Exact
0.9	<1.0	Very Strong (VS)
0.6	0.9	Strong
0.4	0.6	Moderate (Mod)
0.1	0.4	Weak
>0.0	0.1	Very Weak (VW)
0.0		None

A selective exhumation analysis was then performed based on total TRU activity removal, with the results presented in Exhibit II-6. Similar to the Exhibit II-5 results, the Exhibit II-6 chart shows that initially essentially all TRU removed is Pu-238, with very little Am-241, Pu-239, and Pu-240. Again, this is the removal of the SNAP waste stream, i.e., the 14 segments exhumed to remove 95% of the TRU all contain SNAP waste. The Exhibit II-6 table shows that to remove 90% of the total TRU activity would require exhumation of about 7% of the SDA volume, and the Exhibit II-6 SDA schematic shows the same 10 SDA segments as for removal of 90% of the Pu-238 activity. However, to remove 95% of the total TRU activity, two additional Trench 9 segments would have to be removed when compared to what would be required for the removal of 95% of the Pu-238 activity (i.e., 9.9% versus 8.5% of the SDA volume).



Target: TRU		SDA Volume	Pu-238 Activity	Am-241 Activity	Pu-239 Activity	Pu-240 Activity	GTCC Volume
Goal	Activity						
50%	47.4%	2.8%	48.6%	2.0%	0.1%	0.0%	15.8%
75%	73.3%	5.0%	75.3%	2.6%	1.4%	0.4%	27.8%
80%	79.3%	5.7%	81.4%	5.0%	2.5%	1.9%	32.8%
90%	90.3%	7.1%	92.6%	9.0%	3.3%	3.2%	42.9%
95%	95.3%	9.9%	96.6%	49.1%	31.7%	51.8%	51.7%

SDA Trench Segments to Exhume to Remove Pu-238, Am-241, Pu-239, and Pu-240 Activity

Trench Segment Distance (feet)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	Remain	Remain	Remain	Remain	Remain	No Waste	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 2	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 3	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain
Trench 4	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain
Trench 5	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 7	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 8	Ex: 75%	Remain	Remain	Remain	Remain	Ex: 90%	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste	No Waste
Trench 9	Remain	Ex: 80%	Ex: 95%	Ex: 95%	Remain	Remain	Ex: 75%	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 10	Ex: 50%	Ex: 75%	Ex: 90%	Ex: 50%	Ex: 50%	Ex: 95%	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 11	Ex: 95%	Ex: 50%	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 12	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 13	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 14	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain					

Exhibit II-6: SDA Selective Exhumation of TRU Radionuclides

The final portion of the TRU analysis was to take another look at the SNAP waste stream. URS (2002), Section 2.3.1.7 states:

> *The SNAP devices manufactured at Mound Laboratory used plutonium highly enriched in Pu-238. The approximate isotopic abundances of plutonium were: 80* [weight] *percent Pu-238, 16* [weight] *percent Pu-239, 3* [weight] *percent Pu-240, and 1* [weight] *percent Pu-241 (…). Only Pu-238 is shown on shipping papers and there are large variations in specific activities based on the reported activities and masses of Pu-238 SNM. Some specific activities are in the range of 500 to 800 Ci/g and cannot be explained in terms of variations in plutonium isotopic abundances. In view of these considerations,* ***it was decided not to attempt to distribute the reported quantities of SNM over plutonium isotopes but to apply a dummy waste profile and to use the reported quantities of Pu-238 directly for inventory and waste classification calculations****.* [emphasis added]

Table II-3 provides what the SNAP activity would be if the above-quoted "approximate isotopic abundances" were used, instead of assuming only Pu-238 for the four trenches that contain SNAP waste. Table II-3 shows that while there are significant variations in the activities in the individual trenches, there is only a 15% to 21% increase in the total SDA inventory for Pu-239, Pu-240, or Pu-241. The Pu-238 values are essentially identical between the two estimates even at the individual trench level. Based on these results and the fact that Pu-238 controls the TRU removal, no further analysis was performed.

Table II-3: SNAP Plutonium Activities (Ci)

Isotope	Trench 8	Trench 9	Trench 10	Trench 11	Total for All 14 Trenches
	URS 2002, Section 2.3.1.7 SNAP Profile				
Pu-238	4,130	4,280	12,300	5,490	26,300
Pu-239	6.16	6.34	18.2	8.05	38.8
Pu-240	2.60	2.67	7.68	3.40	16.4
Pu-241*	94.2	10.1	298	136	629
	URS 2002, Appendix C				
Pu-238	4,160	4,340	12,300	5,490	26,500
Pu-239	20.7	58.1	2.84	0.48	184
Pu-240	18.2	54.8	0.06	0.05	109
Pu-241*	584	1,890	3.32	8.18	3,890

* Although Pu-241 is not a TRU radionuclide for waste characterization purposes, it decays directly to Am-241.

Target Radionuclide: Uranium-234

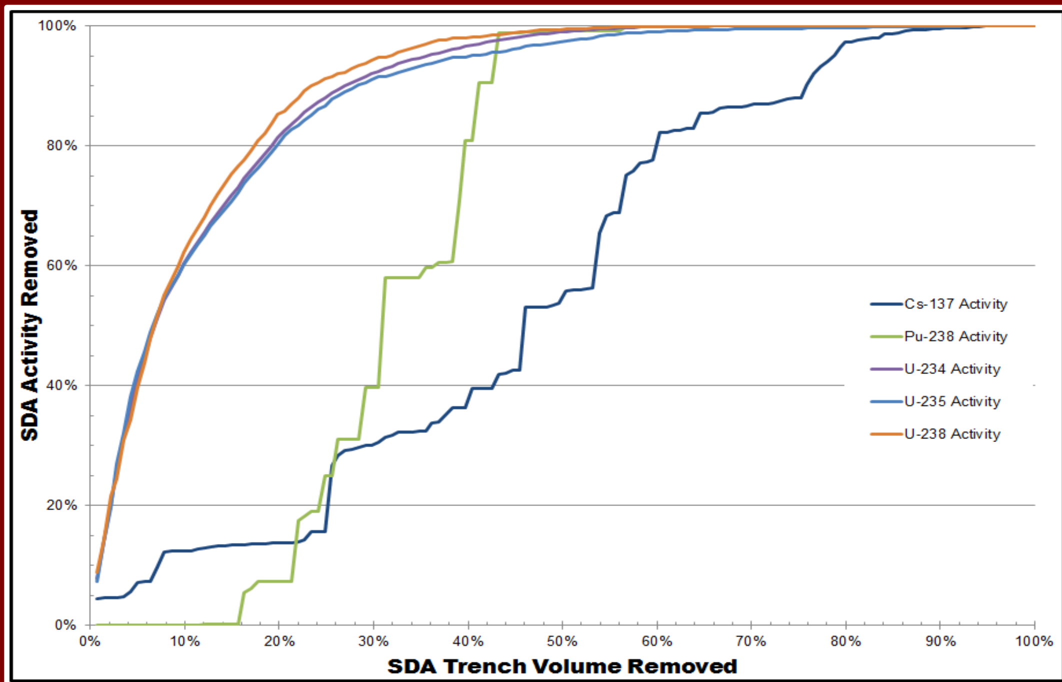
Uranium-234 is a naturally occurring radionuclide that appears primarily in the six URS (2002) Fuel Cycle waste profiles (URS 2002, Section 2.3.1). In the FEIS (DOE 2010), Appendix H performance assessment, U-234 was determined to be the Controlling Nuclide for a number of exposure scenarios. Thus, its selective exhumation may be warranted.

The results of the U-234 selective exhumation analysis are shown in Exhibit II-7. The results show that about 36% of the SDA volume would have to be selectively exhumed to remove 95% of the SDA U-234 activity – a relatively low 2.6 to 1 removal efficiency. Further, as indicated in the Exhibit II-7 schematic, the U-234 that would be removed is spread over Trenches 4 through 14 (excluding Trenches 6 and 7). As a result, for even 50% removal of U-234, an average of only 5.1% of the U-234 activity would be removed for each trench segment exhumed. That removal efficiency would decrease to 2.3% and 1.9% of the U-234 activity removed per trench segment exhumed for 90% and 95% U-234 removal, respectively.

The “tag along” radionuclides shown in Exhibit II-7 include the other two naturally occurring uranium isotopes, U-235 and U-238, as well as Cs-137 as a surrogate for I-129, Tc-99, and C-14, and Pu-238 as a surrogate for TRU waste. The Exhibit II-7 chart and table show that selective exhumation of U-234 would also be effective for removal of U-235 and U-238. However, because U-234 is almost exclusively present in the six Fuel Cycle waste profiles, which do not contain fission products (e.g., Cs-137) or transuranics (e.g., Pu-238), the Exhibit II-7 chart and table show little correlation between the selective exhumation of U-234 and the removal of Cs-137 or Pu-238.

Target Radionuclide: Uranium-233

In the FEIS, Appendix H performance assessment, U-233 was determined to be a Controlling Nuclide for a number of exposure scenarios resulting from facilities other than the SDA. URS (2002), Appendix C gives the total SDA inventory of U-233 as 2.46 Ci, and the Trench 9, Segment 0-49 U-233 inventory as 2.46 Ci. Exhuming Trench 9, Segment 0-49 would reduce the U-233 inventory to 0.0032 Ci, or by a factor of 770. The SDA database indicates that the entire U-233 inventory is comprised of two shipments received in November 1970 from Bettis Atomic Power Laboratory. Thus, virtually 100% of the U-233 SDA inventory can be removed by the exhumation of Trench 9, Segment 0-49, which contains about 0.7% of the total SDA volume. The “tag along” radionuclides are the radionuclides listed in URS 2002, Appendix C for Trench 9, Segment 0-49.



Target: U-234		SDA	Cs-137	Pu-238	U-235	U-238
Goal	Activity	Volume	Activity	Activity	Activity	Activity
50%	51.3%	7.1%	9.7%	0.0%	51.8%	51.6%
75%	76.0%	17.0%	13.6%	6.2%	75.1%	79.3%
80%	80.1%	19.2%	13.7%	7.4%	79.0%	83.7%
90%	90.5%	27.7%	29.3%	31.1%	89.6%	93.0%
95%	95.3%	36.2%	33.7%	59.7%	93.8%	97.3%

SDA Trench Segments to Exhume to Remove U-234 Activity

Trench Segment Distance (feet)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	Remain	Remain	Remain	Remain	Remain	No Waste	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 2	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 3	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain
Trench 4	Ex: 90%	Remain	Remain	Remain	Remain	Ex: 50%	Ex: 50%	Remain	Ex: 90%	Ex: 50%	Ex: 50%	Ex: 90%	Ex: 50%	Ex: 50%
Trench 5	Remain	Ex: 90%	Ex: 80%	Remain	Ex: 75%	Remain	Ex: 95%	Ex: 95%	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 7	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 8	Ex: 95%	Remain	Ex: 50%	Ex: 50%	Ex: 75%	Ex: 90%	Ex: 75%	Ex: 75%	Ex: 95%	Remain	Ex: 95%	No Waste	No Waste	No Waste
Trench 9	Remain	Ex: 90%	Remain	Remain	Ex: 90%	Ex: 75%	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 10	Remain	Remain	Ex: 75%	Ex: 90%	Remain	Ex: 80%	Ex: 90%	Ex: 95%	Ex: 95%	Remain	Ex: 75%	Remain	No Waste	No Waste
Trench 11	Ex: 95%	Ex: 95%	Ex: 90%	Ex: 95%	Ex: 75%	Remain	Remain	Remain	Remain	Ex: 75%	Remain	Remain	No Waste	No Waste
Trench 12	Ex: 75%	Remain	Remain	Remain	Remain	Remain	Ex: 75%	Remain	Remain	Ex: 80%	Remain	Remain	No Waste	No Waste
Trench 13	Remain	Ex: 90%	Remain	Ex: 95%	Remain	Remain	Ex: 90%	Remain	Ex: 50%	Remain	Remain	Remain	Remain	No Waste
Trench 14	Remain	Remain	Ex: 75%	Remain	Ex: 75%	Remain	Ex: 50%	Remain	Remain	Ex: 75%	Ex: 95%	Remain	Remain	No Waste
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain					

Exhibit II-7: SDA Selective Exhumation of U-234

Target Radionuclides: All Targeted Radionuclides

The previous analyses have examined the targeting of a single radionuclide. For the case presented in this section, all the previous radionuclides are targeted together. Exhumation of the trench segments were prioritized based upon their fractional inventory content, rather than on their activity (Curie) content. Additionally, since it is not a long-lived radionuclide, Cs-137 was not included in the prioritization. This approach of excluding Cs-137 was necessary because of the orders of magnitude differences in the activity of Cs-137 versus the various long-lived radio-nuclides.

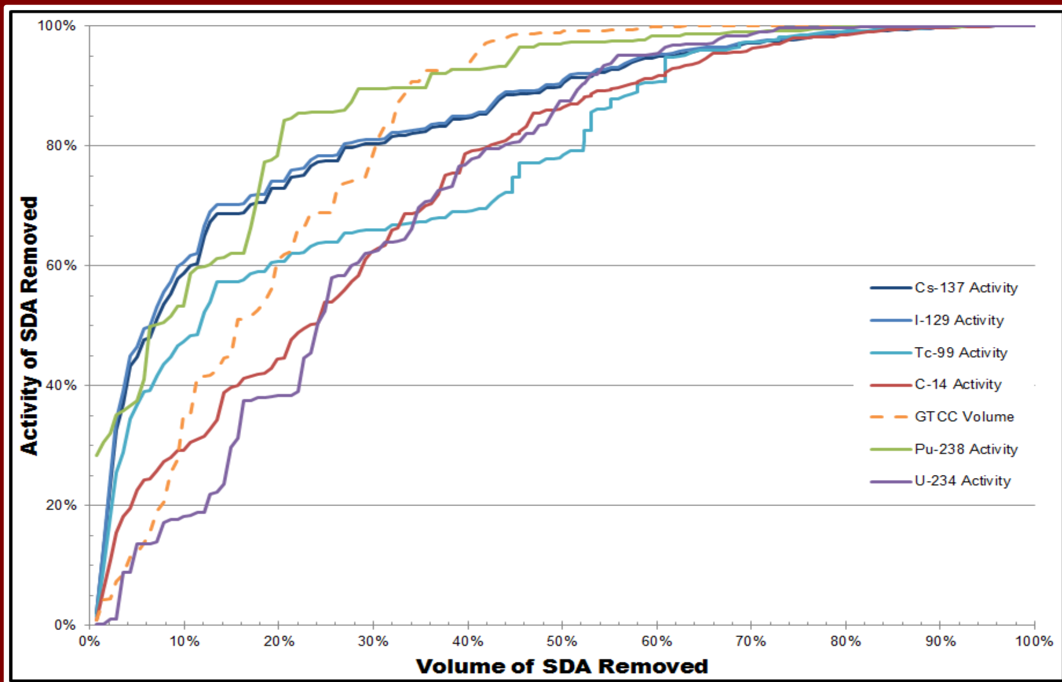
Before presenting the All Targeted results, the results of a correlation analysis are presented to show the relationships between the radionuclide activities. Although to some extent this has already been done in the preceding discussions, e.g., I-129 is related to Cs-137 by a scaling factor(s), the correlation analysis will formalize this discussion. The correlation analysis resulted in the numerical results shown in Table II-4. Descriptive results are also provided in Table II-4 using the criteria provided in Table II-2.

Table II-4: SDA Radionuclide Activity Correlation—Numerical

Radionuclide	Cs-137 Activity	I-129 Activity	Tc-99 Activity	C-14 Activity	Total Activity	GTCC Volume	Pu-238 Activity	U-234 Activity
Cs-137 Activity	1.0	—	—	—	—	—	—	—
I-129 Activity	0.999	1.0	—	—	—	—	—	—
Tc-99 Activity	0.936	0.935	1.0	—	—	—	—	—
C-14 Activity	0.642	0.643	0.592	1.0	—	—	—	—
Total Activity	0.500	0.494	0.583	0.541	1.0	—	—	—
GTCC Volume	0.258	0.250	0.204	0.249	0.597	1.0	—	—
Pu-238 Activity	-0.008	-0.015	-0.042	0.030	0.508	0.716	1.0	—
U-234 Activity	0.064	0.064	0.032	0.194	0.075	0.021	-0.019	1.0
SDA Radionuclide Activity Correlation—Descriptive								
Cs-137 Activity	Exact	—	—	—	—	—	—	—
I-129 Activity	VS	Exact	—	—	—	—	—	—
Tc-99 Activity	VS	VS	Exact	—	—	—	—	—
C-14 Activity	Strong	Strong	Mod	Exact	—	—	—	—
Total Activity	Mod	Mod	Mod	Mod	Exact	—	—	—
GTCC Volume	Weak	Weak	Weak	Weak	Mod	Exact	—	—
Pu-238 Activity	-VW	-VW	-VW	VW	Mod	Strong	Exact	—
U-234 Activity	VW	VW	VW	Weak	VW	VW	-VW	Exact

As suspected, there is a Very Strong correlation between Cs-137, I-129, and Tc-99; a Strong correlation between Cs-137 and C-14; a Very Strong correlation between Pu-238 and GTCC volume; and Very Weak to Weak correlations between U-234 and all other radionuclides.

The results of the All Targeted selective exhumation analysis are shown in Exhibit II-8. Instead of having a target radionuclide removal goal, the Exhibit II-8 table is based on target SDA volume exhumation goals. For example, the Exhibit II-8 SDA table shows that over 90% of the activity of most radionuclides can be removed by the selective exhumation of 50% of the SDA volume. Alternatively, about 50% of the activity of many radionuclides can be removed by the selective exhumation of only 10% of the SDA volume.



Goal	SDA Volume	Cs-137 Activity	I-129 Activity	Tc-99 Activity	C-14 Activity	GTCC Volume	Pu-238 Activity	U-234 Activity
10%	9.9%	58.7%	60.6%	47.3%	29.2%	35.1%	53.2%	18.1%
20%	20.6%	72.9%	74.2%	60.7%	44.6%	61.9%	84.3%	38.3%
30%	30.5%	80.4%	81.1%	65.9%	63.0%	81.1%	89.6%	62.5%
40%	40.4%	84.7%	85.1%	69.2%	79.2%	94.4%	92.8%	77.8%
50%	50.1%	90.6%	91.1%	78.6%	86.5%	99.1%	97.2%	87.5%

SDA Trench Segments to Exhume to Remove All Long-Term Radionuclides

	Trench Segment Distance (feet)													
	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	Remain	Remain	Ex: 50%	Remain	Remain	No Waste	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 2	Ex: 20%	Remain	Remain	Remain	Remain	Remain	Ex: 50%	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 3	Ex: 40%	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Ex: 50%	Ex: 20%	Remain
Trench 4	Ex: 10%	Ex: 10%	Ex: 10%	Ex: 10%	Ex: 10%	Ex: 10%	Ex: 10%	Ex: 10%	Ex: 50%	Ex: 20%	Ex: 10%	Remain	Ex: 30%	Ex: 30%
Trench 5	Ex: 10%	Remain	Ex: 50%	Remain	Ex: 50%	Ex: 20%	Ex: 30%	Ex: 20%	Ex: 20%	Remain	Remain	Remain	No Waste	No Waste
Trench 7	Ex: 50%	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 8	Ex: 20%	Ex: 40%	Ex: 30%	Ex: 20%	Ex: 30%	Ex: 30%	Ex: 40%	Ex: 40%	Ex: 20%	Remain	Ex: 50%	No Waste	No Waste	No Waste
Trench 9	Remain	Ex: 10%	Ex: 40%	Ex: 10%	Ex: 30%	Ex: 20%	Ex: 20%	Ex: 30%	Ex: 50%	Ex: 30%	Remain	Remain	No Waste	No Waste
Trench 10	Ex: 30%	Ex: 30%	Ex: 20%	Ex: 40%	Ex: 40%	Ex: 20%	Remain	Ex: 50%	Remain	Ex: 40%	Remain	Remain	No Waste	No Waste
Trench 11	Ex: 30%	Ex: 10%	Ex: 40%	Ex: 40%	Ex: 30%	Remain	Remain	Remain	Ex: 40%	Ex: 50%	Ex: 50%	Remain	No Waste	No Waste
Trench 12	Ex: 40%	Remain	Remain	Remain	Remain	Ex: 10%	Ex: 30%	Ex: 20%	Remain	Ex: 50%	Remain	Remain	No Waste	No Waste
Trench 13	Ex: 20%	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Ex: 40%	Remain	Remain	Remain	Remain	No Waste
Trench 14	Remain	Remain	Remain	Remain	Remain	Remain	Ex: 40%	Remain	Remain	Ex: 50%	Remain	Remain	Remain	No Waste
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	Remain	Ex: 50%	Ex: 50%	Remain	Remain	Remain	Remain	Remain	Remain					

Exhibit II-8: SDA Selective Exhumation of All Targeted Radionuclides

2. Greater Than Class C Waste

Although the waste in the SDA was buried before 10 CFR Part 61 was promulgated, URS (2002) estimated that about 3% of the waste in the SDA is GTCC waste based upon activities updated as of the 2000 base year. Most of the SDA GTCC waste is because of long-lived radionuclides. In fact, about 90% of all GTCC waste is due to TRU in three waste streams (SNAP [57.9%], Fuel Cycle-MOX [15.3%], and Special Purpose Reactor-Naval [16.6%]), all of which are controlled by the transuranic radionuclide concentration being greater than 100 nCi/g.

The SDA is not a 10 CFR Part 61 disposal facility, and there is no requirement to meet the 10 CFR Part 61 requirements as decommissioning criteria for the closure of the SDA. The purpose of including this section on GTCC waste removal is both to evaluate it as one of several selective exhumation options under consideration, and to ascertain if any correlation exists between the GTCC waste removal scenario and the removal of any other targeted radionuclide.

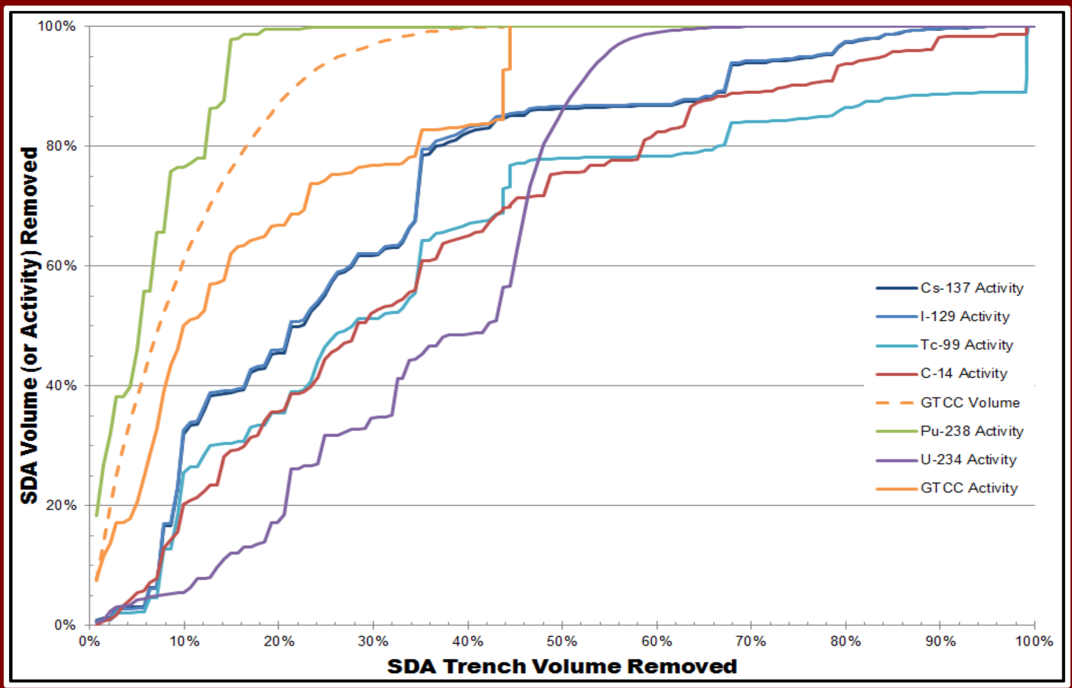
Exhibit II-9 shows the results of selectively removing GTCC waste from the SDA. The Exhibit II-9 chart shows that the GTCC volume removed follows the TRU activity removed, initially Pu-238 and then Pu-239. The last amount of GTCC waste removed is due to the removal of Ni-59 in Reactor Internals waste in Trench 6, which is shown quite clearly in the Exhibit II-9 chart by the nearly vertical step in the GTCC activity removal at about 45% SDA trench volume removed. The step increase in the curve is due to the very small Trench 6 GTCC volume (i.e., <0.1% of the total SDA GTCC volume) associated with the Ni-59 activity removal.

In the Exhibit II-9 table, a 100% removal goal has been added in place of the 75% goal. Complete GTCC removal is feasible, and would require removal of less than half of the SDA volume because there are a number of SDA trench segments and special holes that do not contain any GTCC waste. The Exhibit II-9 SDA schematic shows that 55% (78 out of 141) of the 50-foot trench segments that contain waste do not contain any GTCC waste. Of the Trench 6 Special Holes, 13 out of 19 (68%) do not contain GTCC waste.

Exhibit II-9 shows that removing 50% of the GTCC volume is effective at removing about 65% of the Pu-238 (i.e., TRU) activity, but minimally effective at removing any of the other radionuclides (i.e., each <10% removal). However, 100% removal of the GTCC volume removes 100% of the PU-238 activity (and nearly 100% of the TRU activity), and is also effective at removing each of the other radionuclides, with I-129, Tc-99, and C-14 being each over 70% removed and U-234 being over 56% removed. In order to get from 50% to 100% GTCC volume removal, the SDA volume exhumed increases from 7.1% to 44.5%—an increase of about a factor of 6.3, with an associated cost increase.

3. Trench by Trench Exhumation

In the previous two sections selective exhumation of targeted radionuclides and GTCC waste was examined at the level of individual 50-foot trench segments. A different approach to partial exhumation would be the removal of the full length of one or more trenches. To be most cost effective, the exhumed trench or trenches should be those containing the largest amount of radioactivity. Table II-5 presents the percentage of SDA activity in each of the 14 trenches over the time period of concern, and shows that Trench 6 contains the largest percentage of SDA activity over the entire time period of concern, followed initially (i.e., in 2020) by Trenches 10, 4, 11, 9, and 8. In general, Table II-5 shows that the ranking of the trenches does not change much over the time period of concern. An exception is Trench 4, which moves from being ranked third in 2020 to being ranked sixth in 2140.



Target: GTCC		SDA	GTCC	I-129	Tc-99	C-14	Pu-238	U-234
Goal	Volume	Volume	Activity	Activity	Activity	Activity	Activity	Activity
50%	48.8%	7.1%	32.7%	6.2%	4.6%	7.8%	65.6%	4.9%
80%	81.0%	17.0%	64.4%	42.2%	33.0%	31.4%	98.6%	13.1%
90%	90.4%	22.0%	68.7%	49.9%	39.0%	38.7%	99.6%	26.2%
95%	94.9%	26.2%	75.4%	58.6%	48.9%	46.1%	99.9%	31.7%
100%	100.0%	44.5%	100.0%	85.1%	76.8%	70.2%	100.0%	56.6%

SDA Trench Segments to Exhume to Remove GTCC Volume

Trench Segment Distance (feet)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	No GTCC	No GTCC	Ex: 100%	No GTCC	No GTCC	No Waste	No GTCC	No GTCC	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 2	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 3	Ex: 100%	No GTCC	Ex: 100%	No GTCC	No GTCC	No GTCC	Ex: 100%	No GTCC	No GTCC	No GTCC	No GTCC	Ex: 100%	Ex: 95%	Ex: 100%
Trench 4	Ex: 100%	Ex: 80%	Ex: 80%	Ex: 50%	Ex: 80%	Ex: 90%	Ex: 90%	Ex: 80%	Ex: 100%	No GTCC	Ex: 95%	No GTCC	No GTCC	No GTCC
Trench 5	Ex: 80%	No GTCC	No GTCC	No GTCC	Ex: 100%	Ex: 50%	Ex: 100%	Ex: 100%	Ex: 95%	No GTCC	No GTCC	Ex: 100%	No Waste	No Waste
Trench 7	Ex: 100%	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 8	Ex: 50%	Ex: 100%	Ex: 100%	Ex: 100%	Ex: 100%	Ex: 50%	Ex: 80%	Ex: 80%	Ex: 95%	No GTCC	Ex: 90%	No Waste	No Waste	No Waste
Trench 9	Ex: 100%	Ex: 50%	Ex: 90%	Ex: 95%	Ex: 80%	Ex: 100%	Ex: 80%	Ex: 100%	Ex: 100%	Ex: 95%	No GTCC	No GTCC	No Waste	No Waste
Trench 10	Ex: 80%	Ex: 50%	Ex: 50%	Ex: 80%	Ex: 50%	Ex: 80%	No GTCC	Ex: 100%	No GTCC	No GTCC	No GTCC	No GTCC	No Waste	No Waste
Trench 11	Ex: 50%	Ex: 50%	Ex: 80%	No GTCC	Ex: 100%	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No Waste	No Waste
Trench 12	Ex: 100%	No GTCC	No GTCC	No GTCC	No GTCC	Ex: 80%	No GTCC	Ex: 90%	No GTCC	Ex: 90%	No GTCC	No GTCC	No Waste	No Waste
Trench 13	Ex: 90%	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No Waste
Trench 14	No GTCC	No GTCC	No GTCC	Ex: 100%	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	Ex: 100%	No GTCC	No GTCC	No Waste
	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
Trench 6	No GTCC	No GTCC	No GTCC	No GTCC	Ex: 100%	Ex: 100%	Ex: 100%	No GTCC	No GTCC	No GTCC				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	No GTCC	No GTCC	No GTCC	No GTCC	No GTCC	Ex: 100%	Ex: 100%	No GTCC	Ex: 100%					

Exhibit II-9: SDA Selective Exhumation of GTCC Waste

Table II-5: Total Activity in SDA Trench Inventory Over Time

	2000	2020	2050	2080	2110	2140
Trench 6	19.2%	21.1%	25.9%	28.8%	30.3%	31.2%
Trench 10	16.3%	18.2%	20.0%	21.0%	21.3%	21.1%
Trench 4	15.8%	16.2%	13.7%	11.0%	9.2%	8.1%
Trench 11	12.2%	11.1%	10.1%	10.0%	10.0%	9.9%
Trench 9	10.4%	10.4%	10.1%	9.9%	9.9%	9.9%
Trench 8	10.3%	9.4%	8.6%	8.6%	8.7%	8.9%
Trench 5	7.1%	6.7%	6.5%	6.5%	6.6%	6.7%
Trench 12	3.2%	2.4%	1.8%	1.6%	1.7%	1.9%
Trench 3	1.7%	1.4%	1.0%	0.8%	0.6%	0.5%
Trench 13	1.5%	1.0%	0.5%	0.4%	0.4%	0.5%
Trench 14	1.1%	0.9%	0.7%	0.7%	0.7%	0.8%
Trench 2	0.8%	0.8%	0.7%	0.5%	0.4%	0.3%
Trench 1	0.2%	0.3%	0.2%	0.2%	0.2%	0.1%
Trench 7	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%

The trench with the largest total radionuclide inventory is not necessarily the trench with the largest potential risk. The long-lived radionuclides identified in Section II.B.1 are assumed for purposes of this study to pose the greatest long-term risk (subject to confirmation by the ongoing PPA). Table II-6 has, therefore, been prepared to show the fractional inventory for only the six long-lived radionuclides of greatest concern to risk in each of the 14 SDA trenches. From Table II-6 it is seen that for the fission products (i.e., I-129, Tc-99, and C-14), Trench 4 has the largest inventory, followed by Trench 9. For Pu-238 (i.e., TRU), Table II-6 shows that Trench 10 has the greatest inventory, followed by Trenches 11, 8, and 9. In fact, over 99% of the Pu-238 inventory may be found in these four trenches. For U-234, Table II-6 shows that Trench 4 and Trench 8 have the largest inventories.

Table II-6: Inventory of Activity for Six SDA Radionuclides (2020)

	Cs-137	I-129	Tc-99	C-14	Pu-238	U-234
Trench 1	1.9%	2.1%	1.5%	0.9%	0.0%	0.2%
Trench 2	6.3%	6.4%	5.1%	1.3%	0.0%	0.1%
Trench 3	7.5%	7.6%	6.0%	4.0%	0.0%	0.6%
Trench 4	49.2%	51.7%	39.7%	27.6%	0.1%	34.5%
Trench 5	9.3%	8.7%	10.3%	8.2%	0.6%	5.6%
Trench 6	0.0%	0.0%	18.7%	2.2%	0.0%	0.0%
Trench 7	0.8%	0.8%	0.6%	0.3%	0.0%	0.0%
Trench 8	2.6%	2.4%	2.0%	6.8%	15.7%	18.9%
Trench 9	14.8%	13.9%	10.3%	11.2%	16.4%	5.5%
Trench 10	0.5%	0.4%	0.4%	13.6%	46.4%	8.5%
Trench 11	2.8%	2.4%	1.9%	13.4%	20.7%	6.1%
Trench 12	1.4%	1.1%	1.4%	7.0%	0.1%	5.1%
Trench 13	1.0%	0.8%	0.7%	1.3%	0.0%	5.8%
Trench 14	2.0%	1.7%	1.3%	2.3%	0.0%	9.2%

Using the information from Table II-6, a ranking was developed for the exhumation of each SDA trench. In this ranking Trench 4 would be exhumed first to remove its large fission product inventory; next Trench 9 would be exhumed to remove its fission product and Pu-238 inventories; Trench 10 would then be exhumed to remove its fission product and Pu-238 inventories; and then Trenches 11, 5, and 8 would be exhumed because they have more inventory than the other remaining trenches. The ranking of the seven remaining trenches is shown by the order in which they are listed in Exhibit II-10. Ironically, Trench 6 would be exhumed last because much of its inventory is due to activation products, not fission products or TRU radionuclides, even though it has the largest percentage of SDA activity.

The results of the trench-wise exhumation of the SDA are presented in Exhibit II-10. The first row of the Exhibit II-10 table shows that exhuming Trench 4 alone would be equivalent to exhuming about 10% of the entire SDA, and would remove 52%, 40%, 35%, and 28% of the I-129, Tc-99, U-234, and C-14 inventories. However, the Pu-238 (i.e., TRU) inventory would remain almost unchanged. The sixth row of the Exhibit II-10 table shows that exhuming the top six trenches would be equivalent to exhuming about 52% of the entire SDA, and would remove almost the entire Pu-238 inventory, about 80% of the I-129, C-14, and U-234 inventories, and about 65% of the Tc-99 inventory. The removal of Tc-99 is low because a large portion of its inventory (i.e., about 19%) is located in Trench 6.

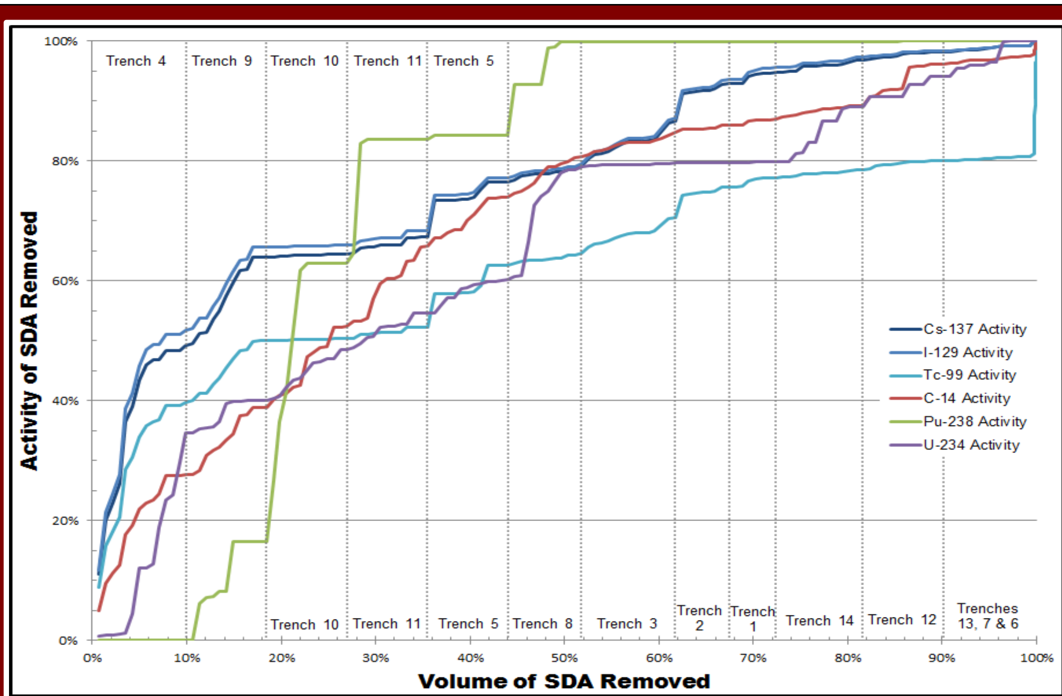
4. Potential Erosion Areas

The SDA is located in an area of the site referred to as the South Plateau. Erdman Brook is located along the northern side of the South Plateau, and Franks Creek in located along its eastern side. Both Erdman Brook and Franks Creek are located in gullies that continue to form, as shown in Exhibit II-11. There is concern that at some future time these gullies will intersect the SDA disposal trenches and expose the waste. The specific trenches that may be at risk of failure due to erosion are not yet known. For purposes of this study, the trenches along the SDA's northern and eastern edges that are commonly believed to be most prone to erosion have been selected for analysis.

In particular, a scenario has been evaluated in which all the waste along the eastern edge of the SDA (i.e., Trenches 1, 2, and 8) would be exhumed, followed by the removal of all the waste in the first 50-foot segments of Trenches 3, 4, and 5 along the northern edge of the SDA. The results of that evaluation are presented in Exhibit II-12.

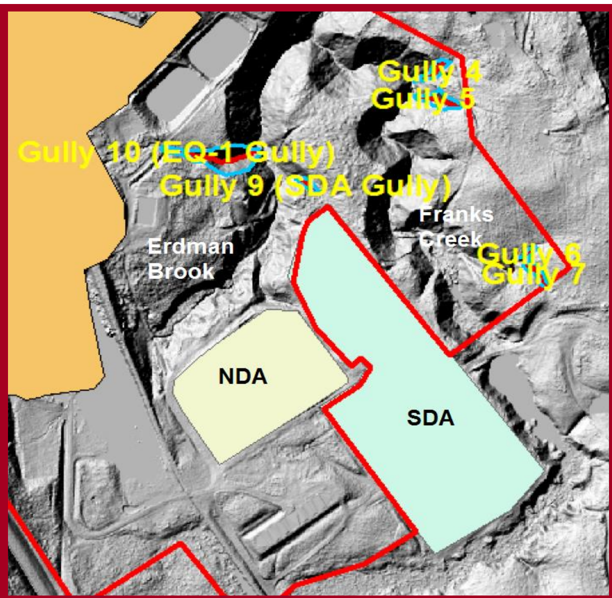
Exhibit II-12 shows that if all the SDA areas commonly believed to be prone to erosion are removed, it would require exhumation of about 21% of the SDA, and would result in the removal of about 30%, 24%, 20%, 16%, and 16% of the I-129, Tc-99, U-234, Pu-238 (i.e., TRU), and C-14 inventories, respectively. About 29% of the short-lived Cs-137 would also be removed. This indicates a removal efficiency of about 1 to 1, which is far below the activity removal efficiency achieved under other selective removal scenarios discussed in previous sections.

If only the waste along the eastern edge of the SDA is removed (Trenches 1, 2, and 8), it would require exhumation of about 18% of the SDA, and would result in the removal of about 19%, 16%, 11%, 9%, and 9% of the U-234, Pu-238, I-129, C-14, and Tc-99 inventories, respectively. The removal efficiency in this case is negative, i.e., less than 1 to 1. Alternatively, if only the waste along the northern edge of the SDA is removed, it would require exhumation of about 3% of the SDA, but would result in the removal of about 24%, 19%, 7%, 1%, and 1% of the I-129, Tc-99, C-14, U-234, and Pu-238 inventories, respectively.



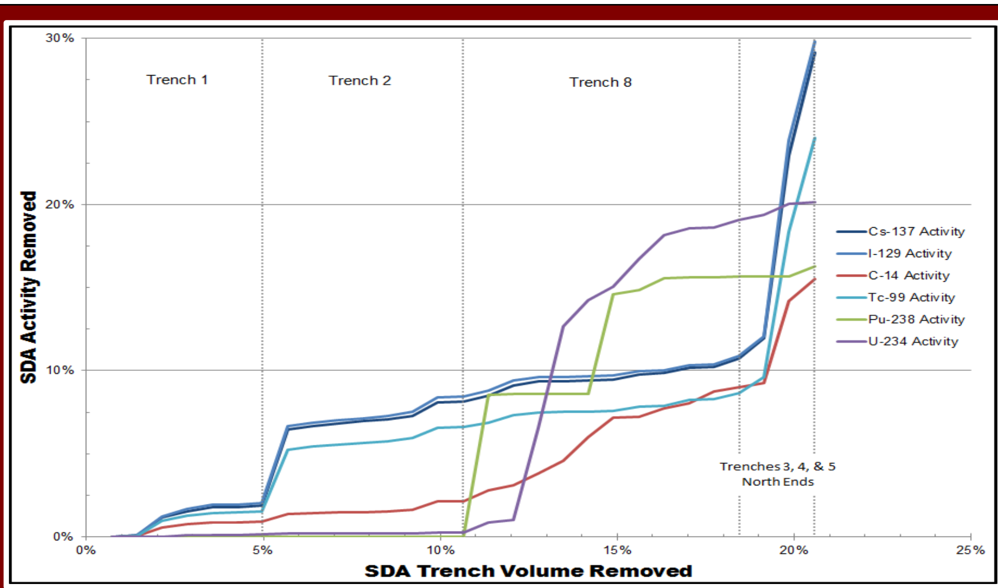
	SDA Volume	Cs-137 Activity	I-129 Activity	Tc-99 Activity	C-14 Activity	Pu-238 Activity	U-234 Activity
Trench 4	9.9%	49.2%	51.7%	39.7%	27.6%	0.1%	34.5%
+ Trench 9	18.4%	64.0%	65.6%	50.0%	38.8%	16.5%	40.0%
+ Trench 10	27.0%	64.5%	65.9%	50.3%	52.4%	62.9%	48.5%
+ Trench 11	35.5%	67.3%	68.4%	52.2%	65.8%	83.6%	54.6%
+ Trench 5	44.0%	76.5%	77.1%	62.6%	73.9%	84.2%	60.1%
+ Trench 8	51.8%	79.1%	79.5%	64.6%	80.8%	99.9%	79.0%
+ Trench 3	61.7%	86.6%	87.1%	70.6%	84.8%	99.9%	79.6%
+ Trench 2	67.4%	92.9%	93.5%	75.7%	86.0%	99.9%	79.7%
+ Trench 1	72.4%	94.8%	95.6%	77.2%	86.9%	99.9%	79.9%
+ Trench 14	81.6%	96.8%	97.3%	78.6%	89.2%	99.9%	89.1%
+ Trench 12	90.1%	98.2%	98.4%	80.0%	96.2%	100.0%	94.2%
+ Trench 13	99.3%	99.2%	99.2%	80.7%	97.4%	100.0%	100.0%
+ Trench 7	99.7%	100.0%	100.0%	81.3%	97.8%	100.0%	100.0%
+ Trench 6	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Exhibit II-10: SDA Selective Exhumation by Trench



Adopted from: ECS 2016, Exhibit 1

Exhibit II-11: South Plateau Surface Topography



	SDA Volume	Cs-137 Activity	I-129 Activity	Tc-99 Activity	C-14 Activity	Pu-238 Activity	U-234 Activity
Trench 1	5.0%	1.9%	2.1%	1.5%	0.9%	0.0%	0.2%
+ Trench 2	10.6%	8.2%	8.4%	6.6%	2.2%	0.0%	0.2%
+ Trench 8	18.4%	10.7%	10.9%	8.6%	9.0%	15.7%	19.1%
+ Trenches 3, 4 & 5 North Ends	20.6%	29.1%	29.8%	24.0%	15.5%	16.3%	20.1%
Trenches 2, 3, 4,5 North Ends Only	2.8%	23.0%	23.5%	19.1%	7.0%	0.6%	1.1%

Exhibit II-12: SDA Selective Exhumation for Erosion Control

C. Exhumed SDA Waste Dose Rates

ECS (2016) developed a MicroShield (Grove 2009) model of a 55-gallon drum full of SDA waste (with a density of 2.35 grams per cubic centimeter) to calculate the dose rates due to Co-60 and/or Cs-137. At 12 inches from the drum surface (Exhibit II-13), the calculated normalized dose rates were 285.6 mR/hr per µCi/cm^3 of Co-60 and 62.8 mR/hr per µCi/cm^3 of Cs-137.

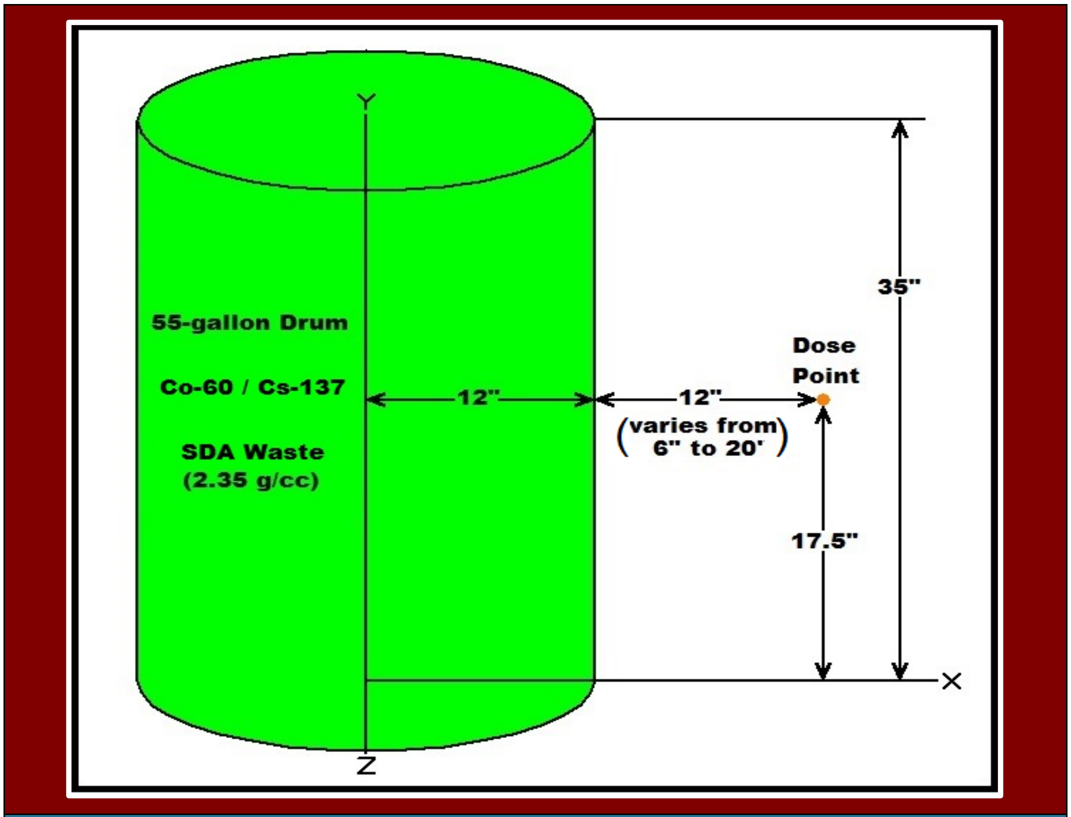


Exhibit II-13: MicroShield Dose Model

An average dose rate for each 50-foot trench segment and for each Trench 6 Special Hole was then calculated by dividing the Co-60 and Cs-137 activities of each 50-foot segment or Special Hole by its waste volume, multiplying the resultant activity concentrations by the normalized dose rates, and summing the two dose rates. Exhibit II-14 shows the results of these calculations superimposed on the SDA schematic for each of the five times of concern, i.e., 2020, 2050, 2080, 2110, and 2140.

State Licensed Disposal Area URS 2002 Cs-137 & Co-60 2020 Unshielded Dose Rate (mR/hr)

Distance (ft)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699	
Trench 1	0.4	4.5	13.7	4.2	4.2	--	5.4	3.9	--	--	--	--	--	--	
Trench 2	32.8	4.6	2.1	1.6	1.2	2.2	6.8	33.9	--	--	--	--	--	--	
Trench 3	13.9	9.4	2.9	6.2	8.2	6.6	5.0	0.8	0.8	0.8	3.4	17.6	15.5	3.8	
Trench 4	63.5	100.5	28.6	85.5	136.4	37.9	43.2	32.9	16.3	12.4	15.3	--	--	8.7	
Trench 5	47.4	0.0	0.1	0.1	0.4	0.1	3.3	8.8	16.9	0.4	0.2	0.2	--	--	
Trench 7	57.1	--	--	--	--	--	--	--	--	--	--	--	--		<0.25
Trench 8	2.2	4.6	1.8	0.2	0.3	0.5	2.4	0.8	4.3	0.3	6.9	--	--		0.25 to 2.5
Trench 9	7.8	13.0	1.0	31.6	16.2	19.8	32.5	22.9	2.2	32.0	1.0	0.1	--		2.5 to 25
Trench 10	0.1	0.7	0.1	2.2	0.2	1.1	0.2	0.4	0.5	0.3	0.4	0.9	--		25 to 250
Trench 11	0.8	13.4	1.5	0.4	1.9	0.2	0.4	0.5	13.8	0.9	0.7	0.1	--		>250
Trench 12	3.3	5.4	1.0	1.0	1.8	3.9	0.9	0.4	0.5	0.8	0.6	0.0	--	--	
Trench 13	0.7	0.8	1.3	0.5	0.9	1.5	1.5	3.3	0.2	0.3	0.4	0.1	0.2	--	
Trench 14	0.8	0.7	0.9	5.5	0.1	0.3	1.2	0.9	0.3	0.8	4.2	9.0	0.1	--	
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10					
	15,200.0	42.8	23.9	20.1	51,500.0	51,500.0	38,500.0	4,690.0	4,690.0	2,750.0					
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19						
	3,720.0	7,040.0	6,410.0	7.6	5.4	53,200.0	53,200.0	32,600.0	53,200.0						

State Licensed Disposal Area URS 2002 Cs-137 & Co-60 2050 Unshielded Dose Rate (mR/hr)

Distance (ft)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699	
Trench 1	0.2	2.2	6.9	2.1	2.1	--	2.7	1.9	--	--	--	--	--	--	
Trench 2	16.3	2.3	1.0	0.8	0.6	1.1	3.4	17.0	--	--	--	--	--	--	
Trench 3	6.9	4.7	1.4	3.1	4.1	3.3	2.5	0.4	0.4	0.4	1.7	8.7	7.7	1.9	
Trench 4	31.8	50.4	14.3	42.2	67.9	18.8	21.6	16.4	8.0	5.7	6.1	--	--	4.3	
Trench 5	22.1	0.0	0.1	0.0	0.2	0.0	1.6	4.3	4.8	0.2	0.1	0.0	--	--	
Trench 7	28.6	--	--	--	--	--	--	--	--	--	--	--	--		<0.25
Trench 8	1.1	2.3	0.9	0.1	0.1	0.2	1.1	0.4	1.8	0.1	3.5	--	--		0.25 to 2.5
Trench 9	3.8	6.5	0.5	15.8	8.1	9.9	16.2	11.4	1.1	16.0	0.5	0.0	--		2.5 to 25
Trench 10	0.1	0.1	0.0	1.1	0.1	0.5	0.1	0.2	0.3	0.1	0.2	0.5	--		25 to 250
Trench 11	0.4	6.5	0.7	0.2	0.9	0.1	0.2	0.2	6.8	0.4	0.3	0.1	--		>250
Trench 12	1.1	0.8	0.4	0.5	0.9	1.9	0.3	0.2	0.2	0.4	0.3	0.0	--	--	
Trench 13	0.4	0.4	0.6	0.2	0.4	0.7	0.2	1.6	0.1	0.2	0.2	0.0	0.1	--	
Trench 14	0.4	0.3	0.3	2.7	0.1	0.1	0.6	0.5	0.1	0.4	2.1	4.4	0.0	--	
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10					
	298.0	0.8	0.5	0.4	1,010.0	1,010.0	753.0	91.6	91.6	53.8					
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19						
	72.7	138.0	125.0	0.1	0.1	1,040.0	1,040.0	637.0	1,040.0						

State Licensed Disposal Area URS 2002 Cs-137 & Co-60 2080 Unshielded Dose Rate (mR/hr)

Distance (ft)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699	
Trench 1	0.1	1.1	3.4	1.1	1.1	--	1.4	1.0	--	--	--	--	--	--	
Trench 2	8.2	1.1	0.5	0.4	0.3	0.5	1.7	8.5	--	--	--	--	--	--	
Trench 3	3.5	2.4	0.7	1.6	2.1	1.6	1.2	0.2	0.2	0.2	0.8	4.4	3.9	0.9	
Trench 4	16.0	25.3	7.2	21.2	34.1	9.4	10.8	8.2	4.0	2.9	3.0	--	--	2.2	
Trench 5	11.1	0.0	0.0	0.0	0.1	0.0	0.8	2.1	2.3	0.1	0.1	0.0	--	--	
Trench 7	14.3	--	--	--	--	--	--	--	--	--	--	--	--		<0.25
Trench 8	0.6	1.2	0.5	0.1	0.1	0.1	0.5	0.2	0.9	0.1	1.7	--	--		0.25 to 2.5
Trench 9	1.9	3.3	0.2	7.9	4.1	5.0	8.1	5.7	0.5	8.0	0.2	0.0	--		2.5 to 25
Trench 10	0.0	0.0	0.0	0.5	0.0	0.3	0.1	0.1	0.1	0.1	0.1	0.2	--		25 to 250
Trench 11	0.2	3.3	0.4	0.1	0.5	0.1	0.1	0.1	3.4	0.2	0.2	0.0	--		>250
Trench 12	0.5	0.4	0.2	0.2	0.4	1.0	0.2	0.1	0.1	0.2	0.1	0.0	--	--	
Trench 13	0.2	0.2	0.3	0.1	0.2	0.4	0.1	0.8	0.0	0.1	0.1	0.0	0.1	--	
Trench 14	0.2	0.2	0.2	1.4	0.0	0.1	0.3	0.2	0.1	0.2	1.0	2.2	0.0	--	
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10					
	8.0	0.0	0.0	0.0	24.9	24.9	18.7	2.3	2.3	1.3					
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19						
	1.8	3.4	3.1	0.0	0.0	25.8	25.8	15.8	25.8						

All dose rates were calculated at 1 foot from the source.

Exhibit II-14: Dose Rate for SDA Segments at 2020, 2050, 2080, 2110, and 2140

State Licensed Disposal Area URS 2002 Cs-137 & Co-60 2110 Unshielded Dose Rate (mR/hr)

	Distance (ft)													
	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	0.0	0.6	1.7	0.5	0.5	--	0.7	0.5	--	--	--	--	--	--
Trench 2	4.1	0.6	0.3	0.2	0.1	0.3	0.9	4.3	--	--	--	--	--	--
Trench 3	1.7	1.2	0.4	0.8	1.0	0.8	0.6	0.1	0.1	0.1	0.4	2.2	1.9	0.5
Trench 4	8.0	12.7	3.6	10.6	17.1	4.7	5.4	4.1	2.0	1.4	1.5	--	--	1.1
Trench 5	5.6	0.0	0.0	0.0	0.1	0.0	0.4	1.1	1.2	0.0	0.0	0.0	--	--
Trench 7	7.2	--	--	--	--	--	--	--	--	--	--	--	--	<0.25
Trench 8	0.3	0.6	0.2	0.0	0.0	0.1	0.3	0.1	0.4	0.0	0.9	--	--	0.25 to 2.5
Trench 9	1.0	1.6	0.1	4.0	2.0	2.5	4.1	2.9	0.3	4.0	0.1	0.0	--	2.5 to 25
Trench 10	0.0	0.0	0.0	0.3	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.1	--	25 to 250
Trench 11	0.1	1.6	0.2	0.0	0.2	0.0	0.0	0.1	1.7	0.1	0.1	0.0	--	>250
Trench 12	0.3	0.2	0.1	0.1	0.2	0.5	0.1	0.0	0.1	0.1	0.1	0.0	--	--
Trench 13	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.4	0.0	0.0	0.0	0.0	0.0	--
Trench 14	0.1	0.1	0.1	0.7	0.0	0.0	0.2	0.1	0.0	0.1	0.5	1.1	0.0	--
	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
Trench 6	1.3	0.0	0.0	0.0	3.2	3.2	2.4	0.3	0.3	0.2				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	0.2	0.4	0.4	0.0	0.0	3.3	3.3	2.0	3.3					

State Licensed Disposal Area URS 2002 Cs-137 & Co-60 2140 Unshielded Dose Rate (mR/hr)

	Distance (ft)													
	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	0.0	0.3	0.9	0.3	0.3	--	0.3	0.2	--	--	--	--	--	--
Trench 2	2.1	0.3	0.1	0.1	0.1	0.1	0.4	2.2	--	--	--	--	--	--
Trench 3	0.9	0.6	0.2	0.4	0.5	0.4	0.3	0.0	0.0	0.0	0.2	1.1	1.0	0.2
Trench 4	4.0	6.4	1.8	5.3	8.6	2.4	2.7	2.1	1.0	0.7	0.8	--	--	0.5
Trench 5	2.8	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.6	0.0	0.0	0.0	--	--
Trench 7	3.6	--	--	--	--	--	--	--	--	--	--	--	--	<0.25
Trench 8	0.1	0.3	0.1	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.4	--	--	0.25 to 2.5
Trench 9	0.5	0.8	0.1	2.0	1.0	1.3	2.1	1.4	0.1	2.0	0.1	0.0	--	2.5 to 25
Trench 10	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	--	25 to 250
Trench 11	0.0	0.8	0.1	0.0	0.1	0.0	0.0	0.0	0.9	0.1	0.0	0.0	--	>250
Trench 12	0.1	0.1	0.1	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	--	--
Trench 13	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	--
Trench 14	0.0	0.0	0.0	0.3	0.0	0.0	0.1	0.1	0.0	0.1	0.3	0.6	0.0	--
	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
Trench 6	0.6	0.0	0.0	0.0	1.4	1.4	1.1	0.1	0.1	0.1				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	0.1	0.2	0.2	0.0	0.0	1.5	1.5	0.9	1.5					

All dose rates were calculated at 1 foot from the source.

Exhibit II-14 (Continued): Dose Rate for SDA Segments at 2020, 2050, 2080, 2110, and 2140

An initial estimate of the amount of radiation protection that is required for a given selective exhumation scenario can, therefore, be determined by comparing the trench segments required to meet the removal goal for that selective exhumation scenario with the dose values reported in Exhibit II-14. Based on the 10CFR §1201 and §835.202 occupational dose limit of 5 rem per year and a standard 2,000 hour work-year, a dose rate of 2.5 mrem/hr is considered an appropriate value that would allow work to be performed without special shielding. With reference to Exhibit II-14, this would indicate that any trench segment shaded yellow or orange at a given time period could be exhumed without shielding to protect against gamma exposure. This, of course, is intended for use only as a comparative evaluation tool and does not strictly apply due to localized variability in waste activity (additional discussion on the limitations on the Exhibit II-14 dose rates is provided at the end of this section).

As stated above the dose rates presented in Exhibit II-14 were calculated at one foot (12 inches) from the surface of the drum. It is likely that the dose recipient would be located further from the drum. Exhibit II-15 provides dose rate multipliers that can be used to adjust the Exhibit II-14 dose rates to account for the recipient being at a different distance. For example, the dose rates reported in Exhibit II-14 will be one order of magnitude less if the recipient is 5.3 feet from the source, and two orders of magnitude less if the recipient is 18.2 feet from the source.

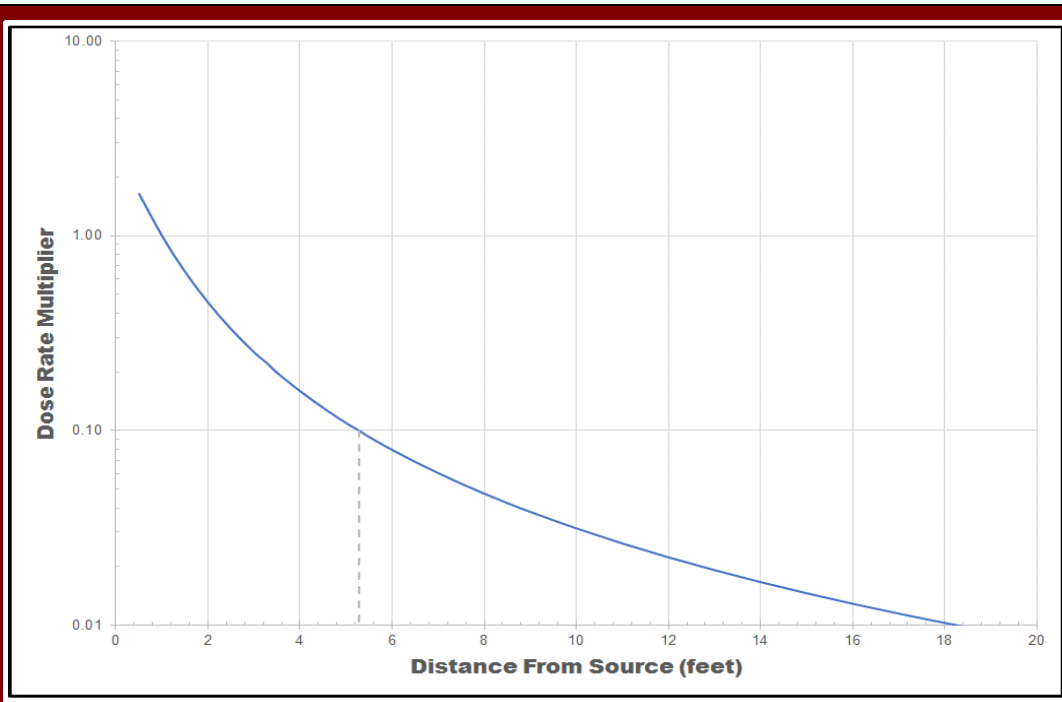


Exhibit II-15: Dose Rate Multiplier as a Function of Distance

With a dose rate goal of 2.5 mrem/hr, the recipient about 5.3 feet from the source, and if I-129 is the targeted radionuclide, Exhibit II-1 (page 17) shows that many of the segments required to be exhumed to meet the 50% (or 75%) removal goal are the same segments that Exhibit II-14 shows to have the largest 2020 dose rates. By waiting until 2080, Exhibit II-14 shows that most of the activity in the trench segments targeted for removal would have decayed such that the corresponding distance adjusted dose rates would be below 25 mR/hr, i.e., below 2.5 mrem/yr at 5.3 feet. By 2110, the dose rates for all the 50% or 75% goal segments would be below 2.5 mR/hr at 5.3 feet.

Alternatively, if Pu-238 (i.e., TRU) is the targeted radionuclide, comparing the Exhibit II-5 removal segments to the Exhibit II-14 distance adjusted dose rate segments shows that none of the segments required to be exhumed to meet any of the removal goals exceed 2.5 mR/hr (at 5.3 feet) for any of the times of concern. With reference to Exhibit II-9, removal of 100% of GTCC waste would require the exhumation of six Trench 6 Special Holes, which Exhibit II-14 shows to have 2020 dose rates greater than 50 R/hr (5 R/hr at 5.3 feet). Due to radioactive decay, the dose rate for these same Special Holes is reduced to 3.3 mR/hr or less by 2110.

There are some limitations with using the Exhibit II-14 dose rates that need to be stated. These include:

1. This Technical Memorandum uses a dose rate of 2.5 mrem/hr as the divide between contact and remote operations, as was the case for ECS (2016), but recognizes that this is not a strict criterion and could change. For comparison, the West Valley site utilizes a 0.25 mrem/hr administrative dose limit, the West Valley site also uses 5 mrem/hr to define radiation zones, DOE's divide between contact and remote waste is 200 mrem/hr (DOE 1997), and NRC is considering reducing the occupational limit from 5 rem/yr (2.5 mrem/hr) to 2 rem/yr (1.0 mrem/hr) (FR 2014).

2. The dose rates are based on the 50-foot segment average concentration, so it is expected that there would be "hot spots" within each segment where the dose rate is larger than that

reported in Exhibit II-14. For example, during the exhumation of six 1,000 gallon tanks from NDA SH-10, the measured average tank contact dose rate ranged from 0.1 to 200 mR/hr (DOE 1987, page 33).

3. The Exhibit II-14 dose rates are based only on Cs-137 and Co-60 activities. While this is a good 2020 assumption, for the later time periods when these two radionuclides have significantly decayed, other radionuclides may make non-negligible contributions to the dose rate.

4. The MicroShield model (Exhibit II-13) only accounts for the dose rate due to a single 55-gallon drum, and does not attempt to model waste that may be uncovered at the dig face or disposed in another type of container. Although 55-gallon drums were used for the disposal of a large portion of the SDA waste (approximately 40%, as per the SDA database), other types of containers were also used. Some of these other containers (particularly larger ones) may have larger dose rates, see Section III.B (specifically, Table III-5) for more information on this topic.

Even with these limitations, it is believed that the dose rates provided in Exhibit II-14 are useful at this decision-making phase of the process, subject to refinement during the detailed design phase of the project.

D. Example: 10% SDA Exhumation

Assume for example that it is desired to reduce the SDA exhumation cost by about 90%. Because much of the costs are associated with the actual removal, processing, packaging, shipment, and disposal of the exhumed waste, one way to do this would be to reduce the volume of the SDA that is exhumed. As discussed in previous sections, a rough order of magnitude estimate of how to reduce the cost by 90% would be to reduce the volume exhumed by 90%; that is, to remove only 10% of the total SDA volume. For the SDA, this would be represented by the exhumation of fourteen 50-foot trench segments.

Each of the exhumation schemes analyzed in Section B was re-examined to determine the amount of each radionuclide that would be removed by exhuming 14 trench segments. The exhumation of the entire 14 segments of Trench 4 was another scenario evaluated to achieve 10% exhumation, as was the exhumation of the northern 11 segments of Trench 4 plus the northernmost segments of Trenches 2, 3, and 5 to reduce the erosion risk. The estimated inventory removed by each of these scenarios is presented in Table II-7.

Table II-7: Inventory Removed by 10% SDA Exhumation Scenarios

Exhumation Scenario	Cs-137 Activity	I-129 Activity	Tc-99 Activity	C-14 Activity	GTCC Volume	Pu-238 Activity	U-234 Activity
All Targeted	58.7%	60.6%	47.3%	29.2%	35.1%	53.2%	18.1%
Target: Cs-137	65.7%	67.4%	51.4%	29.0%	23.3%	9.3%	15.6%
Target: I-129	65.7%	67.4%	51.4%	29.0%	23.3%	9.3%	15.6%
Target: Tc-99	64.3%	66.2%	62.3%	32.4%	23.3%	9.1%	20.5%
Target: C-14	40.3%	42.0%	32.3%	47.7%	12.3%	2.1%	19.0%
Target: GTCC	32.0%	32.6%	25.4%	20.8%	60.9%	76.5%	5.5%
Target: Pu-238	5.9%	5.4%	4.1%	15.7%	53.1%	97.1%	9.1%
Target: U-234	12.4%	12.5%	10.7%	15.3%	0.0%	0.0%	60.3%
Trench 4	49.2%	51.7%	39.7%	27.6%	17.6%	0.1%	34.5%
Erosion / T-4	60.4%	62.8%	49.4%	29.6%	20.7%	0.7%	23.8%

For the “All Targeted” radionuclide case, Table II-7 shows that over 50% of the Cs-137, I-129, and Pu-238 and close to 50% of the Tc-99 activities would be removed, along with significant amounts of the C-14 and U-234 activity and GTCC volume. When Cs-137 or I-129 are the target, Table II-7 shows that over 50% of the Cs-137, I-129, and Tc-99 activities would be removed, along with a significant amount of the C-14 activity and GTCC volume, but only a small amount of Pu-238 activity would be removed. When Tc-99 is the target, Table II-7 shows results similar to when Cs-137 or I-129 are the target, except that the amount of Tc-99 removed is larger due to the exhumation of four Trench 6 Special Holes in addition to the 14 trench segments. Finally, Table II-7 shows that when C-14, GTCC, Pu-238, or U-234 are the target, the amount of targeted material removed increases (sometimes significantly), but the removed inventory for the other radionuclides decreases (sometimes significantly).

Thus, targeting either Cs-137 or “All Targeted” radionuclides results in the most significant overall reduction in SDA inventory, with “All Targeted” radionuclides removing significantly more Pu-238 (i.e., TRU) and targeting Cs-137 removing slightly more Cs-137, I-129, and Tc-99. Exhibit II-16 shows that for either 10% SDA exhumation scheme, 10 of the same trench segments would be exhumed.

10% SDA (14 Segments) Exhumation, Scenario: All Targeted

Trench Segment Distance (feet)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	Remain	Remain	Remain	Remain	Remain	No Waste	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 2	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 3	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain
Trench 4	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Remain	Remain	Exhume	Remain	Remain	Remain
Trench 5	Exhume	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 7	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 8	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste	No Waste
Trench 9	Remain	Exhume	Remain	Exhume	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 10	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 11	Remain	Exhume	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 12	Remain	Remain	Remain	Remain	Remain	Exhume	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 13	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 14	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain					

10% SDA (14 Segments) Exhumation, Scenario: Target: Cs-137

Trench Segment Distance (feet)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	Remain	Remain	Remain	Remain	Remain	No Waste	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 2	Exhume	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 3	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain
Trench 4	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Remain	Remain	Remain	Remain	Remain	Remain
Trench 5	Exhume	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 7	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 8	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste	No Waste
Trench 9	Remain	Remain	Remain	Exhume	Remain	Exhume	Exhume	Remain	Remain	Exhume	Remain	Remain	No Waste	No Waste
Trench 10	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 11	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 12	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 13	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 14	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain					

10% SDA (14 Segments) Exhumation, Scenario: Erosion / T-4

Trench Segment Distance (feet)

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	650-699
Trench 1	Remain	Remain	Remain	Remain	Remain	No Waste	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 2	Exhume	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 3	Exhume	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain
Trench 4	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Exhume	Remain	Remain	Remain
Trench 5	Exhume	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 7	Remain	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste	No Waste
Trench 8	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste	No Waste
Trench 9	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 10	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 11	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 12	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste	No Waste
Trench 13	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 14	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	No Waste
Trench 6	SPH-01	SPH-02	SPH-03	SPH-04	SPH-05	SPH-06	SPH-07	SPH-08	SPH-09	SPH-10				
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain				
	SPH-11	SPH-12	SPH-13	SPH-14	SPH-15	SPH-16	SPH-17	SPH-18	SPH-19					
	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain	Remain					

Exhibit II-16: 10% SDA Exhumation – Trench Segments Exhumed

III. NRC-Licensed Disposal Area

The NDA was operated by Nuclear Fuel Services, Inc. (NFS), under license from the Atomic Energy Commission (now the NRC), for disposal of solid radioactive waste generated from on-site fuel reprocessing operations. Beginning in 1966, solid radioactive waste materials from the nearby Main Plant Process Building exceeding 200 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. In addition, from 1982-1986, the WVDP buried approximately 200,000 ft^3 of waste in twelve trenches in the NDA. A more complete description of the NDA is provided in the Task 1.1 Technical Memorandum (ECS 2016a).

A. Selective Exhumation Scenarios

1. Activity Based Exhumation

For this study, the NDA and associated waste have been divided into the following three distinct areas: (1) the NFS Deep Holes, (2) the NFS Special Holes, and (3) the WVDP disposal trenches. Table III-1 presents a summary of the URS (2000) waste volume and inventory for each of the three areas. Table III-1 shows that although they make-up over 50% of the NDA waste volume, the WVDP trenches contain less than about 1% of the radionuclide inventory. Therefore, because the primary objective for selective exhumation is risk reduction, removal of the waste from the WVDP trenches was not considered.

Table III-1: NDA Waste Inventory Summary by Area

Disposal Area	Volume		Activity				
	Hole/ Trench	Waste	Cs-137	C-14	Tc-99	U-233	Pu-239
Deep Holes	13.9%	7.1%	47.0%	100.0%	48.5%	47.5%	54.2%
Special Holes	37.6%	37.9%	52.2%	0.0%	50.7%	51.7%	45.1%
WVDP Trenches	48.4%	55.1%	0.8%	0.0%	0.8%	0.8%	0.7%

Unlike the SDA, where waste was accepted and disposed from many different sources, all the waste in the NDA originated from the on-site reprocessing plant. Therefore, the NDA waste is much more homogeneous than the SDA waste. This is shown in Table III-1 as well as Exhibit III-1. With the exception of C-14, Table III-1 shows that the activity of the remaining four radionuclides is approximately evenly divided between the Deep Holes and the Special Holes. C-14 is primarily an activation product associated with the hulls and fuel assembly hardware from the reprocessing plant, which were disposed only in the Deep Holes.

The information from Table III-1 is depicted graphically in Exhibit III-1, which shows the percentage of each radionuclide activity in the Deep Holes and Special Holes as a function of the combined NDA hole and trench volume. The horizontal axis in Exhibit III-1 only extends to 50% because the Deep Holes and Special Holes compose only 50% of the NDA volume, whereas the vertical axis extends to 100% because the Deep Holes and Special Holes comprise >99% of the NDA activity.

Because exhumation methods are expected to differ, the Deep Holes and Special Holes have been grouped separately in Exhibit III-1. The vertical dashed line in Exhibit III-1 is set at approximately 13% of the NDA volume, which corresponds to the total volume of the Deep Holes. The portions of the curves to the left of the dashed line represent the distribution of activity of each radionuclide with volume within the Deep Holes. The upper curves represent those radionuclides that are contained exclusively in the Deep Holes, whereas the lower curves show that only about 50% of the activity of the majority of radionuclides is contained in the Deep Holes. The remaining 37% of the total NDA volume (to the right of the dashed line) corresponds to the volume of the Special Holes. The portion of each curve to the right of the dashed line shows the distribution of the activity of each radionuclide in the Special Holes with NDA volume. The ‘zero point’ for the curve for a given radionuclide in the Special Holes is the total activity of that radionuclide in the Deep Holes (i.e., the activity value at the dashed line) and the percent volume at the dashed line (~13%). Based on this interpretation, no radionuclide has more than about 50% of its total activity in the Special Holes.

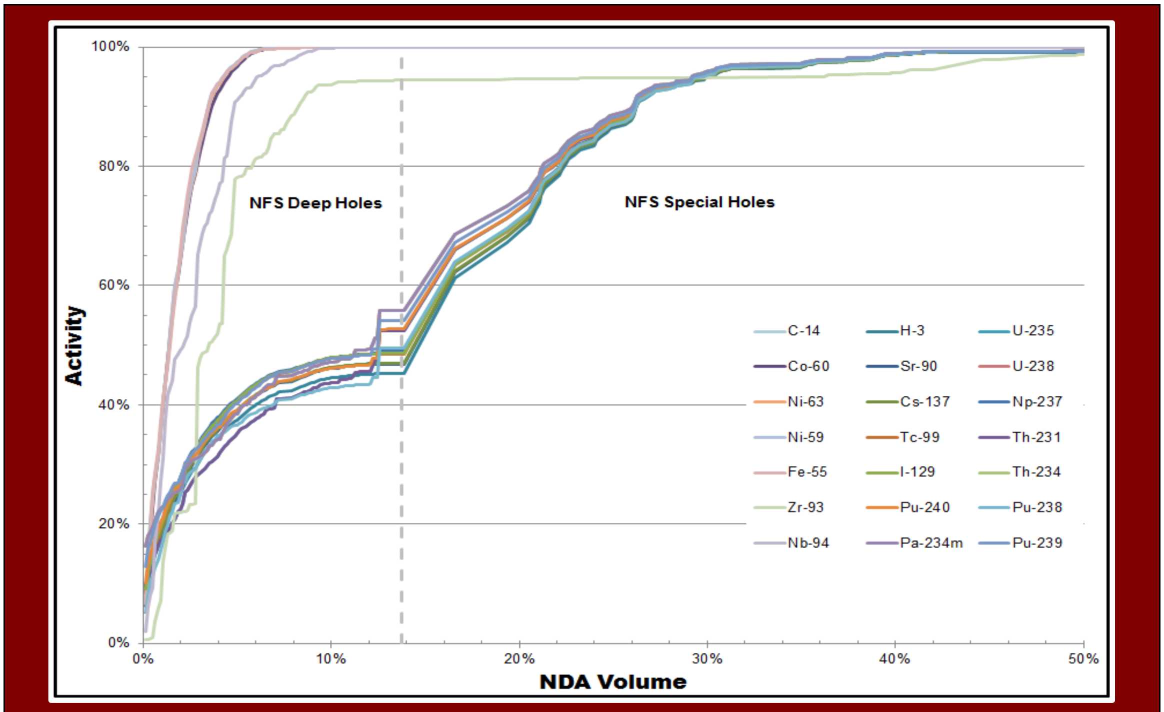


Exhibit III-1: NDA Waste Activity Versus Hole Volume

Although it is not possible to differentiate each of the plotted radionuclides in Exhibit III-1 (in fact some are directly on top of others), the point is that all the NDA radionuclides have nearly identical profiles. Thus, if you targeted one radionuclide (e.g., Cs-137) for removal, all the other radionuclides (e.g., Tc-99, I-129, Pu-238, etc.) would be removed to an almost identical extent, as shown in Table III-2. Again, this is the case due to all the NDA waste coming from a single source (i.e., the on-site reprocessing plant) and having nearly identical radionuclide profiles.

As Exhibit III-1 shows, the exceptions to this are the activation products, which are 100% contained within the Deep Holes. This is due to the activation products being associated with the spent fuel hulls and fuel assembly hardware, which were all disposed of in the Deep Holes. Once the hulls had been removed in the head end of the reprocessing plant, there were no more activation products to contaminate downstream reprocessing waste (i.e., spent solvent, filters, resins, failed equipment, etc.) disposed in the Special Holes. The curves for two radionuclides (Nb-94 and Zr-93) are shown to be positioned between the two clusters in Exhibit III-1. These two radionuclides are formed by both activation and fission, and if they became the target for selective exhumation the sequencing of holes would need to be treated differently.

Table III-2 is a tabular presentation of the information from Exhibit III-1. The tabulated values once again illustrate the point that the radionuclides listed all have essentially the same activity profile, and that targeting one radionuclide would, in essence, remove the same amount of activity across all the radionuclides listed. The values in the second column of Table III-2 show that to remove 50% of the NDA activity, 13.9% of the NDA volume would have to be removed. This volume is approximately the equivalent of the entire volume of the Deep Holes, which is consistent with the fact that about 50% of the total NDA activity is contained in the Deep Holes. Removal of more than 50% of the NDA activity would require removing a combination of Deep Holes and Special Holes, as neither group of holes contains more than 50% of the NDA activity.

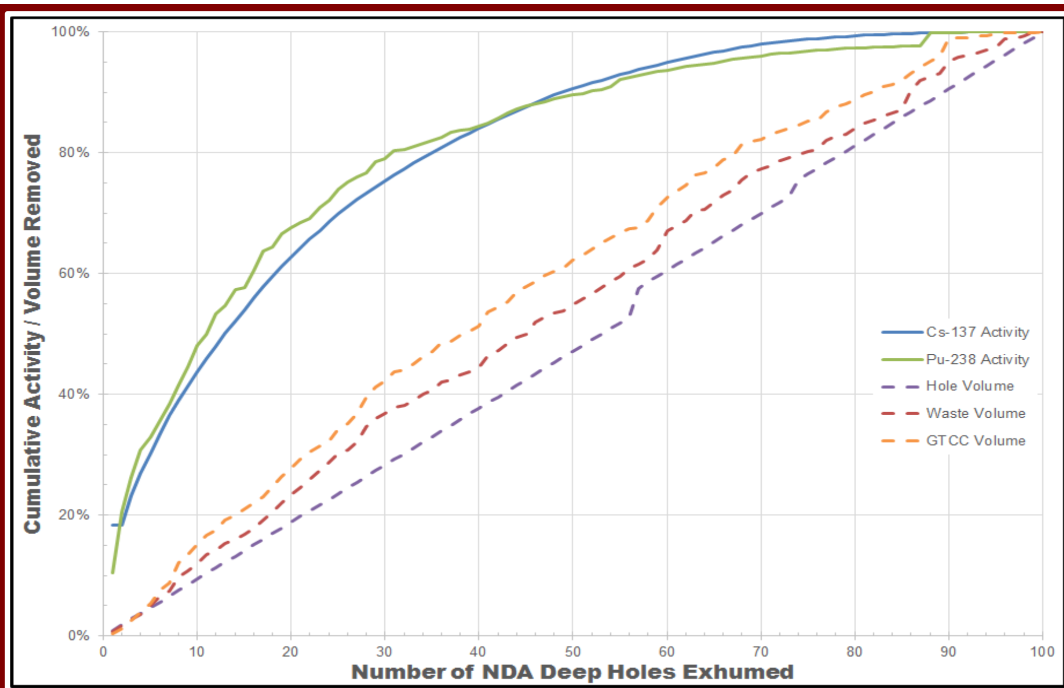
Table III-2: NDA Waste Activity Versus Hole Volume

Goal / Nuclide	50%	75%	80%	90%	95%
NDA Volume	**13.9%**	**21.1%**	**22.4%**	**26.3%**	**30.1%**
H-3	45.2%	73.9%	80.2%	90.2%	95.0%
Sr-90	46.8%	74.6%	80.7%	90.5%	95.1%
Cs-137	47.0%	74.6%	80.8%	90.5%	95.1%
Tc-99	48.5%	75.3%	81.3%	90.8%	95.2%
I-129	48.6%	75.4%	81.3%	90.8%	95.3%
Pa-233	49.1%	75.5%	81.4%	90.8%	95.3%
Np-237	49.1%	75.5%	81.4%	90.8%	95.3%
Pu-238	49.6%	75.5%	81.3%	90.5%	95.4%
Th-231	52.4%	76.9%	82.3%	91.0%	95.6%
U-235	52.4%	76.9%	82.3%	91.0%	95.6%
Pu-240	52.7%	77.0%	82.4%	91.1%	95.7%
Pu-239	54.2%	77.7%	82.9%	91.3%	95.8%
U-238	55.9%	78.5%	83.6%	91.7%	96.0%
Th-234	55.9%	78.5%	83.6%	91.7%	96.0%
Pa-234m	55.9%	78.5%	83.6%	91.7%	96.0%

Exhibit III-1 shows that while the radionuclide profiles are nearly identical for all NDA waste, the activity level in each Deep Hole or Special Hole is not. For both the NFS Deep Holes and the NFS Special Holes, Exhibit III-1 shows an initial steep rise in the activity that is removed compared to the waste volume removed, which then tends to level off at higher percentages of activity removal. These differences in activity are applied to selective removal scenarios in the next two sections, which separately evaluate the Deep Holes and the Special Holes for selective removal. The Special Holes are shallower than the Deep Holes and would seem to be more readily exhumed; however, there is a larger volume in the NFS Special Holes due to their larger footprint, which could lead to higher removal and disposal costs.

Exhumation Target: NDA Deep Holes

Exhibit III-2 plots the hole volume, waste volume, GTCC volume, and activity versus the number of Deep Holes. Cs-137 and Pu-238 activities are plotted to represent fission product and transuranic activities, respectively. Exhibit III-2 shows a nearly linear relationship between the hole and waste volumes and the number of Deep Holes, indicating that the hole configuration and volumes are nearly the same for all the Deep Holes. However, as discussed above, there is an initial step rise in both activities followed by a leveling off, indicating that some Deep Holes contain more radioactivity than others. Thus, the most efficient exhumation scenario would be to target the deep holes that contain the largest activity levels. (Note that removing the holes in order of decreasing activity is more efficient from an activity removal standpoint, but may not represent the most cost-effective removal scenario in the field. For example, if the holes with the largest activities are randomly scattered across the entire NFS Deep Hole area, then it may be more cost-effective to remove other holes in closer proximity to each other or to simply remove the entire area than try to target specific holes. This level of comparative analysis will be performed in later stages of the decision-making process.



Number of Holes	Hole Volume	Waste Volume	Cs-137 Activity	Pu-238 Activity	GTCC Volume
5	4.7%	5.0%	30.2%	32.9%	5.4%
15	14.1%	16.9%	54.0%	57.7%	21.0%
25	23.6%	30.3%	69.9%	74.0%	34.4%
50	47.1%	54.7%	90.6%	89.6%	62.2%
75	76.4%	80.2%	98.8%	96.9%	85.2%
99	100.0%	100.0%	100.0%	100.0%	100.0%

Exhibit III-2: NDA Deep Hole Selective Exhumation

Table III-3 contains a listing of the 25 Deep Holes and 25 Special Holes that contain the largest activities. As shown, exhuming the Top 5 most radioactive Deep Holes would remove about 30% to 33% of the radioactivity, while removing less than 5% of the volume (removal efficiency of about 6 to 1). Exhuming the Top 15 most radioactive Deep Holes would remove about 54% to 58% of the radioactivity, while removing about 14% of the volume, for a removal efficiency of about 4 to 1. Finally, exhuming the Top 25 most radioactive Deep Holes would remove about 70% to 75% of the radioactivity, while removing less than 25% of the volume, for a removal efficiency of about 3 to 1.

Table III-3: Exhumation of Top 25 Deep Holes and Special Holes

Rank	Deep Holes				Special Holes			
	Number	Cs-137	Pu-238	Volume	Number	Cs-137	Pu-238	Volume
1	48	18.4%	10.5%	1.0%	SH-99	29.1%	29.5%	7.2%
2	2-1	18.4%	20.6%	1.9%	SH-105	40.2%	40.8%	14.5%
3	6-2	23.3%	26.2%	2.9%	SH-138	46.1%	46.8%	17.7%
4	50	26.9%	30.8%	3.8%	SH-89	49.8%	50.5%	18.4%
5	7-1	30.2%	32.9%	4.7%	SH-123	52.2%	52.9%	19.1%
6	6-1	33.5%	35.6%	5.7%	SH-56	54.4%	55.2%	19.3%
7	9-2	36.6%	38.3%	6.7%	SH-90	56.6%	57.4%	19.7%
8	56	39.1%	41.6%	7.6%	SH-134	58.7%	59.5%	20.8%
9	63	41.4%	44.6%	8.6%	SH-136	60.6%	61.5%	21.9%
10	55	43.8%	48.1%	9.5%	SH-125	62.2%	63.1%	22.2%
11	81	45.9%	50.0%	10.5%	SH-60	63.8%	63.6%	22.4%
12	88	48.0%	53.3%	11.4%	SH-91	65.4%	65.2%	22.9%
13	7-2	50.1%	54.6%	12.4%	SH-113	67.0%	66.8%	23.4%
14	49	52.1%	57.3%	13.3%	SH-137	68.6%	68.4%	24.2%
15	42	54.0%	57.7%	14.1%	SH-2	70.1%	69.8%	26.1%
16	54	55.9%	60.6%	15.2%	SH-132	71.5%	71.3%	26.9%
17	62	57.8%	63.8%	16.2%	SH-79	72.9%	72.6%	29.1%
18	1-4	59.6%	64.5%	17.1%	SH-102	74.2%	73.9%	29.4%
19	82	61.2%	66.5%	18.1%	SH-126	75.5%	75.3%	30.2%
20	8-2	62.7%	67.6%	19.0%	SH-122	76.8%	76.6%	31.0%
21	7-3	64.2%	68.5%	20.0%	SH-117	78.1%	77.9%	31.4%
22	71	65.7%	69.2%	20.9%	SH-87	79.3%	79.1%	32.2%
23	84	67.1%	71.0%	21.9%	SH-88	80.5%	80.3%	32.5%
24	80	68.5%	72.2%	22.8%	SH-27	81.7%	81.5%	32.8%
25	51	69.9%	74.0%	23.6%	SH-58	82.9%	82.7%	32.9%

Exhibit III-2 can be used to determine the volume to be exhumed to remove an even larger percentage of the radioactivity. For example, exhuming 50 Deep Holes would remove about 90% activity and require removal of about 47% of the hole volume (removal efficiency of approximately 2 to 1). As expected, the removal efficiency decreases as the holes with lesser activity are progressively removed.

Exhibit III-3 is a schematic of the NDA Deep Hole area, showing the location of each hole. Using the ranking from, Exhibit III-3 shows the five Deep Holes with the largest activity outlined in red, while the next ten Deep Holes are outlined in deep purple, and the holes with the 16th through 25th-ranked activity levels are outlined in orange. The prioritized holes are shown to be spread throughout the NDA Deep Hole area, which raises the aforementioned question of what combination of holes would provide the optimum tradeoff of activity removed versus operational efficiency and cost. Again, this question is beyond the scope of this study and will be addressed in the final development of alternatives in the SEIS.

The locations shown in Exhibit III-3 are approximate, as they are "based on paced off estimates" (WVNS 1993). The actual locations of SH-10 and SH-11 were found to be shifted 3 feet from the map locations during a 1987 tank removal project (DOE 1987). Also, the NDA database identifies Deep Hole 2-1, but not Deep Hole 2-2, while WVNS (1993) identifies Deep Hole 2-2, but not Deep Hole 2-1. In Exhibit III-3, Deep Hole 2-2 is identified as a "Top 5" activity hole based on the Table III-3 activity associated with Deep Hole 2-1.

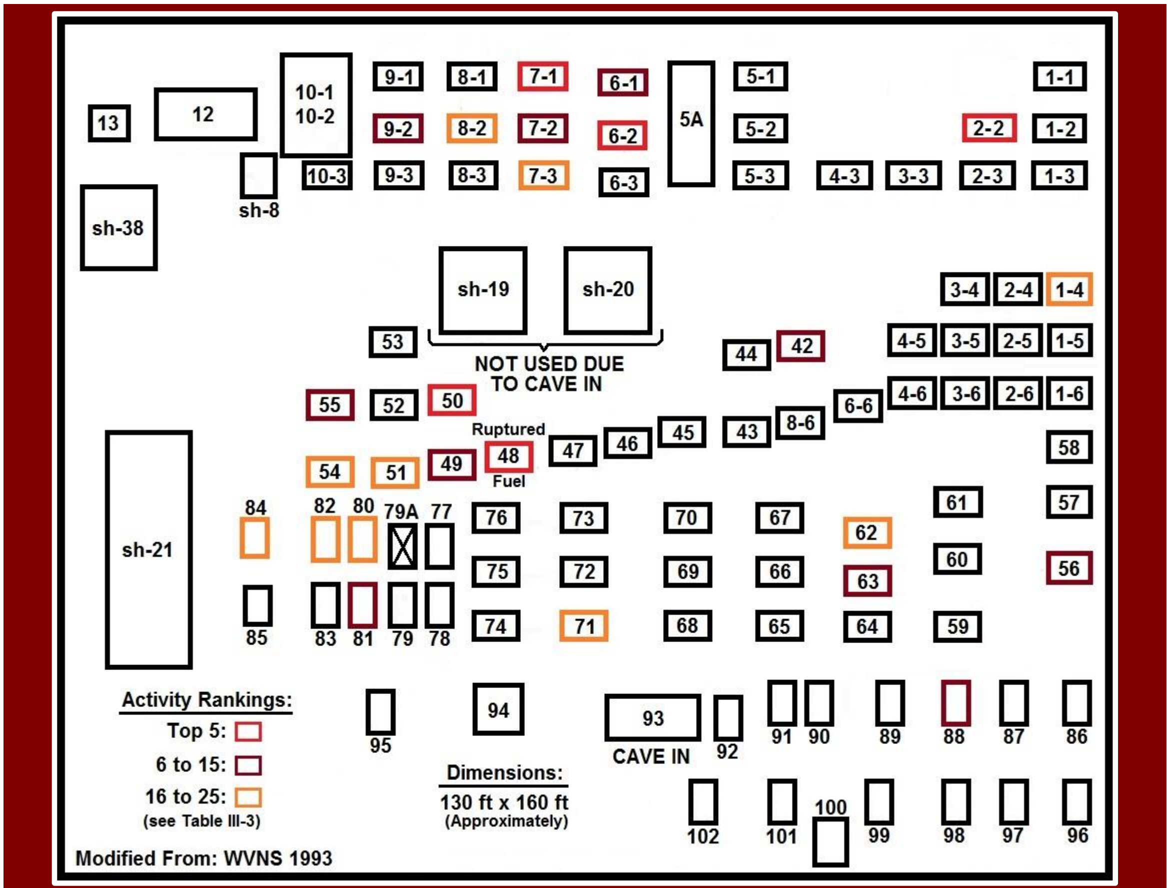


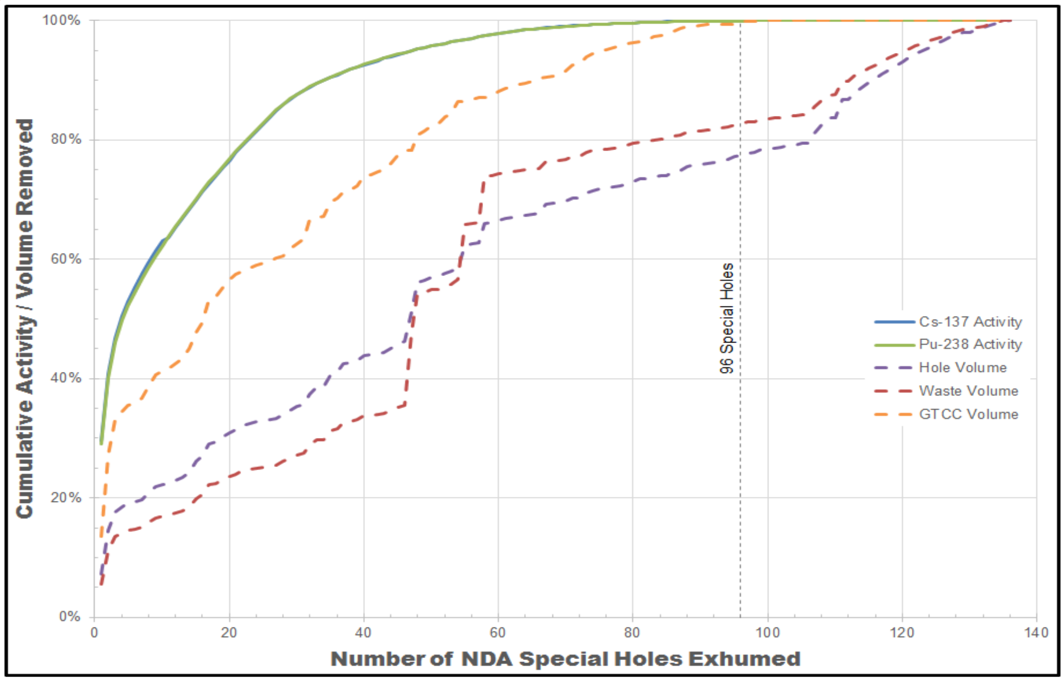
Exhibit III-3: Schematic: NDA Deep Hole Selective Exhumation

Exhumation Target: NDA Special Holes

The NDA database contains information for 136 Special Holes of various lengths and widths, but only reports the depth of eight Special Holes. The average ratio of hole volume to waste volume from these eight Special Holes was used to estimate the depth and volume of the remaining 128 Special Holes.

Exhibit III-4 plots the hole volume, waste volume, GTCC volume, and activity versus the number of Special Holes. As in Exhibit III-2, Cs-137 and Pu-238 activities are plotted to represent fission product and transuranic activities, respectively. Exhibit III-4 shows some non-linearity in the relationship between the hole and waste volumes and the number of Special Holes exhumed, indicating that the volumes of the Special Holes differ. From an activity standpoint, there is an initial step rise in both the Cs-137 and Pu-238 activities followed by a leveling off, indicating that some Special Holes contain more radioactivity than others. Exhibit III-4 also shows that over 99.9% of the activity would be removed by exhuming the first 96 Special Holes, while the last 40 Special Holes contain less than 0.1% of the activity. As a result, 99.95% of the activity can be removed by exhuming about 77.5% of the Special Hole volume.

Exhibit III-5 is a schematic of the NDA, with the Top 10 activity containing Special Holes shown in red, and the top 11 to 25 activity containing Special Holes shown in orange. Exhibit III-5 shows that eight of the Top 10 and 18 of the Top 25 activity containing Special Holes are located on the west side of the NDA.



Number of Holes	Hole Volume	Waste Volume	Cs-137 Activity	Pu-238 Activity	GTCC Volume
3	17.7%	13.6%	46.8%	46.1%	33.1%
10	22.2%	16.9%	63.1%	62.2%	41.4%
25	32.9%	25.1%	82.7%	82.9%	59.4%
50	56.9%	54.8%	95.7%	95.7%	82.4%
75	71.8%	78.4%	99.4%	99.3%	94.9%
96	77.5%	82.7%	99.9%	99.9%	99.9%
136	100.0%	100.0%	100.0%	100.0%	100.0%

Exhibit III-4: NDA Special Hole Selective Exhumation

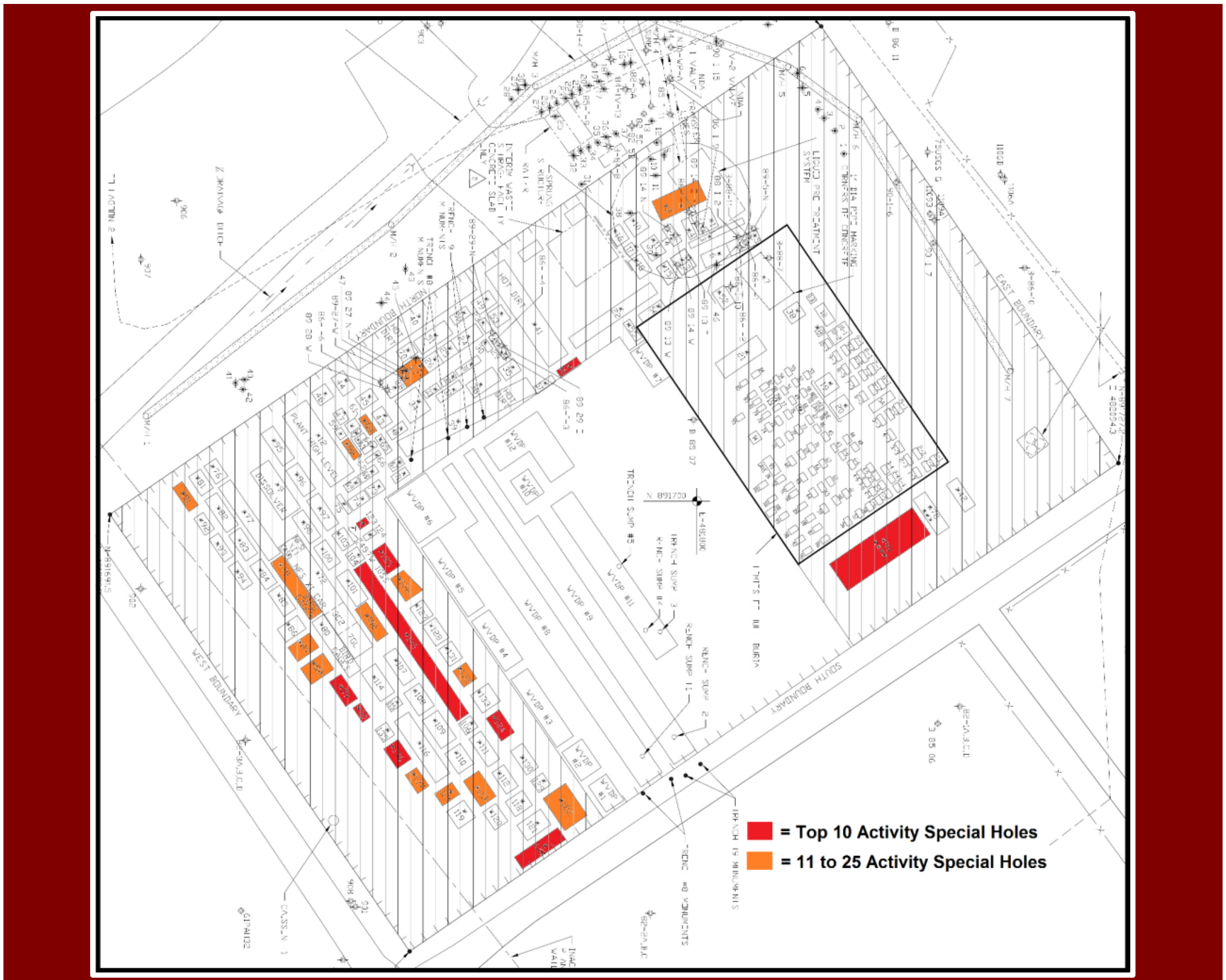


Exhibit III-5: Schematic: NDA Special Hole Selective Exhumation

2. Greater Than Class C Waste

URS (2000), Table S-1 indicates that about 99.6% of the NDA total activity is associated with GTCC waste. Although URS (2000) does not present a hole-by-hole breakdown of GTCC waste, the information is provided in supporting Excel files provided by Dr. Wild. This breakdown shows that 97 of the 99 Deep Holes and 94 of the 96 Special Holes contain GTCC waste and greater than 99.9% of the NDA activity. Thus, targeting GTCC waste for removal would not result in any substantial benefit when compared to targeting activity. Additionally, in order to remove all the GTCC waste, essentially all the waste would need to be removed and would be equivalent to the complete removal scenario.

A partial removal scenario targeting GTCC waste could result in leaving behind holes that contain a large portion of the NDA activity. For example, the two Deep Holes with the largest activities, Deep Holes 48 (a spent fuel element) and 2-1 (TRU containing sample bottles), would be exhumed only after 90% and 97% of the other Deep Holes had been exhumed if only targeting GTCC waste.

Unlike the Deep Holes, the three Special Holes with the largest activities, SH-105 (filter media, O2 sludge, debris), SH-99 (failed or discarded equipment), and SH-138 (FRS resin, O2 sludge, WTF filter, etc.), also have the largest amounts of GTCC waste. This is shown in Exhibit III-4 in the initial step increase in the GTCC volume removed, which shows that the first three holes exhumed remove about one-third of the Special Hole GTCC volume and about 46% of the Special Hole activity.

3. Potential Erosion Areas

Like the SDA, the NDA is located in an area of the site referred to as the South Plateau. Erdman Brook is located along the northern side of the South Plateau, as shown in Exhibit II-11. There is concern that at some future time the Erdman Brook gully will intersect the northernmost NDA Special Holes and expose the waste. The evaluation of if or when the Erdman Brook gully will intersect the Special Holes is being performed by the Erosion Work Group. This work is not yet complete, so for purposes of this study the 78 Special Holes along the northern portion of the NDA, which is commonly believed to be the area most prone to erosion, are evaluated in this section. The orange box in Exhibit III-6 shows the area of the NDA containing the 78 Special Holes that would be exhumed under this scenario.

With reference to Table III-3, one of the Top 10 Special Holes with the highest activity and six of the Top 25 Special Holes are contained within the group of 78 Special Holes to be exhumed under the erosion mitigation scenario. The 78 Special Holes represent about 57% of the 136 NDA Special Holes and contain about 52% of the Special Hole waste volume, but only 21% of the Special Hole activity. Nineteen of the 78 Special Holes are among the group of 40 Special Holes that contribute less than 0.1% to the total Special Hole activity (see the Exhibit III-4 discussion, above). If these very low activity Special Holes are not exhumed under this scenario, then the remaining 59 Special Holes that would be exhumed represent about 43% of the 136 NDA Special Holes, and contain about 48% of the Special Hole waste volume and still only about 21% of the Special Hole activity. As indicated by these numbers, the removal efficiency for the Special Holes potentially subject to erosion is very low, i.e., less than 0.5 to 1.

Included in the 78 Special Holes to be exhumed under this scenario are SH-10 and SH-11. Eight 1,000 gallon tanks that were leaking radioactively contaminated kerosene were removed from these two Special Holes in 1987. URS (2000), Section 6.4.3 briefly describes the 1987 exhumation effort, while DOE (1987) gives a detailed description of the effort and results.

It should also be noted that WVNS (1993) shows SH-23 and SH-33 on the north side of the NDA. However, the NDA database has no entries for either SH-23 or SH-33; therefore, they were not included in the URS (2000) NDA inventory estimate. If SH-23 and SH-33 are on the north side of the NDA, they would also be subject to erosion potential exhumation.

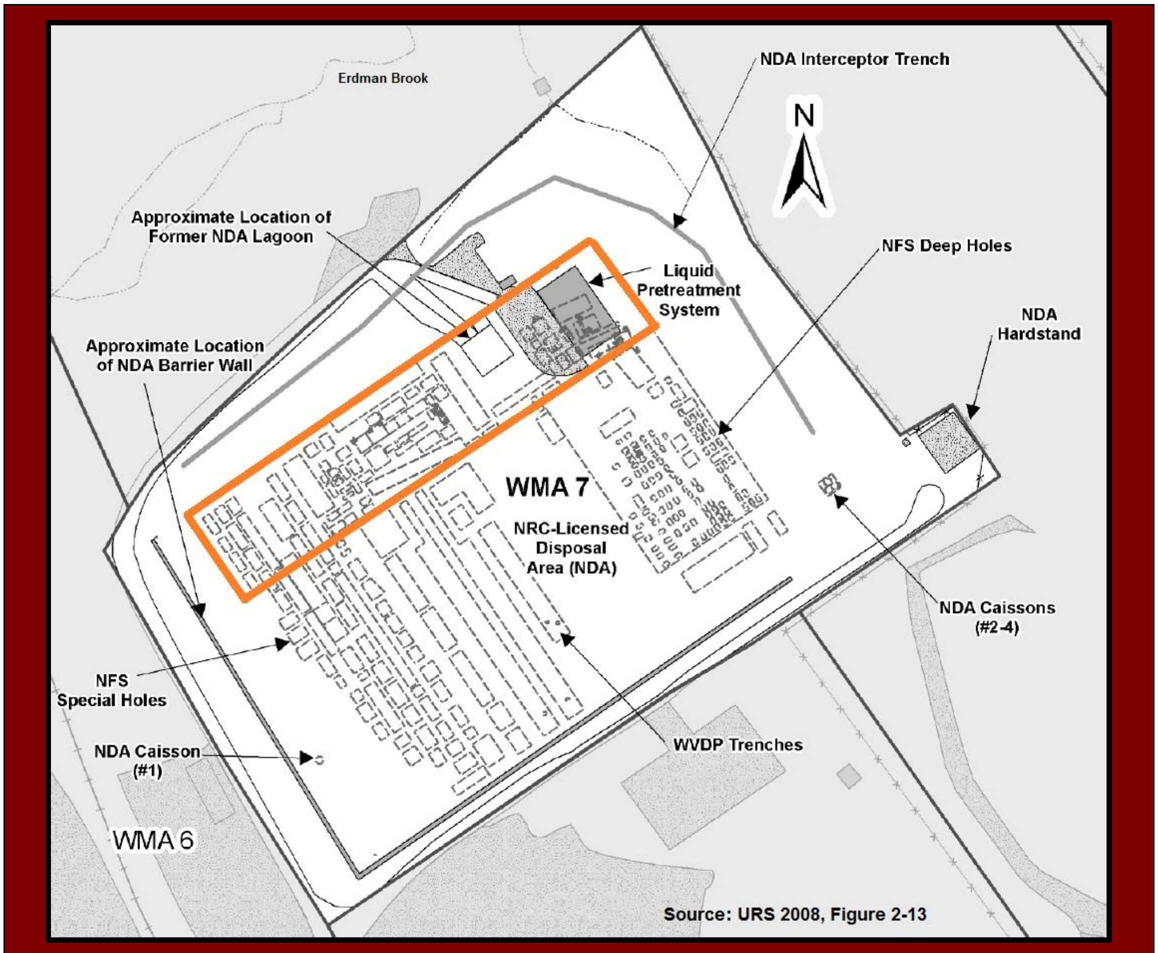


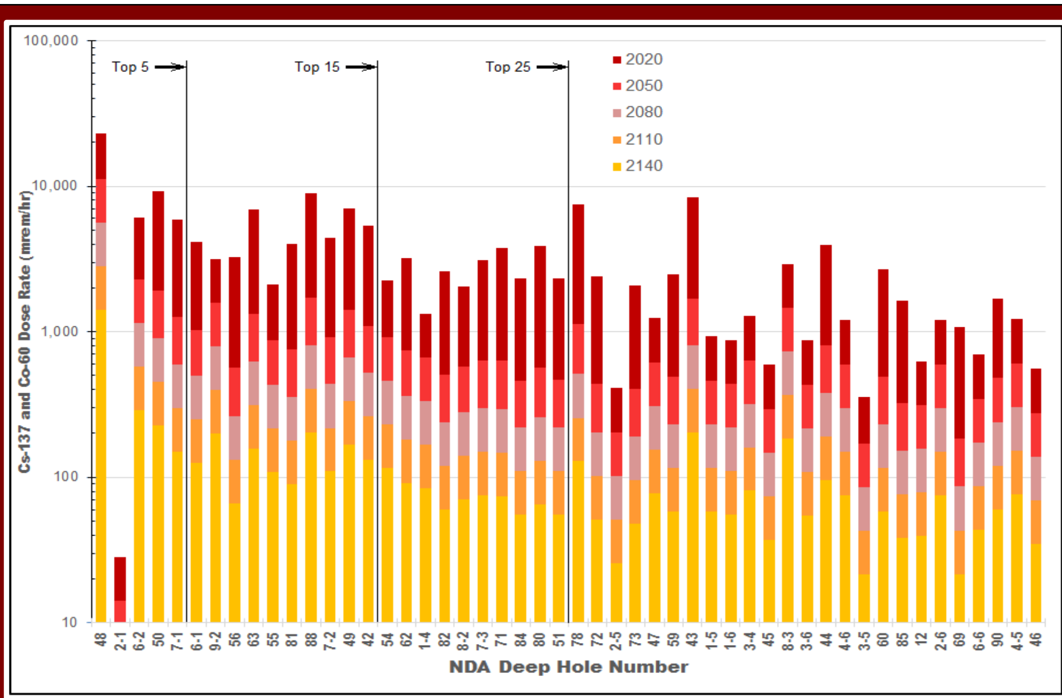
Exhibit III-6: Erosion Prone NDA Special Holes

B. Exhumed NDA Waste Dose Rates

Using the same normalized dose factors that were described and used in Section II.C, Exhibit III-7 and Exhibit III-8 present the calculated dose rates from the NDA Deep Holes and Special Holes, respectively.

Exhibit III-7 shows that the dose rate for 24 of the Top 25 activity Deep Holes is greater than 25 mrem/hr until the year 2050, which is more than an order of magnitude greater than the dose rate goal of 2.5 mrem/hr (see the discussion in Section II.C). At 2140 the dose rate from 24 of the Top 25 Deep Holes is greater than the 2.5 mrem/hr dose rate goal, implying that some form of direct dose radiation protection would be required even after 120 years into the future. When all 99 of the NDA Deep Holes are looked at, Exhibit III-7 shows that 93, 87, 82, 72, and 58 Deep Holes have dose rates more than an order of magnitude above the goal at 2020, 2050, 2080, 2110, and 2140, respectively. At 2140, the dose rate from 88 of the Deep Holes (62%) is still greater than the 2.5 mrem/hr dose rate goal.

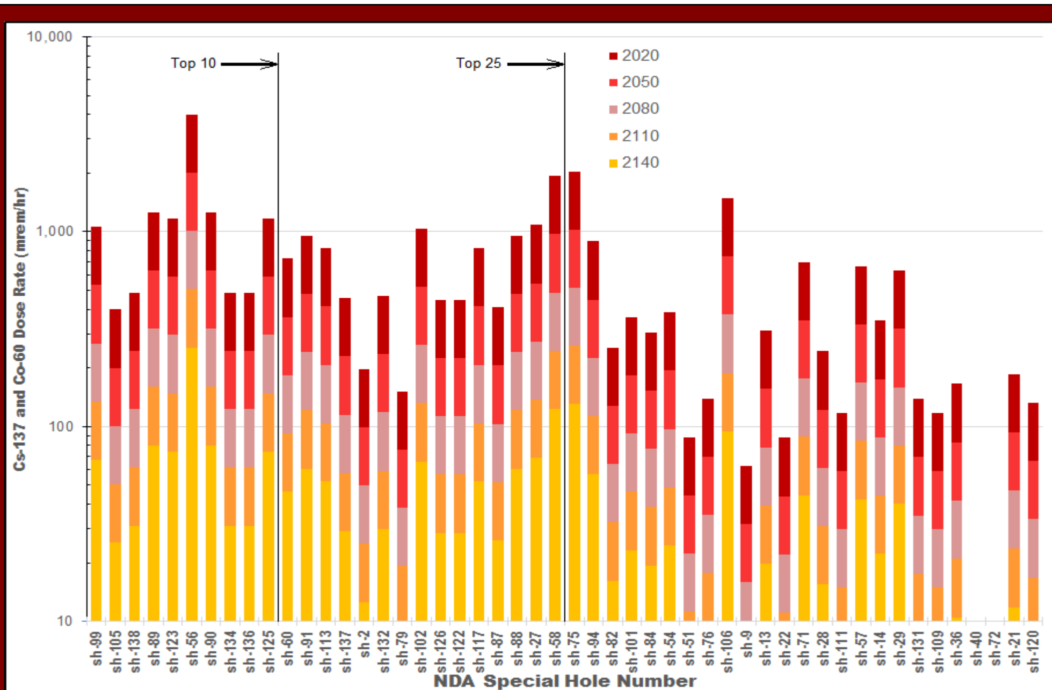
With reference to Exhibit III-8, the NDA Special Hole dose rates are significantly lower than the Deep Hole dose rates. Nevertheless, the dose rate for all Top 25 activity Special Holes is greater than the 2.5 mrem/hr goal until the year 2110, at which time only one of the Top 25 Special Holes falls below that level. Exhibit III-8 also shows that there are a significant number of Special Holes with dose rates below 2.5 mrem/hr (50 at 2020 increasing to 61 at 2110). Unfortunately, most of these Special Holes do not contain significant amounts of activity (including the 40 Special Holes that contain <0.01% of the activity), so their exhumation would not have a significant effect on the amount of residual radioactivity.



Deep Holes	Dose Range (mrem/hr)	Deep Hole within Dose Range				
		2020	2050	2080	2110	2140
Top 25	>250	24	24	21	10	2
	25 to 250	1	0	3	14	22
	2.5 to 25	0	1	1	1	0
	0.25 to 2.5	0	0	0	0	1
	<0.25	0	0	0	0	0
All 99	>250	71	49	31	13	2
	25 to 250	22	38	51	59	56
	2.5 to 25	5	9	14	22	30
	0.25 to 2.5	0	2	2	4	9
	<0.25	1	1	1	1	2

All dose rates were calculated at 1 foot from the source.

Exhibit III-7: NDA Deep Hole Exhumed Waste Dose Rates



Special Holes	Dose Range (mrem/hr)	Special Hole within Dose Range				
		2020	2050	2080	2110	2140
Top 25	>250	24	15	10	2	1
	25 to 250	1	10	15	22	22
	2.5 to 25	0	0	0	1	2
	0.25 to 2.5	0	0	0	0	0
	<0.25	0	0	0	0	0
All 136	>250	42	21	11	2	1
	25 to 250	40	53	53	45	29
	2.5 to 25	22	23	29	39	45
	0.25 to 2.5	25	9	13	18	26
	<0.25	7	30	30	32	35

All dose rates were calculated at 1 foot from the source.

Exhibit III-8: NDA Special Hole Exhumed Waste Dose Rates

The last paragraph of Section II.C discusses some limitations on the applicability of the normalized dose rates. These same limitations also apply to the Exhibit III-7 and Exhibit III-8 dose rates. The container type is of particular concern for the NDA, in which case most of the waste was not disposed in 55-gallon drums. Table III-4, which was developed from information provided in the NDA database, shows that much of the NDA Deep Hole waste was disposed in 30-gallon drums, whereas 150 ft^3 boxes were used for much of the Special Hole waste.

Table III-4: NDA Disposal Container Types

Container Description	URS 2000 ID	Deep Holes		Special Holes	
		Waste (ft^3)	Percentage	Waste (ft^3)	Percentage
55-gallon drum	D02	1,338	5.1%	2,756	2.0%
30-gallon drum	D01	11,745	45.2%	537	0.4%
1,000-gallon Tank	D07	540	2.1%	4,315	3.2%
1,100-gallon Tank	D08	0	0.0%	6,450	4.7%
'bird cage'	D03	456	1.8%	2,058	1.5%
Other Drums/Tanks	Various	107	0.4%	1,204	0.9%
55-gallon box	B06	3,342	12.9%	2,690	2.0%
15 ft^3 wooden box	B10	3,150	12.1%	555	0.4%
150 ft^3 box	B21	0	0.0%	39,750	29.1%
Other Boxes	Various	5,317	20.5%	21,126	15.5%
Not containerized, or container not identified	Not Applicable	0	0.0%	55,009	40.3%
Total		25,994	100.0%	136,451	100.0%

Table III-4 also shows that the Special Holes contain a large volume of waste for which the NDA database does not identify the type of disposal container. This includes nine of the Top 10 activity containing Special Holes and 20 of the Top 25, including the two holes with the largest activities (SH-99 [failed or discarded equipment] and SH-105 [filter media, O2 sludge, and debris]).

In order to show the effect of disposal container type on the normalized dose rate, Table III-5 presents the normalized dose rates for some commonly used disposal containers. The Table III-5 results show that the smaller 30-gallon drum has slightly lower dose rates than the assumed 55-gallon drum, while the larger containers have higher to significantly higher dose rates.

Table III-5: Container Type Dose Rates Multipliers

Container Type	Dose Rate* Multiplier	
	Co-60	Cs-137
30-gallon Drum	0.73	0.74
55-gallon Drum	1.00	1.00
150 ft^3 Box	2.82	2.77
1,100-gallon Tank	3.50	3.37
Excavator: 0.6 ft^3 Bucket	0.33	0.36
Excavator: 3.25 ft^3 Bucket	0.88	0.91
Excavator: 2.36 yd^3 Bucket	2.48	2.45

* All dose rates calculated at 1 foot.

It is possible that the containers have corroded during the time that they have been buried, making their original packaging somewhat immaterial to the calculation of dose rates. In this case, the analysis was extended to the calculation of dose rates under the assumption that the waste would be exhumed using an excavator bucket. According to the Caterpillar website (Cat 2017), excavator buckets can range in size from 0.6 ft^3 to 2.36 yd^3. Using a MicroShield model of an excavator bucket (Exhibit III-9), the normalized dose rates to an individual standing directly in front and 1 foot away from the center of the excavator bucket have been calculated. The bottom three rows of Table III-5 provide dose rates from various sized excavator buckets. Compared to the dose rate from a 55-gallon drum, the excavator bucket dose rates range from lower, to about the same, to much higher, depending on the size of the bucket.

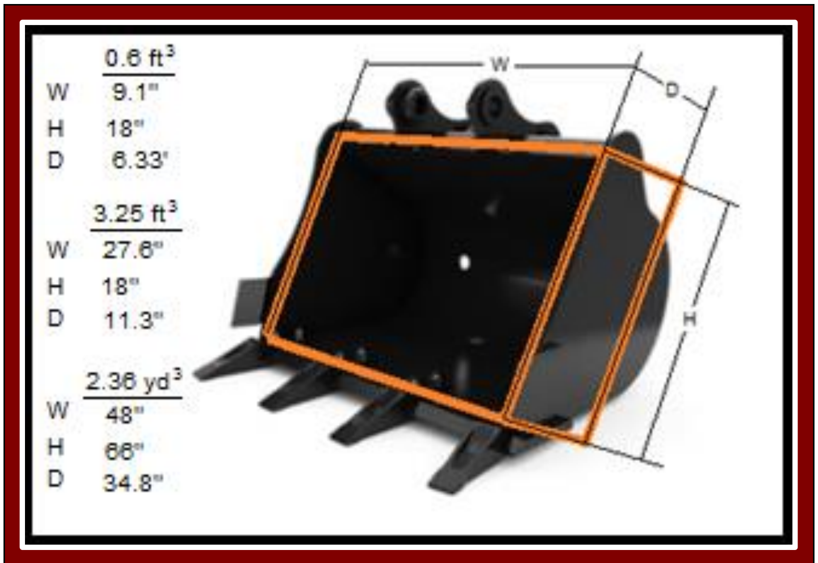


Exhibit III-9: MicroShield Model of Excavator Bucket

In conclusion, the dose rates presented in this section provide a rough first estimate of what to expect during the exhumation of the NDA, and are believed to be sufficient to scope out the types of direct dose radiation protection measures that would be required. However, it is recognized that much more refined dose rate calculations would be required prior to the initiation of any actual exhumation. It is envisioned that those calculations would be hole-specific, taking into account the total activity of each hole (not just Cs-137 and Co-60), the types of container within the hole, and the exhumation method being proposed.

IV. Summary of Results

This Technical Memorandum has been prepared as a response to the following question 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 1:*** Can the long-lived inventory in the SDA, NDA, and WTF be somehow selectively removed to reduce the time that these facilities will pose a hazard? If so, at what cost?

The following sections provide a summary of the results for the SDA and NDA selective exhumation analyses, including an estimate of the comparative removal efficiency of the selective exhumation scenarios. For this analysis, "removal efficiency" has been defined as the amount of activity removed versus the volume exhumed, with cost assumed to be directly related to volume exhumed (as discussed in Section I.A). For the reasons described in Section I.A, the WTF was not included in the Task 1.3 analysis.

A. State Licensed Disposal Area

For the SDA three categories of exhumation scenarios were analyzed: 1) exhumation of the 'long-lived' radionuclides (i.e., 10CFR 61, Table 2 with some exceptions); 2) exhumation of GTCC waste; and 3) exhumation of the waste disposal areas commonly believed to be most prone to erosion or slope failure. A trench by trench exhumation scenario was also analyzed. Each scenario was defined by an exhumation target (e.g., radiological activity) and an exhumation standard (e.g., 100% of GTCC waste, 75% of all I-129 activity, 90% of transuranic activity, etc.). Under a given selective exhumation scenario, exhumation was assumed to occur first in the 50-foot trench segment with the greatest amount of the target, then in the 50-foot segment with the next highest amount of the target, and so on until the exhumation standard was met. For each selective exhumation scenario, plots of the percentage of target removed versus the percentage of waste removed were presented and discussed in detail in Section II.B.

Below is a summary of the principal results of the SDA selective exhumation analysis:

1) Removal of the long-lived fission products (e.g., I-129, Tc-99, and C-14) would require exhumation of primarily Trench 4, followed by 50-foot segments from Trench 9, and then certain segments from Trenches 5, 2, and 3.
2) Removal of the long-lived fission products is initially quite cost effective, e.g., 50% of the I-129 activity can be removed by exhuming only 5% of the SDA volume—a 10 to 1 removal efficiency. As more long-lived fission products are removed the efficiency decreases, e.g., exhumation of 28% of the SDA volume is required to remove 90% of the I-129 activity—a 3.2 to 1 removal efficiency.
3) Long-lived fission products are generally located in trenches containing Cs-137; therefore, while a complementary removal of high-activity Cs-137 would be realized, removal of long-lived fission products would generally require either additional dose radiation protection measures or delaying exhumation to allow for decay of the short-lived Cs-137.
4) Removal of transuranic (TRU) waste would require exhumation of certain 50-foot segments primarily from Trench 10, followed by segments of Trenches 11, 8, and 9.

5) Removal of TRU is initially quite cost effective, e.g., 50% of the TRU activity can be removed by exhuming 2.8% of the SDA volume—an 18 to 1 removal efficiency. As more long-lived TRU waste is removed, the efficiency decreases only slightly, e.g., 90% of the TRU activity can be achieved by exhuming only 7.1% of the SDA volume—still almost a 13 to 1 removal efficiency.

6) The direct dose rates for the trench segments associated with TRU exhumation are generally less than 2.5 mrem/hr; therefore, less robust measures to protect workers from radiation exposure would be required if targeting TRU waste removal.

7) Uranium-234 is spread out over much of the SDA, including Trench 4 (south end), Trench 5, and Trenches 8 through 14. Removal of U-234 is initially quite cost effective, e.g., 50% of the U-234 activity can be removed by exhuming 7% of the SDA volume—a 7 to 1 removal efficiency. As more U-234 is removed the efficiency decreases, e.g., exhumation of 28% of the SDA volume is required to remove 90% of the U-234 activity—a 3.2 to 1 removal efficiency. Targeting the removal of U-234 would also effectively remove U-235 and U-238, but would not be an effective strategy for removing long-lived fission products or TRU.

8) The direct dose rates for many of the trench segments associated with U-234 exhumation are generally less than 2.5 mrem/hr. However, a few of the segments contain high dose rates (e.g., in Trenches 4 and 9) that would result in requiring additional dose radiation protection measures.

9) Targeting a combination of long-lived fission products, TRU, and U-234 would require exhumation of segments from Trench 4, and then from Trenches 5 and Trenches 8 through 11, and a few others.

10) Removal of a combination of radionuclides is initially quite cost effective, e.g., exhumation of 10% of the SDA volume would remove 60%, 53%, and 18% of the I-129, TRU, and U-234 activity, respectively. Exhumation of 50% of the SDA volume would remove 91%, 97%, and 88% of the I-129, TRU, and U-234 activity, respectively. Since these removal percentages are so high, exhumation of the SDA beyond 50% would not be cost-effective for these radionuclides. Of course, for any one radionuclide, these efficiencies are not as effective as targeting that radionuclide, e.g., when TRU is targeted, exhumation of only 7.1% of the SDA volume is required to remove 90% of the TRU activity.

11) Targeting GTCC waste would initially target the same trench segments as targeting TRU, which accounts for nearly 90% of the GTCC volume. Next, specific 50-foot segments from Trench 4 would be targeted, likely due to the presence of Cs-137, and finally Trench 6 holes would be targeted, due to the presence of Ni-63 and Nb-94.

12) No advantage has been identified for targeting the GTCC waste when compared to targeting either TRU or a combination of radionuclides.

13) Targeting the segments commonly believed to be most prone to erosion (i.e., the SDA's northern and eastern edges) would remove waste from the area within 50 feet of the edge of the SDA, thereby decreasing the potential and delaying the time when an erosion gully could/would expose the waste. However, this selective exhumation scenario is not effective at removing activity from the SDA, i.e., exhumation of 21% of the SDA volume to protect against erosion would remove only 30%, 16%, and 20% of the I-129, TRU, and U-234 activity, respectively.

14) For the trench by trench removal scenario, Trench 4 would be the most effective target and Trench 6 the least effective for the analyzed radionuclides. Removing six complete trenches under an optimum scheme would require exhuming 52% of the SDA volume and would remove 80%, 100%, and 79% of the I-129, TRU, and U-234 activity, respectively.

15) Lastly, if it is desired to only exhume 10% of the SDA (implying a 90% cost reduction), then the exhumation should occur in Trench 4 and several other 50-foot segments in other trenches. The specific non-Trench 4 segments would depend on the secondary goal of the exhumation (e.g., TRU removal, long-lived fission product removal, or erosion protection).

B. NRC Licensed Disposal Area

For the NDA, three categories of exhumation scenarios were evaluated: 1) exhumation of the 'long-lived' radionuclides (i.e., 10CFR 61, Table 2, with some exceptions); 2) exhumation of GTCC waste; and 3) exhumation of the waste disposal areas commonly believed to be most prone to erosion or slope failure.

Below is a summary of the principal results of the NDA selective exhumation analysis:

1) The NDA's Deep Holes and Special Holes each contain about 50% of the NDA's activity, while the WVDP trenches contain <1% of the activity. Thus, selectively exhuming the WVDP trenches would not be an effective means of reducing the NDA's activity, and was not further investigated.

2) Fission products and TRU radionuclides have very similar profiles across the NDA's Deep Holes and Special Holes. For example, the percentage amount of Cs-137 (representing fission products) in any one hole or group of holes is nearly the same as the percentage of Pu-238 (representing TRU) in the same hole or group of holes. As a result, targeting specific radionuclides for exhumation is not beneficial for the NDA, since the same holes would be targeted to remove a given percentage of Cs-137 as would be targeted to remove the same percentage of Pu-238 (or any other TRU or fission product).

3) Activation products are an exception to the condition reported in the previous paragraph. The activation products do not appear in the Special Holes, only in the Deep Holes. The Deep Holes contain fuel rod cladding and other fuel assembly hardware, which contain activation products generated in the upstream head end in the reprocessing plant, whereas the Special Holes contain waste from further downstream in the reprocessing plant, after the cladding and hardware had been removed. Within the Deep Holes only, the condition cited in the previous bullet would also apply to the activation products.

4) Because of differences in location and depth between the Deep Holes and Special Holes, which could result in a difference in exhumation approach and technologies, it makes sense to analyze the selective exhumation of the Deep Holes separate from the exhumation of the Special Holes.

5) Exhuming the Top 10, Top 25, and Top 50 most radioactive Deep Holes would remove about 45%, 75%, and 90% of the Deep Hole radioactivity, respectively, while removing approximately 10%, 25%, and 47% of the volume, respectively. For the Top 10 Deep Holes the activity removal to removal efficiency is 4.5 to 1; for the Top 25 the efficiency drops to 3 to 1; and for the Top 50 the efficiency is <2 to 1.

6) The dose rate for 24 of the Top 25 activity Deep Holes is greater than 25 mrem/hr until the year 2110. In the year 2140, the dose rate from 24 of the Top 24 Deep Holes remains

greater than the 2.5 mrem/hr dose rate goal, implying that some form of direct dose radiation protection would be required for waste removal from the Deep Holes regardless of when the work was performed.

7) When all 99 of the NDA Deep Holes are looked at, the dose rates would exceed 25 mrem/yr in 75 holes in 2020, 54 holes in 2050, 40 holes in 2080, 17 holes in 2110, and 3 holes in 2140. By 2140, the dose rate from 61 of the Deep Holes (62%) would still be greater than the 2.5 mrem/hr dose rate.

8) Exhuming the Top 10, Top 25, and Top 50 most radioactive Special Holes would remove about 63%, 82%, and 96% of the Special Hole radioactivity, respectively, while removing less than 22%, 33%, and 57% of the volume, respectively. For the Top 10 Special Holes, the activity removal to removal efficiency is 2.9 to 1; for the Top 25 the efficiency drops to 2.5 to 1; and for the Top 50 the efficiency is <2 to 1.

9) The dose rate for all Top 25 activity Special Holes is greater than 2.5 mrem/hr until the year 2110, at which time only one Special Hole falls below that level. There are a significant number of Special Holes with dose rates below 2.5 mrem/hr (50 holes in 2020, increasing to 100 holes in 2110). Unfortunately, most of these Special Holes do not contain a significant amount of activity. For example, the 40 Special Holes that have the least activity cumulatively contain <0.1% of the total activity of the Special Holes. From an activity reduction point of view, the exhumation of these 40 Special Holes would not have a significant effect of the amount of residual radioactivity if selectively removed.

10) For both the NDA Deep Holes and Special Holes, it may be more effective to target specific areas for removal, rather than specific holes. For example, most of the Special Holes with the highest activity are located on the western side of the NDA. Therefore, it may be more effective to exhume the entire western side of the NDA. Likewise, the Deep Holes with the highest activity are located throughout a 130 foot by 160 foot area. Therefore, it may be more effective to exhume the entire area than attempt to locate and exhume a series of specific Deep Holes.

11) For both the Deep Holes and Special Holes, targeting GTCC waste for removal would not result in any substantial benefit when compared to targeting activity removal. Essentially all the Deep Holes and Special Holes would need to be removed to remove all the GTCC waste, which would be classified as complete removal rather than a selective removal scenario. On the other hand, partial removal that targets GTCC waste would result in leaving behind holes that contain a large portion of the NDA activity.

12) Targeting the NDA holes that are commonly believed to be most prone to erosion (i.e., the NDA's northern edges) to prevent or delay the time when an erosion gully could/would expose the NDA waste would remove waste from 78 Special Holes. These 78 Special Holes represent about 57% of the 136 NDA Special Holes, but contain only about 21% of the Special Hole activity, resulting in a negative removal efficiency of about 1 to 2.7.

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