

**DETERMINATION OF REPORTABLE
RADIONUCLIDES FOR DWPF SLUDGE BATCH 4
(MACROBATCH 5)**

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May 2008

Environmental and Chemical Process Technology Research Programs
Savannah River National Laboratory
Aiken, SC 29808

Prepared for the U.S. Department of Energy Under Contract Number
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SAVANNAH RIVER NATIONAL LABORATORY

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EXECUTIVE SUMMARY

The Waste Acceptance Product Specifications (WAPS)¹ 1.2 require that “The Producer shall report the inventory of radionuclides (in Curies) that have half-lives longer than 10 years and that are, or will be, present in concentrations greater than 0.05 percent of the total inventory for each waste type indexed to the years 2015 and 3115”. As part of the strategy to meet WAPS 1.2, the Defense Waste Processing Facility (DWPF) will report for each waste type, all radionuclides (with half-lives greater than 10 years) that have concentrations greater than 0.01 percent of the total inventory from time of production through the 1100 year period from 2015 through 3115. The initial listing of radionuclides to be included is based on the design-basis glass as identified in the Waste Form Compliance Plan (WCP)² and Waste Form Qualification Report (WQR)³. However, it is required that this list be expanded if other radionuclides with half-lives greater than 10 years are identified that may meet the greater than 0.01% criterion for Curie content.

Specification 1.6 of the WAPS, International Atomic Energy Agency (IAEA) Safeguards Reporting for High Level Waste (HLW), requires that the ratio by weights of the following uranium and plutonium isotopes be reported: U-233, U-234, U-235, U-236, U-238, Pu-238, Pu-239, Pu-240, Pu-241, and Pu-242. Therefore, the complete set of reportable radionuclides must also include this set of U and Pu isotopes.

The DWPF is receiving radioactive sludge slurry from HLW Tank 40. The radioactive sludge slurry in Tank 40 is a blend of the previous contents of Tank 40 (Sludge Batch 3) and the sludge that was transferred to Tank 40 from Tank 51. The blend of sludge from Tank 51 and Tank 40 defines Sludge Batch 4 (also referred to as Macrobatch 5 (MB5)). This report develops the list of reportable radionuclides and associated activities and determines the radionuclide activities as a function of time. The DWPF will use this list and the activities as one of the inputs for the development of the Production Records that relate to the radionuclide inventory.

This work was initiated through Task Technical Request HLW/DWPF/TTR-2005-0034; Rev. 0 entitled *Sludge Batch 4 SRNL Shielded Cells Testing*⁴. Specifically, this report details results from performing, in part, Subtask 3 of the TTR and, in part, meets Deliverable 7 of the TTR. The work was performed following the Technical Task and Quality Assurance Plan (TTQAP), WSRC-RP-2006-00310, Rev. 1⁵ and Analytical Study Plan (ASP), WSRC-RP-2006-00458, Rev. 1⁶.

In order to determine the reportable radionuclides for Sludge Batch 4 (SB4) (Macro Batch 5 (MB5)), a list of radioisotopes that may meet the criteria as specified by the Department of Energy’s (DOE) WAPS was developed. All radioactive U-235 fission products and all radioactive activation products that could be in the SRS HLW were considered. In addition, all U and Pu isotopes

¹ Office of Environmental Management, *Waste Acceptance Product Specifications for Vitrified High-Level Waste Forms*, USDOE Document DOE/EM-0093, Rev. 2, December 1996.

² Washington Savannah River Company, *DWPF Waste Form Compliance Plan*, WSRC-IM-91-116-0, Rev. 8, Savannah River Site, March 2006.

³ Washington Savannah River Company, *DWPF Waste Form Qualification Report, Volume 4: Reporting the Radionuclide Inventory of the DWPF Product*, WSRC-IM-91-116-4, Rev. 3, Savannah River Site, 2006.

⁴ Davis, B. A., *Technical Task Request: Sludge Batch 4 SRNL Shielded Cells Testing*, HLW/DWPF/TTR-2005-0034, Rev. 0, Savannah River Site, January 2006.

⁵ Bannochie, C. J. and Pareizs, J. M., *Task Technical and Quality Assurance Plan: Qualification of DWPF Sludge Batch 4 (Macrobatch 5) in the SRNL Shielded Cells*, WSRC-RP-2006-00310, Rev. 1, Savannah River Site, October 2006.

⁶ Bannochie, C. J. and Pareizs, J. M., *Analytical Study Plan: Qualification of DWPF Sludge Batch 4 (Macrobatch 5) in the SRNL Shielded Cells*, WSRC-RP-2006-000458, Rev. 1, Savannah River Site, November 2006.

identified in WAPS 1.6 were included in the list. This list was then evaluated and some isotopes excluded from the projection calculations.

Based on measurements and analytical detection limits, twenty-nine radionuclides have been identified as reportable for DWPF SB4 (MB5) as specified by WAPS 1.2. The 29 reportable nuclides are:

Ni-59	Ni-63	Se-79	Sr-90	Zr-93	Nb-93m
Tc-99	Sn-126	Cs-137	Sm-151	U-233	U-234
Np-237	U-238	Pu-238	Pu-239	Pu-240	Am-241
Pu-241	Pu-242	Am-242m	Am-243	Cm-244	Cm-245
Cm-246	Cm-247	Bk-247	Cm-248	Cf-251	

The WCP and WQR require that all of radionuclides present in the Design Basis glass be considered as the initial set of reportable radionuclides. For SB4 (MB5), all of the radionuclides in the Design Basis glass are reportable except for three radionuclides: Pd-107, Cs-135, and Th-230. At no time through the calendar year 3115 did any of these three radionuclides contribute to more than 0.01% of the radioactivity on a Curie basis.

Two additional uranium isotopes (U-235 and -236) must be added to the list of reportable radionuclides in order to meet WAPS 1.6. All of the Pu isotopes and other U isotopes (U-233, -234, and -238) identified in WAPS 1.6 were already determined to be reportable according to WAPS 1.2. This brings the total number of reportable radionuclides for SB4 to thirty-one.

The radionuclide measurements made for SB4 (MB5) are the most extensive conducted to date. Some method development/refinement occurred during the conduct of these measurements, leading to lower detection limits and more accurate measurement of some isotopes than was previously possible. Continuous improvement in the analytical measurements will likely continue, and this in turn should lead to improved detection limit values for some radionuclides and actual measurements for still others.

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LIST OF ACRONYMS AND ABBREVIATIONS

AD	Analytical Development
ASP	Analytical Study Plan
DOE	Department of Energy
dpm	disintegrations per minute
DWPF	Defense Waste Processing Facility
g	gram
HLW	High Level Waste
ICP-AES	Inductively Coupled Plasma – Atomic Emission Spectroscopy
ICP-MS	Inductively Coupled Plasma – Mass Spectrometry
MB2	Macrobatch 2
MB3	Macrobatch 3
MB4	Macrobatch 4
MB5	Macrobatch 5
μCi	micro-Curies
PHA	Pulse Height Analysis
QA	Quality Assurance
SB1B	Sludge Batch 1B
SB2	Sludge Batch 2
SB3	Sludge Batch 3
SB4	Sludge Batch 4
SCO	SRNL Shielded Cells Operations
SpA	Specific Activity (Ci/g)
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SRTC	Savannah River Technology Center
$t_{1/2}$	half-life
TTQAP	Task Technical and Quality Assurance Plan
TTR	Task Technical Request
WAPS	Waste Acceptance Product Specifications
WCP	Waste Form Compliance Plan
wt%	Weight Percent
WQR	Waste Form Qualification Report

1.0 INTRODUCTION

1.1 Background

The Waste Acceptance Product Specifications (WAPS)¹ 1.2 require that “The Producer shall report the inventory of radionuclides (in Curies) that have half-lives longer than 10 years and that are, or will be, present in concentrations greater than 0.05 percent of the total inventory for each waste type indexed to the years 2015 and 3115.” As part of the strategy to meet WAPS 1.2, the Defense Waste Processing Facility (DWPF) will report for each waste type, all radionuclides (with half-lives greater than 10 years) that have concentrations greater than 0.01 percent of the total inventory from time of production through the 1100 year period from 2015 through 3115. The initial listing of radionuclides to be included is based on the design-basis glass as identified in the Waste Form Compliance Plan (WCP)² and Waste Form Qualification Reports (WQR)³. However, it is required that this list be expanded if other radionuclides with half-lives greater than 10 years are identified that may meet the greater than 0.01% criterion for Curie content.

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1.2 Radionuclides Identified For Consideration as Reportable

In order to determine the reportable radionuclides for Sludge Batch 4 (Macrobatches 5), a list of radioisotopes that may meet the criteria as specified by the Department of Energy’s (DOE) WAPS was developed. All radioactive U-235 fission products and all radioactive activation products that could be in the SRS HLW were considered. New to the list are three isotopes recently identified: Cd-113m, Ba-133, and Bk-247. In addition, all U and Pu isotopes identified in WAPS 1.6 have been included in this list.

Table 1-1 presents the list of radioisotopes identified for consideration as reportable. The radioisotopes that were deleted from the list and the arguments that support that decision are presented in Table 1-2.

Table 1-1. List of Radioisotopes Considered for Sludge Batch 4 (Macrobatch 5)

Radioisotope	Radioisotope	Radioisotope	Radioisotope
C-14 ^a	Sn-126 ^b	Ra-226 ^d	Pu-241 ^a
Ni-59 ^a	I-129 ^b	Ac-227 ^d	Am-241 ^a
Co-60 ^a	Ba-133 ^b	Th-229 ^d	Pu-242 ^a
Ni-63 ^a	Cs-135 ^b	Th-230 ^d	Am-242m ^a
Se-79 ^b	Cs-137 ^b	Pa-231 ^d	Am-243 ^a
Rb-87 ^b	La-138 ^b	Th-232 ^c	Cm-243 ^a
Sr-90 ^b	Ce-142 ^{b,c}	U-232 ^a	Cm-244 ^a
Zr-93 ^b	Nd-144 ^b	U-233 ^a	Cm-245 ^a
Nb-93m ^b	Pm-147 ^b	U-234 ^d	Cm-246 ^a
Nb-94 ^b	Sm-147 ^b	U-235 ^c	Cm-247 ^a
Zr-96 ^b	Sm-149 ^b	U-236 ^a	Bk-247 ^a
Tc-99 ^b	Nd-150 ^b	Np-236 ^a	Cm-248 ^a
Cd-113 ^{b,c}	Sm-151 ^b	Np-237 ^a	Cf-249 ^a
Pd-107 ^b	Eu-152 ^b	U-238 ^c	Cf-250 ^a
Cd-113m ^b	Eu-154 ^b	Pu-238 ^a	Cf-251 ^a
In-115 ^b	Bi-210m ^d	Pu-239 ^a	
Sn-121m ^b	Pb-210 ^d	Pu-240 ^a	

^a Activation product

^b Fission product

^c Naturally occurring radionuclide that resulted in the waste from processing at SRS

^d Decay product of an actinide isotope in SRS waste

Table 1-2. Radioisotopes Excluded for Determination of Reportable Radioisotopes for Sludge Batch 4 (Macrobatch 5)

Radioisotope	Radioisotope
C-14 ⁱ	Nd-144 ⁱⁱⁱ
Nb-94 ⁱⁱ	Nd-150 ⁱⁱⁱ
Zr-96 ⁱⁱⁱ	Sm-147 ⁱⁱⁱ
Cd-113 ⁱⁱⁱ	Sm-149 ⁱⁱⁱ
In-115 ⁱⁱⁱ	Eu-152 ⁱⁱ
La-138 ⁱⁱⁱ	Np-236 ^{iv}
Ce-142 ⁱⁱⁱ	U-232 ^v

ⁱ C-14 is volatilized during DWPF Chemical and Melt Cell processing and is not immobilized in the glass⁷.

ⁱⁱ “Nb-94 and Eu-152 are shielded isotopes: the isobaric fission product decay chain for these stops at a stable isotope before reaching these. They are therefore produced predominately by secondary processes and are present only in very small amounts. They have not been observed in the sludge slurry”⁸.

ⁱⁱⁱ Zr-96, Cd-113, In-115, La-138, Ce-142, Nd-144, Nd-150, Sm-147 and Sm-149 were deleted because their long half-lives (> 1.05E11 years) make their activities negligible at all times⁸.

^{iv} “No data was available for Np-236 but it is known to be made in only very small amounts in reactor irradiation. Np-236 is a minor product of fast neutron spallation. It was neglected”⁸.

^v “U-232 is present only in very small amounts and decays rapidly compared to other actinide isotopes that are much more abundant (it is primarily obtained as a contaminant at a few ppm from the reactor irradiation of Th-232)”⁸.

2.0 EXPERIMENTAL

The details for sample acquisition from Tank 40 – SB4, preparation of the digestions, and measurement of the elemental composition have been published separately⁹. The results for those radionuclides that required additional separation techniques that were not included in the referenced report have been included in this report. Details of the separation and detection methods are provided. All measurements and counting analyses were done by SRNL Analytical Development (AD).

2.1 Direct Methods

2.1.1 ICP-MS

Inductively coupled plasma – mass spectrometry (ICP-MS) was employed to analyze separate sub-samples of the aqua regia digestions of Tank 40 – SB4 dried solids described in a previous report⁹. Measurements were first converted to weight percents on a dried solids basis and then converted to activities using the specific activity of each isotope taken from References 10 and 17. The isotopes obtained from direct ICP-MS measurements included: Zr-93, Tc-99, Sm-151, Th-232, U-233, U-234, U-235, U-236, Np-237, U-238, Pu-239, Pu-240, and Pu-242.

2.1.2 Gamma Counting

Gamma Pulse Height Analysis (PHA) was performed on separate sub-samples of the peroxide fusion digestions of Tank 40 – SB4 dried solids described in a previous report⁹. Detectors were carefully calibrated with known standards. Since detection efficiencies for gamma-rays vary with energy, they were determined for these specific radionuclide energies during the calibration process. The counting geometry was established during calibration and carefully duplicated for these measurements. Samples were diluted as necessary to achieve accurate counting. The isotopes obtained from Gamma PHA counting included: Co-60, Cs-137, Eu-154, Eu-155, and Am-241.

2.1.3 Liquid Scintillation Counting

Liquid scintillation counting was performed on separate sub-samples of the peroxide fusion digestions of Tank 40 – SB4 dried solids described in a previous report⁹. The scintillation cocktail used for the analysis was Ultima Gold AB since it is specifically formulated for alpha-beta discrimination and is the best choice for samples dissolved in mineral acids. Measurements were performed on one of three Packard Instruments which automatically correct for quenching and many other interference problems commonly associated with liquid scintillation counting. This method was used to determine total Beta activity. Diluted aliquots of digested slurry were analyzed for 10 minutes. Diluted aliquots of digested slurry were also spiked with an alpha standard and analyzed for 10 minutes to measure and correct for any alpha/beta discrimination cross-talk issues.

2.2 Separation Methods

These analytical methods involved separation techniques that enabled radionuclides that were at low concentrations to be measured more accurately and to determine more reliable and lower detection limits for the radionuclides that had concentrations so low that they could not be detected. These techniques are now SRNL AD procedures and will only be summarized here. Aliquots of the peroxide fusions or the aqua regia dissolutions were analyzed along with blanks. In all cases, the activity in the blanks did not contribute any significant activity to the radionuclides being analyzed.

2.2.1 Ni-59/-63 Method

This separation is based on isolation of Ni from the dissolved sludge using a column containing dimethylglyoxime as an extractant that is specific for Ni. Each of the solutions resulting from the

sodium peroxide dissolutions of the four samples of dried sludge slurry was spiked with a stable Ni carrier to trace the Ni separation and was then passed through a column containing the above extractant. The absorbed Ni was then eluted from each column. The Ni-59 was measured in the eluted solutions by its characteristic X-rays and Ni-63 by its beta particles. Total Ni in each eluted solution was measured by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The radiochemical Ni analyses were corrected for the Ni carrier recoveries as measured by ICP-AES.

2.2.2 Se-79 Method

Four aliquots of wet sludge slurry were spiked with a known amount of stable Se as a carrier. The samples were digested with concentrated nitric acid. The Fe in the dissolutions was reduced to Fe (II) using ascorbic acid to ensure it would not interfere with subsequent decontamination steps designed to extract Y-90, the lanthanides and the actinides from the Se traced dissolutions. The dissolutions were then treated with resins (Bio-Rad AMP-1, Eichrom Sr, RE, and Actinide resins) to reduce levels of Sr-90, Cs-137, Y-90, the lanthanides and the actinides to levels low enough to allow for their removal from the Shielded Cells. The Se traced dissolutions were then further decontaminated with a Bio-Rad AMP-1, Eichrom Sr and RE resin treatment. The total Se was reduced to Se metal using titanium (III) chloride, hydroxylamine hydrochloride, and ascorbic acid. The precipitated Se metal was then washed repeatedly with deionized water and dilute nitric acid. The Se metal was then dissolved with concentrated HBr, and the resulting SeBr_4 was extracted by solvent-solvent extraction using a tri-butyl phosphate/n-paraffin solvent extraction system. The Se was back extracted from the solvent. Aliquots of the purified Se fraction were then analyzed. A portion was neutron activated in a Cf-252 neutron source at SRNL to determine the total amount of Se present in order to calculate the recovery of Se from the radiochemical separation. A second portion was counted by liquid scintillation to determine the Se-79 beta activity. The yields of the stable Se carrier were applied to the Se-79 beta activity result to determine Se-79 activities in the sample aliquots initially treated.

2.2.3 Sr-90 Method

Aliquots of each sample from the sodium peroxide dissolutions⁹ were spiked with a stable Sr carrier, and a stable Ce carrier. The Sr carrier was used for separation yielding purposes and the Ce carrier was used to enhance the separation rates of undesirable isotopes such as Y-90, the lanthanides or the actinides. The spiked sample aliquots were initially oxidized using nitric acid. The Sr in the samples was extracted using commercially available Sr extraction resin. This resin also extracts some of the Pu under the conditions used to extract the Sr. The Pu was washed from the resin using an oxalic acid/nitric acid mixture. The Sr was eluted from the resin, and the resulting solution concentrated. A portion of the purified Sr solution was neutron activated in a Cf-252 neutron activation facility at SRNL to determine the total Sr and in order to calculate the fraction of Sr isolated by the procedure. A second portion of each of the Sr fractions was stored for five to seven days to allow Y-90 to grow in. Each fraction was then counted by liquid scintillation analysis to determine the Y-90 activity. The Sr-90 beta activity in each case was calculated from the Y-90 activity. The yields of the stable Sr carriers were applied to the Sr-90 beta activity results to determine Sr-90 activities in the original aliquots of the solutions resulting from the dissolution of the dried sludge slurry samples.

2.2.4 Gamma Counting Following Cs-137 Removal

This method was used to determine Ru-106, Sb-125, Ba-133, Ce-144, Sn-121m, and Sn-126. These gamma emitters could not be determined directly because of the high Cs-137 activity in the samples. Consequently the Cs-137 was removed. Aliquots of each of the four sodium peroxide dissolutions⁹ of the dried sludge slurry samples were treated with two batch additions of an ammonium phosphomolybdate resin to selectively remove the Cs-137 from the aliquots. This allowed gammas for isotopes at low concentrations to be detected or allowed lower detection limits to be determined for those isotopes that were not detected. The Cs-137 decontaminated aliquots were then gamma counted in two different detectors. The first was a high purity coaxial germanium detector to detect the gamma rays

from Ru-106, Sb-125, Ba-133, Ce-144, and Sn-126. Only Sb-125 was detected. Because of their low concentrations the other isotopes were not detected. To obtain reliable and lower detection limits for these radionuclides, each of the solutions was counted for 27.8 hours. The detection limits were used to calculate the maximum activity of each for input to the projection calculations. Of this group of radionuclides, only Sn-126 has a half-life greater than 10 years. Even though the others have half-lives less than 10 years, their activities were included to calculate the total Curies present in SB3 at the selected decay times. The second detector was a Be thin window, semi-planar, high purity germanium detector. This detector has a high counting efficiency for low energy gamma rays (37.2 keV) that are used to measure Sn-121m. The Sn-121m concentration was so low that it was not detected. Again to obtain a reliable low detection limit, each of the four aliquots was counted for 13.9 hours.

2.2.5 I-129 Method

The radionuclide I-129 is a long-lived beta emitting fission product ($t_{1/2} = 1.6E+07$ years) that is in SRS wastes. Four aliquots of wet sludge slurry were spiked with a known amount of stable KI to act as an iodine tracer/carrier. The samples were digested with 8M nitric acid. The iodate/iodine in the samples was reduced with sodium sulfite to minimize losses of iodine in the Shielded Cells I-129 procedure. The Fe in the dissolutions was reduced to Fe (II) using ascorbic acid to ensure it would not interfere with subsequent decontamination steps designed to extract Y-90, the lanthanides and the actinides from the KI traced dissolutions. The dissolutions were then treated with resins (Bio-Rad AMP-1, Eichrom Sr, RE, and Actinide resins) to reduce levels of Sr-90, Cs-137, Y-90, the lanthanides and the actinides. The traced samples were then rendered caustic, treated a second time with a sodium sulfite reduction, and filtered to ensure Sr-90 and Y-90 levels were reduced low enough to allow for sample removal from the Shielded Cells. The samples were decontaminated a final time with a resin treatment to remove Cs-137 and the actinide elements. The solution was then treated with $AgNO_3$ in order to precipitate the iodide ion as AgI. The precipitate was analyzed by low energy gamma spectroscopy to determine the amount of I-129 present. I-129 is detected by its characteristic gamma and x-ray emissions. The precipitate was then neutron activated in a Cf-252 neutron source at SRNL to determine the total amount of iodine present in order to calculate the recovery of I-129 in the radiochemical separation.

2.2.6 Pu-238/-241 Method

Pu-241 is a beta-emitting Pu isotope that cannot be measured directly in the dissolved dried sludge slurry solutions because of its low concentration. Pu-241 has a relatively short half-life (15 years). Its concentration, along with that for Pu-238, was determined by isolating the Pu from each solution by a thenoyltrifluoroacetone extraction procedure. The extracted Pu was then analyzed by beta and alpha counting to determine the ratio of beta activity from Pu-241 to the alpha activity from the other isotopes of Pu (Pu-238, Pu-239, Pu-240, and Pu-242). In the original dissolution solutions, the total alpha activity from the Pu isotopes was determined by alpha counting and ICP-MS. Knowing the total alpha activity from Pu in the solutions resulting from the extraction allows the concentration of Pu-241 in the original dissolution solutions to be calculated using the beta/alpha ratio determined in the extracted solution. In the extracted solution, the alpha counting technique also gives the alpha counts due specifically to Pu-238 so that the total amount of Pu-238 can be determined. The activities of these two radionuclides were then used in the calculations to determine the reportable radionuclides.

2.2.7 Am/Cm Method

This method was used for Am-241, Am-242m, Cm-242, Am-243, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, Bk-247, Cf-249, Cf-250, and Cf-251. These radionuclides are neutron activation products produced in the SRS reactors. These isotopes are difficult to measure because of their low concentrations in the sludge slurry and the dilutions necessary to get the dissolved slurry samples out of the Shielded Cells. Of these isotopes, the Am-241 can be easily and accurately analyzed directly by long term gamma counting of the dissolved sludge (see Section 2.1.2). For the other radionuclides listed above, a separation method has been developed by AD for isolating Am, Cm, Bk and Cf from a wet

sludge slurry solution. The slurry is digested in the Shielded Cells with concentrated nitric acid. The actinides are then extracted from the dissolution using a commercially available ion exchange resin (Eichrom RE). As Y-90 co-extracts with the trivalent actinides on RE resin, the treated samples were held in the Shielded Cells for two weeks to allow the Y-90 to decay. The solutions were purified further with a second RE resin extraction followed by an Eichrom Ln resin extraction. The Am, Cm, Bk, and Cf extracts were then analyzed by alpha and low energy gamma counting techniques as well as by ICP-MS. The radionuclides Cm-242, Am-242m, and Cm-244 were measured by alpha spectroscopy, Am-241, Am-243, Cm-243, Cm-245, Cm-247, Bk-247, Cf-249, and Cf-251 were measured by low energy gamma spectroscopy, and Cm-246 was measured by ICP-MS. The fraction of each actinide element isolated by this ion exchange technique was determined by comparing the measured concentrations of Am-241 in the eluted solutions with their respective concentration in the original dissolved slurry that was measured by direct gamma counting of Cs-137 removed aliquots of the dissolved slurry.

By using this technique, the radionuclides Cm-242, Am-242m, Am-243, Cm-244, and Cm-246 were detected and measured along with the Am-241. All the other radionuclides had concentrations below the detection limit of the analytical methods. These radionuclides were Cm-243, Cm-245, Cm-247, Bk-247, Cf-249, and Cf-251. For these, the detection limits were then used as the maximum concentrations or activities that could be present. The activity of Cf-250 in the input for the calculations was set identical to that of Cm-242 since the latter bounds the Cf isotope's alpha particle energy at 6.0 MeV.

2.2.8 Sm-151/Pm-147 Method

Aliquots of each sample from the sodium peroxide dissolutions⁹ were spiked with a stable Sm carrier. The Sm carrier was used for separation yielding purposes. The spiked sample aliquots were initially oxidized using nitric acid. The Sm and Pm along with other trivalent species in the samples were extracted using Eichrom RE resin. The Sm and Pm were then extracted from the other radionuclides present using Eichrom Ln resin. A portion of the purified Pm/Sm solution was neutron activated in a Cf-252 neutron activation facility at SRNL to determine the total Sm and in order to calculate the fraction of Sm isolated by the procedure. A second portion of each of the Pm/Sm fractions was then counted by liquid scintillation analysis to determine the Pm-147 and Sm-151 activity. The Pm-147 measurement was conducted using a higher energy beta window which was free of any interference from the low energy Sm-151 beta. The Sm-151 beta result is corrected for any Pm-147 events occurring in its beta counting window when necessary. The yields of the stable Sm carriers were applied to the Sm-151 and the Pm-147 beta activity results to determine Sm-151 and Pm-147 activities in the original aliquots of the solutions resulting from the dissolution of the dried sludge slurry samples. A Pm-147 spiked sample was run through the process to monitor and correct for any slight differences in the chemical recoveries of Sm and Pm.

2.3 Calculated Activities of the Remaining Radionuclides

2.3.1 Nb-93m

The radionuclide Nb-93m ($t_{1/2} = 16.1$ years)¹² is in SRS HLW as the decay product of the radioactive fission product Zr-93 ($t_{1/2} = 1.53E+06$ years). For previous sludge batches both the Zr-93 and Nb-93m became reportable after the waste was ~100 years old^{20,21,22}. The concentration of Nb-93m during SB4 vitrification can be calculated if the age of the sludge and the concentration of Zr-93 are known.

The age of the waste can be calculated from the measured concentration at mass 90 that is composed of Sr-90 ($t_{1/2} = 28.5$ years) and its daughter Y-90 ($t_{1/2} = 2.67$ days) that decays to stable Zr-90. The radionuclide Sr-90 is the initial long lived radioactive product of the isobaric decay chain at mass 90. In the ICP-MS analysis of the aqua regia dissolutions of the SB4 total solids, the concentration at mass 90 which is composed of Sr-90, Y-90, and Zr-90 was 0.0118 wt%. The concentration of Sr-90 determined by radioactive counting was 0.00530 wt% (see Section 2.2.3). Thus the fraction of Sr-90 that remained

in this sludge is 0.449. With the half-life of Sr-90 and standard equation for radioactive decay¹¹, the age of the sludge can be calculated. The result is 33 years.

The concentration of Zr-93 in SB4 measured by ICP-MS is 0.0105 wt%. Because of the large difference in the half-lives of Zr-93 and its radioactive daughter Nb-93m, these radionuclides are in secular equilibrium. Consequently, the initial concentration (wt%) of Nb-93m as input to the decay calculations can be calculated from the age of the waste and radioactive decay equation for two radionuclides that are in secular equilibrium as shown in Equation 5-4 on page 130 in Reference 11.

2.3.2 Pd-107

The noble metal Pd-107 is a pure beta emitter with a very long half-life (6.5E+06 years). This radionuclide could not be detected in the SB4 dissolved dried slurry samples by ICP-MS due to the presence of natural silver. Natural Ag contains the isotope Ag-107, which interferes with the measurement of Pd-107. The concentration of Pd-105 could be measured in the solutions thus the concentration of Pd-107 was calculated from the concentration of Pd-105. This was done by multiplying the ratio of the product of the fission yields and masses for Pd-107 and Pd-105 by the measured wt% for Pd-105 as determined by ICP-MS.

2.3.3 Cd-113m

With a half life of 13.7 years and specific activity of 217 Ci/g¹⁰, Cd-113m may also qualify as a WAPS reportable radionuclide. However, Cd-113m primarily decays by β emission and thus would require a careful separation technique to measure in sludge slurry. Also, the determination of Cd-113m by ICP-MS of the dissolved dried solids is essentially impossible because of the presence of natural Cd in the sludge. Natural Cd is 12.3 % Cd-113 with its half-life is greater than 1.1E11 years¹². This makes its activity negligible at all times⁸. Finally, the fission yield of Cd-113m is very small, 1.66E-04%¹³, and thus its concentration is expected to be very small in the HLW sludge.

An upper limit of the mass concentration of Cd-113m can be estimated by using the fission yield scaling factor (FYSF)¹⁴. The FYSF relates the concentration of a fission product in the total sludge solids to the fission yield and the atomic mass of that fission product. The atomic mass of that isotope has to be included in the equation because fission yields are given in terms of atoms produced per 100 fissions of U-235 and not in terms of mass percent of the isotope produced. The equation for the concentration in weight percent is then:

$$\text{Concentration (wt\%)} = \text{FYSF (fission yield} \times \text{atomic mass)} \quad (1)$$

Thus the FYSF for each measured isotope can be calculated from the Equation 2.

$$\text{FYSF}_i = \text{wt\%}_i / (\text{fy}_i \times \text{am}_i) \quad (2)$$

Where FYSF_i ≡ the fission yield scaling factor based on isotope i
 wt%_i ≡ the weight per percent of isotope i in the HLW total dried solids
 fy_i ≡ the fission yield of isotope i
 am_i ≡ the atomic mass of isotope i.

Several of the U-235 fission products have the six critical chemical and nuclear properties that allow calculation of a constant FYSF for a particular sludge. These properties are discussed in Reference 14. In SB4, there are 14 isotopes that have these six properties. The FYSF's calculated for these 14 isotopes are presented in the Table 2-1. The measured concentrations in the Table 2-1 were determined by ICP-MS analysis of four samples of dissolved SB4 total solids by the aqua regia method. The average of the

FYSF's calculated for the fourteen fission products is 3.18E-05 with a relative standard deviation of 13%.

Table 2-1. Calculated Values of the Fission Yield Scaling Factor (FYSF) for Fourteen U-235 Fission Products in SB4

Isotope	Measured Wt% of Total Solids	Fission Yield	FYSF
Ru-101	1.29E-02	5.20	2.45E-05
Ru-102	1.17E-02	4.30	2.67E-05
Rh-103	8.40E-03	3.03	2.69E-05
Ru-104	6.75E-03	1.88	3.45E-05
La-139	3.00E-02	6.41	3.36E-05
Ce-140	3.55E-02	6.22	4.08E-05
Pr-141	2.72E-02	5.80	3.33E-05
Ce-142	2.88E-02	5.85	3.47E-05
Nd-143	2.40E-02	5.96	2.82E-05
Nd-144	2.75E-02	5.50	3.47E-05
Nd-145	1.68E-02	3.93	2.95E-05
Nd-146	1.42E-02	3.00	3.25E-05
Sm-147	9.35E-03	2.25	2.83E-05
Sm-148	9.28E-03	1.67	3.76E-05
Average	-	-	3.18E-05

With the FYSF for SB4, the maximum possible concentration in terms of weight percent of dried solids can be estimated for the other U-235 fission products. These estimations are a maximum for the other fission products because they do not have the necessary six properties as the fission products given in Table 2-1. For example, the radionuclide Cd-113m has a very large neutron absorption cross section (20,000 barns¹²), and thus it was transmuted in the reactors at SRS to stable Cd-114 while the reactors were in operation. Consequently, the concentration calculated for Cd-113m with Equation 1 and a fission yield of 1.66E-04% can be considered the maximum concentration and is estimated below:

$$\text{Concentration Cd-113m (wt\%)} = 3.18\text{E-}05 \times 1.66\text{E-}04 \times 113 = 5.97\text{E-}07 \text{ wt\%}.$$

2.3.4 Cs-135

The radionuclide Cs-135 cannot be detected by ICP-MS in the sludge slurry due to its low concentration and the large amount of natural Ba-135 (same mass as the Cs-135). Cs-135 cannot be detected by counting techniques either because of its long half-life ($t_{1/2} = 2.3\text{E}+06$ years). The detection by ICP-MS of Cs-135 in the supernate is possible because Ba-135 is insoluble in caustic supernate. The same philosophy applies to Ba-137 and Cs-137. Thus, Ba does not interfere with the analyses of Cs-135 or Cs-137 in the supernate. By using the ratio of Cs-135 to Cs-137 in the supernate, and the amount of Cs-137 in the sludge slurry, the activity for Cs-135 in the sludge slurry can be calculated. The weight percent of Cs-135 was then converted to $\mu\text{Ci/g}$ and used in the calculations to determine if Cs-135 was reportable.

2.3.5 Cm-248

The radionuclide Cm-248 is another radionuclide that needs to be considered as possibly reportable but which cannot be measured due to its low concentration. The concentration of this isotope had to be estimated using the ratio of Cm-248 to Cm-247 predicted for the DWPF design basis glass¹⁵. The predicted ratio of the mass of Cm-248 to the mass of Cm-247 was 0.023. An upper limit of the

concentration of Cm-248 was calculated by multiplying the upper limit for the concentration of Cm-247 measured by the Am/Cm method by this ratio. This upper limit was then converted to activity of Cm-248 using the specific activity of Cm-248. This result was entered into the reportable isotope projection calculations.

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3.0 RESULTS AND DISCUSSION

3.1 Summary of the Activities and Radionuclides for Input

The complete list of radionuclides and their activities that were considered in the determination of reportable radionuclides are provided in Table 3-1. For those radionuclides with measured concentrations, the initial activities were calculated by using the weight percent reported for each radioisotope and its specific activity with the following equation: $A_o = M_o * SpA$, where A_o = Initial Activity, M_o = mass in weight percent and SpA = specific activity of the isotope.

For each radionuclide listed in Table 3-1 there is an associated specific activity in units of Ci/g, wt% of total solids, activity in $\mu\text{Ci/g}$, and the method used to determine or estimate the value.

The total measured alpha activity of the digested samples was 226 $\mu\text{Ci/g}$. Total measured beta activity was measured at 1.45E+04 $\mu\text{Ci/g}$.

Table 3-1. List of Radionuclides and Activities Used as Input to the *RadDecay*[®] Program

Radionuclide	Specific Activity (Ci/g)	Wt% of Total Solids	Activity (μ Ci/g)‡	Method
Ni-59	8.08E-02	7.02E-04	5.67E-01	Ni-59/-63
Co-60	1.13E+03	7.57E-08	8.56E-01	Direct Gamma Counting
Ni-63	6.17E+01	1.07E-04	6.58E+01	Ni-59/-63
Se-79	6.97E-02	2.31E-05	1.61E-02	Se-79
Sr-90	1.36E+02	5.30E-03	7.23E+03	Sr-90
Y-90*	5.44E+05	1.33E-06	7.23E+03	Secular equilibrium w/ Sr-90
Zr-93	2.51E-03	1.05E-02	2.64E-01	ICP-MS
Nb-93m	2.83E+02	7.41E-08	2.09E-01	Calculated from Zr-93 and Waste Age
Tc-99	1.70E-02	8.31E-04	1.41E-01	ICP-MS
Pd-107	5.14E-04	1.16E-04	5.98E-04	Calculated from Pd-105
Cd-113m	2.17E+02	5.97E-07	1.29E+00	Based on Fission Yield
Sn-121m	5.91E+01	<3.38E-08	<3.18E-02	Cs-Removed Gamma Counting
Sb-125	1.03E+03	<1.81E-08	<1.86E-01	Cs-Removed Gamma Counting
Te-125m*	1.80E+04	<1.04E-09	<1.86E-01	Secular equilibrium w/ Sb-125
Sn-126	2.84E-02	<1.14E-03	<3.24E-01	Cs-Removed Gamma Counting
I-129	1.77E-04	2.95E-04	5.20E-04	I-129
Ba-133	2.50E+02	<3.66E-08	<9.14E-02	Direct Gamma Counting
Cs-135	1.15E-03	1.02E-04	1.18E-03	Calculated from Cs-135/-137 ratio
Cs-137	8.70E+01	2.87E-04	2.49E+02	Direct Gamma Counting
Ba-137m*	5.38E+08	4.45E-11	2.39E+02	Secular equilibrium w/ Cs-137
Pm-147	9.27E+02	<1.55E-06	<1.44E+01	Pm-147/Sm-151
Sm-151	2.63E+01	4.28E-04	1.13E+02	Pm-147/Sm-151
Eu-154	2.70E+02	4.28E-06	1.15E+01	Direct Gamma Counting
Eu-155	4.65E+02	2.61E-07	1.22E+00	Direct Gamma Counting
Th-232	1.10E-07	4.62E-02	5.07E-05	ICP-MS
U-233	9.68E-03	<1.97E-04	<1.91E-02	ICP-MS
U-234	6.25E-03	5.44E-04	3.40E-02	ICP-MS
U-235	2.16E-06	2.96E-02	6.41E-04	ICP-MS
U-236	6.47E-05	1.26E-03	8.12E-04	ICP-MS
Np-237	7.05E-04	3.69E-03	2.60E-02	ICP-MS
U-238	3.36E-07	5.25E+00	1.77E-02	ICP-MS
Pu-238	1.71E+01	7.13E-04	1.22E+02	Pu-238/-241
Pu-239	6.22E-02	1.66E-02	1.03E+01	ICP-MS
Pu-240	2.28E-01	1.98E-03	4.51E+00	ICP-MS
Pu-241	1.03E+02	1.05E-04	1.08E+02	Pu-238/-241
Pu-242	3.82E-03	1.53E-04	5.83E-03	ICP-MS
Am-241	3.43E+00	5.14E-04	1.76E+01	Direct Gamma Counting
Am-242m	9.72E+00	7.20E-07	7.00E-02	Am/Cm
Am-243	1.99E-01	8.23E-04	1.64E+00	Am/Cm
Cm-242	3.31E+03	1.75E-09	5.78E-02	Am/Cm
Cm-243	5.16E+01	<1.15E-06	<5.96E-01	Am/Cm
Cm-244	8.09E+01	1.12E-04	9.07E+01	Am/Cm
Cm-245	1.72E-01	<2.04E-05	<3.49E-02	Am/Cm
Cm-246	3.07E-01	6.19E-06	1.90E-02	Am/Cm – ICP-MS
Cm-247	9.28E-05	<6.09E-03	<5.65E-03	Am/Cm
Bk-247	1.03E+00	<1.32E-06	<1.36E-02	Am/Cm
Cm-248	4.25E-03	<1.39E-04	<5.91E-03	Calculated Ratio Cm-247/-248
Cf-249	4.38E+00	<1.69E-07	<7.39E-03	Am/Cm
Cf-250	1.09E+02	5.29E-08	5.78E-02	Am/Cm
Cf-251	1.86E+00	<1.01E-06	<1.88E-02	Am/Cm
Total			1.55E+04	

* Included because this isotope is in secular equilibrium with a parent for which a measured value was available.

‡ Less than values represent the minimum detection limit value and hence are an upper bound for that isotope's activity.

3.2 Identification of Reportable Radionuclides

Based on radionuclides and activities provided in Table 3-1, a commercially available computer program was used to identify which radionuclides were reportable through calendar year 3115. The program is called *RadDecay*[®] version 3.0¹⁶.

The initial activities for 50 isotopes were entered into *RadDecay*[®] and the results of two calculations with the index years 2015 and 3115 (1110 years) are presented in Appendix A and Appendix L. Those radionuclides that are reportable are designated in these tables by a “yes”. Additional calculations were performed for every 100 years up to 1100 years. These results are presented in Appendix B through K. Microsoft Excel spreadsheets were used to calculate the total activity in $\mu\text{Ci/g}$ of dried sludge solids at each time and the percent of the activity that each of the radionuclides contributed.

The calculations performed by *RadDecay*[®] v. 3.0 were verified against a separate program called *Radioactive Decay Calculator*¹⁷. A comparison between the outputs of the two programs for a series of calculations is given in the Software QA Plan¹⁸. This comparison demonstrates the accuracy of the *RadDecay*[®] v. 3.0 program. Both software packages have a software QA classification of “C”¹⁹. In addition to this check, a separate independent evaluation utilizing the input radionuclides and an earlier version of *RadDecay*[®] v. 1.13 was conducted. The reportable radionuclides determined by this evaluation were the same as those reported here. The results of the calculations with *RadDecay*[®] v.3.0 for each 100 year interval starting in 2015 through 3115 are given in Appendices A – L.

The total Curie content of the dried sludge in the year 2015 is $1.31\text{E}+04$ $\mu\text{Ci/g}$. This value is greater than the $6.80\text{E}+03$ $\mu\text{Ci/g}$ total represented by the reportable radionuclides in Appendix A. The difference is due to the significant contribution to the activity from radionuclides having half-lives shorter than ten years. These radionuclides include (in decreasing order of activity contribution): Y-90, Ba-137m, Pm-147, Eu-154, Eu-155, Sn-121, and Np-239.

Appendix L presents the reportable radionuclides indexed to the year 3115. The total Curie content of the dried sludge in 3115 is $2.32\text{E}+01$ $\mu\text{Ci/g}$. This value is slightly greater than the $2.13\text{E}+01$ $\mu\text{Ci/g}$ total represented by the radionuclides identified as reportable. The difference is due to the minor contribution to the total activity from radionuclides having half-lives shorter than 10 years. These radionuclides include (in decreasing order of activity contribution): Np-239, Sb-126m, Sb-126, Pa-233, Th-234, Pa-234m, and Pu-243.

Twenty-nine radionuclides have been identified as reportable for DWPF SB4 (MB5) as specified by WAPS 1.2. Consistent with the strategy detailed in the WCP and WQR, each of these radionuclides has a half-life greater than 10 years and contributes more than 0.01 % of the radioactivity on a Curie basis at some point from production through the 1100-year period between 2015 and 3115. The 29 reportable radionuclides are given in Table 3-2. The calculations at every one hundred years out to 1100 years demonstrated that only one radionuclide became reportable during this time period, Am-242m, which was reportable for the years between 2215 and 2615, but no longer reportable in 2715. The data for these intermediate year calculations can be found in Appendices B-K.

Table 3-2. Reportable Radionuclides in DWPF Sludge Batch 4 (Macrobatch 5)

Ni-59	Ni-63	Se-79	Sr-90	Zr-93	Nb-93m
Tc-99	Sn-126*	Cs-137	Sm-151	U-233*	U-234
Np-237	U-238	Pu-238	Pu-239	Pu-240	Am-241
Pu-241	Pu-242	Am-242m	Am-243	Cm-244	Cm-245*
Cm-246	Cm-247*	Bk-247*	Cm-248*	Cf-251*	

* Based upon an analytical detection limit.

The WCP and WQR require that all of the radionuclides present in the Design Basis glass be considered as the initial set of reportable radionuclides. All of the radionuclides in the Design Basis glass are reportable except for three radionuclides: Pd-107, Cs-135, and Th-230. At no time during the 1100-year period between 2015 and 3115 did any of these three radionuclides contribute to more than 0.01% of the radioactivity on a Curie basis.

Seven of the 29 reportable radionuclides for SB4 are not part of either the design-basis list of radionuclides² or the list of Pu and U isotopes identified in WAPS 1.6. These include Am-242m, Cm-245, Cm-246, Cm-247, Bk-247, Cm-248, and Cf-251. One of these radionuclides (Cm-246) was also reported for SB1B (MB2)²⁰, three of these radionuclides (Cm-245, Cm-246, and Cf-251) were also reported for SB2 (MB3)²¹, and six of these radionuclides (Am-242m, Cm-245, Cm-246, Cm-247, Cm-248, and Cf-251) were reported for SB3 (MB4)²²

The list of reportable radionuclides that were determined for SB1B (MB2)²⁰ contained two radionuclides that were not reportable for SB2 (MB3), SB3 (MB4) or in the current SB4 (MB5). These radionuclides were I-129 and Th-229. Sn-121m was reportable for SB1B (MB2), SB2 (MB3), and SB3 (MB4), but due to an improved detection limit is not reportable for SB4 (MB5). Similarly, Cf-249 was reportable for SB3, but due to an improved detection limit for the input value, it is not reportable for SB4. C-14, reported in the first two batch analyses, has been excluded from consideration for future sludge batches⁷. For easier comparison, the reportable nuclides for SB1B, SB2, and SB3 have been reproduced in Table 3-3 through Table 3-5.

Table 3-3. Reportable Radionuclides in DWPF Sludge Batch 1B (Macrobatch 2)²⁰

C-14	Ni-59	Ni-63	Se-79	Sr-90	Zr-93
Nb-93m	Tc-99	Sn-121m	Sn-126	I-129	Cs-137
Sm-151	Th-229	U-233	U-234	Np-237	U-238
Pu-238	Pu-239	Pu-240	Am-241	Pu-241	Pu-242
Am-243	Cm-244	Cm-246			

²⁰ Fellingner, T. L, Bibler, N. E., and Harbour, J. R., *Characterization of and Waste Acceptance Radionuclides to be Reported for DWPF Macrobatch 2 (ESP 215 – ESP 221)*, WSRC-RP-99-00436, Revision 1, Savannah River Site, March 2004.

Table 3-4. Reportable Radionuclides in DWPF Sludge Batch 2 (Macrobatch 3)²¹

C-14	Ni-59	Ni-63	Se-79	Sr-90	Zr-93
Nb-93m	Tc-99	Sn-121m	Sn-126	Cs-137	Sm-151
U-233	U-234	Np-237	U-238	Pu-238	Pu-239
Pu-240	Am-241	Pu-241	Pu-242	Am-243	Cm-244
Cm-245	Cm-246	Cf-251			

²¹ Bibler, N. E., DiPrete, D. P., and Harbour, J. R., *Determination of Reportable Radionuclides for DWPF Sludge Batch 2 (Macrobatch 3)*, WSRC-TR-2002-00255, Revision 0, Savannah River Site, September 2002.

Table 3-5. Reportable Radionuclides in DWPF Sludge Batch 3 (Macrobatch 4)²²

Ni-59	Ni-63	Se-79	Sr-90	Zr-93	Nb-93m
Tc-99	Sn-121m	Sn-126	Cs-137	Sm-151	U-233
U-234	Np-237	U-238	Pu-238	Pu-239	Pu-240
Am-241	Pu-241	Pu-242	Am-242m	Am-243	Cm-244
Cm-245	Cm-246	Cm-247	Cm-248*	Cf-249	Cf-251

²² Bannoche, C. J. and Bibler, N. E., *Determination of Reportable Radionuclides for DWPF Sludge Batch 3 (Macrobatch 4)*, WSRC-TR-2005-00157, Rev. 0, Savannah River Site, May 2005.

3.3 The Ratio by Weight of U and Pu Isotopes

The WQR requires that the relative concentrations of the uranium and plutonium isotopes be provided from the analysis of each Macrobatch (in this case MB5 – Sludge Batch 4) in order to meet the WAPS IAEA Safeguards Reporting for HLW Specification (WAPS 1.6). The data for uranium isotopes are given in Table 3-6.

Table 3-6. Uranium Isotope Distribution in DWPF Sludge Batch 4 (Macrobatch 5)

Isotope	Weight Percent	Percent Distribution
U-233	<1.97E-04	0.00373
U-234	5.44E-04	0.0103
U-235	2.96E-02	0.561
U-236	1.26E-03	0.0238
U-238	5.25E+00	99.4
Total	6.76E+00	100

The data for the plutonium isotopes is given in Table 3-7.

Table 3-7. Plutonium Isotope Distribution in DWPF Sludge Batch 4 (Macrobatch 5)

Isotope	Weight Percent	Percent Distribution
Pu-238	7.13E-04	3.66
Pu-239	1.66E-02	84.9
Pu-240	1.98E-03	10.1
Pu-241	1.05E-04	0.536
Pu-242	1.53E-04	0.783
Total	2.45E-02	100

All of the Pu isotopes and U-233, -234, and -238 are already reportable since they meet the requirement of having half-lives greater than 10 years and a contribution to the overall activity of greater than 0.01% on a Curie basis through the year 3115. In order to be compliant with WAPS 1.6, U-235 and U-236 also become reportable even though they contribute less than 0.01% to the total activity (U-235 at 0.003% and U-236 at 0.004% in 3115).

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4.0 CONCLUSIONS

Twenty-nine radionuclides have been identified as reportable for DWPF SB4 (MB5) as specified by WAPS 1.2. Consistent with the strategy detailed in the WCP and WQR, each of these radionuclides has a half-life greater than ten years and contributes more than 0.01% of the radioactivity on a Curie basis at some point from production through the 1100 year period between 2015 and 3115. The 29 reportable nuclides are:

Ni-59	Ni-63	Se-79	Sr-90	Zr-93	Nb-93m
Tc-99	Sn-126	Cs-137	Sm-151	U-233	U-234
Np-237	U-238	Pu-238	Pu-239	Pu-240	Am-241
Pu-241	Pu-242	Am-242m	Am-243	Cm-244	Cm-245
Cm-246	Cm-247	Bk-247	Cm-248	Cf-251	

The WCP and WQR require that all of radionuclides present in the Design Basis glass be considered as the initial set of reportable radionuclides. For SB4 (MB5), all of the radionuclides in the Design Basis glass are reportable except for three radionuclides: Pd-107, Cs-135, and Th-230. At no time through the year 3115 did any of these three radionuclides contribute to more than 0.01% of the radioactivity on a Curie basis.

Two additional uranium isotopes (U-235 and -236) must be added to the list of reportable radionuclides in order to meet WAPS 1.6. All of the Pu isotopes and other U isotopes (U-233, -234, and -238) identified in WAPS 1.6 were already determined to be reportable according to WAPS 1.2. This brings the total number of reportable radionuclides for SB4 to 31.

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5.0 RECOMMENDATIONS

The radionuclide measurements made for SB4 (MB5) are the most extensive conducted to date. Some method development/refinement occurred during the conduct of these measurements, leading to lower detection limits and more accurate measurement of some isotopes than was previously possible. Continuous improvement in the analytical measurements will likely continue, and this in turn should lead to improved detection limit values for some radionuclides and actual measurements for still others.

Efforts to revise the Waste Acceptance Product Specification¹ to change the current initial index year from 2015 to 2010, would result in the inability to index the initial assay as early as Macrobatches 8 since this will be assayed after 2010 (i.e. one would have to “un-decay” the waste activity to an earlier year) With the unlikely transfer of vitrified materials to a permanent geologic repository by 2015, it would probably be better to change the initial index year to the expected completion of vitrification activities at DWPF.

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6.0 REFERENCES

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7.0 ACKNOWLEDGEMENTS

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APPENDIX A. ACTIVITIES OF DRIED SLUDGE IN YEAR 2015 ($\mu\text{Ci/g}$)

Nuclide	Y 2015 μCi/g	Fraction of Activity	Reportable
Ac-225	1.24E-05	9.47E-10	
Ac-227	9.82E-09	7.47E-13	
Ac-228	2.89E-05	2.20E-09	
Am-241	1.84E+01	1.40E-03	Yes
Am-242	6.75E-02	5.14E-06	
Am-242m	6.78E-02	5.16E-06	
Am-243	1.64E+00	1.25E-04	Yes
At-217	1.24E-05	9.47E-10	
At-218	6.61E-13	5.03E-17	
Ba-133	5.82E-02	4.43E-06	
Ba-137m	2.00E+02	1.53E-02	
Bi-210	2.24E-10	1.70E-14	
Bi-211	9.50E-09	7.23E-13	
Bi-212	2.00E-05	1.52E-09	
Bi-213	1.24E-05	9.47E-10	
Bi-214	3.30E-09	2.52E-13	
Bk-247	1.36E-02	1.03E-06	
Cd-113m	9.03E-01	6.87E-05	
Cf-249	7.29E-03	5.55E-07	
Cf-250	3.99E-02	3.04E-06	
Cf-251	1.87E-02	1.42E-06	
Cm-242	5.60E-02	4.26E-06	
Cm-243	5.03E-01	3.83E-05	
Cm-244	6.94E+01	5.28E-03	Yes
Cm-245	3.49E-02	2.66E-06	
Cm-246	1.90E-02	1.45E-06	
Cm-247	5.65E-03	4.30E-07	
Cm-248	5.91E-03	4.50E-07	
Co-60	3.41E-01	2.60E-05	
Cs-135	1.18E-03	8.98E-08	
Cs-137	2.12E+02	1.61E-02	Yes
Eu-154	6.63E+00	5.04E-04	
Eu-155	4.59E-01	3.49E-05	
Fr-221	1.24E-05	9.47E-10	
Fr-223	1.35E-10	1.03E-14	
I-129	5.20E-04	3.96E-08	
Nb-93m	2.26E-01	1.72E-05	
Ni-59	5.67E-01	4.32E-05	
Ni-63	6.26E+01	4.76E-03	Yes
Np-237	2.60E-02	1.98E-06	
Np-238	3.23E-04	2.46E-08	
Np-239	1.64E+00	1.25E-04	
Np-240m	3.18E-10	2.42E-14	
Pa-231	9.49E-08	7.22E-12	
Pa-233	2.60E-02	1.98E-06	
Pa-234	5.84E-05	4.44E-09	
Pa-234m	1.77E-02	1.34E-06	
Pb-209	1.24E-05	9.47E-10	
Pb-210	2.25E-10	1.72E-14	
Pb-211	9.50E-09	7.23E-13	
Pb-212	2.00E-05	1.52E-09	
Pb-214	3.30E-09	2.52E-13	
Pd-107	5.98E-04	4.55E-08	
Pm-147	2.27E+00	1.73E-04	
Po-210	1.79E-10	1.36E-14	
Po-211	2.66E-11	2.03E-15	
Po-212	1.28E-05	9.74E-10	
Po-213	1.22E-05	9.27E-10	

Nuclide	Y 2015 μCi/g	Fraction of Activity	Reportable
Po-214	3.30E-09	2.51E-13	
Po-215	9.50E-09	7.23E-13	
Po-216	2.00E-05	1.52E-09	
Po-218	3.30E-09	2.52E-13	
Pu-238	1.15E+02	8.79E-03	Yes
Pu-239	1.03E+01	7.84E-04	Yes
Pu-240	4.57E+00	3.48E-04	Yes
Pu-241	7.71E+01	5.87E-03	Yes
Pu-242	5.83E-03	4.44E-07	
Pu-243	5.65E-03	4.30E-07	
Pu-244	3.18E-10	2.42E-14	
Ra-223	9.50E-09	7.23E-13	
Ra-224	2.00E-05	1.52E-09	
Ra-225	1.25E-05	9.53E-10	
Ra-226	3.32E-09	2.53E-13	
Ra-228	2.89E-05	2.20E-09	
Rn-219	9.50E-09	7.23E-13	
Rn-220	2.00E-05	1.52E-09	
Rn-222	3.30E-09	2.52E-13	
Sb-125	3.23E-02	2.46E-06	
Sb-126	4.54E-02	3.45E-06	
Sb-126m	3.24E-01	2.47E-05	
Se-79	1.61E-02	1.23E-06	
Sm-147	3.00E-10	2.29E-14	
Sm-151	1.07E+02	8.15E-03	Yes
Sn-121	2.26E-02	1.72E-06	
Sn-121m	2.91E-02	2.22E-06	
Sn-126	3.24E-01	2.47E-05	
Sr-90	6.12E+03	4.66E-01	Yes
Tc-99	1.41E-01	1.07E-05	
Te-125m	7.81E-03	5.94E-07	
Th-227	9.49E-09	7.22E-13	
Th-228	2.00E-05	1.52E-09	
Th-229	1.26E-05	9.61E-10	
Th-230	2.22E-06	1.69E-10	
Th-231	6.41E-04	4.88E-08	
Th-232	5.07E-05	3.86E-09	
Th-234	1.77E-02	1.35E-06	
Tl-207	9.47E-09	7.21E-13	
Tl-208	7.17E-06	5.46E-10	
Tl-209	2.69E-07	2.05E-11	
U-233	1.91E-02	1.45E-06	
U-234	3.64E-02	2.77E-06	
U-235	6.41E-04	4.88E-08	
U-236	8.13E-04	6.19E-08	
U-237	1.89E-03	1.44E-07	
U-238	1.77E-02	1.35E-06	
U-240	3.18E-10	2.42E-14	
Y-90	6.12E+03	4.66E-01	
Zr-93	2.64E-01	2.01E-05	
TOTAL	1.31E+04	1.00E+00	

APPENDIX B. ACTIVITIES OF DRIED SLUDGE IN YEAR 2115 ($\mu\text{Ci/g}$)

Nuclide	Y 2115 μCi/g	Fraction of Activity	Reportable	Nuclide	Y 2115 μCi/g	Fraction of Activity	Reportable
Ac-225	1.92E-04	1.42E-07		Po-214	9.70E-07	7.20E-10	
Ac-227	1.04E-06	7.71E-10		Po-215	1.04E-06	7.70E-10	
Ac-228	5.07E-05	3.76E-08		Po-216	5.07E-05	3.76E-08	
Am-241	1.79E+01	1.33E-02	Yes	Po-218	9.70E-07	7.20E-10	
Am-242	4.28E-02	3.17E-05		Pu-238	5.24E+01	3.89E-02	Yes
Am-242m	4.30E-02	3.19E-05		Pu-239	1.03E+01	7.63E-03	Yes
Am-243	1.62E+00	1.21E-03	Yes	Pu-240	4.70E+00	3.49E-03	Yes
At-217	1.92E-04	1.42E-07		Pu-241	6.61E-01	4.91E-04	Yes
At-218	1.94E-10	1.44E-13		Pu-242	5.83E-03	4.33E-06	
Ba-133	9.16E-05	6.80E-08		Pu-243	5.65E-03	4.20E-06	
Ba-137m	1.99E+01	1.48E-02		Pu-244	4.87E-09	3.61E-12	
Bi-210	5.39E-07	4.00E-10		Ra-223	1.04E-06	7.70E-10	
Bi-211	1.04E-06	7.70E-10		Ra-224	5.07E-05	3.76E-08	
Bi-212	5.07E-05	3.76E-08		Ra-225	1.92E-04	1.43E-07	
Bi-213	1.92E-04	1.42E-07		Ra-226	9.70E-07	7.20E-10	
Bi-214	9.70E-07	7.20E-10		Ra-228	5.07E-05	3.76E-08	
Bk-247	1.29E-02	9.57E-06		Rn-219	1.04E-06	7.70E-10	
Cd-113m	5.52E-03	4.10E-06		Rn-220	5.07E-05	3.76E-08	
Cf-249	5.98E-03	4.44E-06		Rn-222	9.70E-07	7.20E-10	
Cf-250	1.99E-04	1.48E-07		Sb-125	4.38E-13	3.25E-16	
Cf-251	1.73E-02	1.29E-05		Sb-126	4.53E-02	3.37E-05	
Cm-242	3.55E-02	2.63E-05		Sb-126m	3.24E-01	2.40E-04	
Cm-243	4.42E-02	3.28E-05		Se-79	1.61E-02	1.19E-05	
Cm-244	1.51E+00	1.12E-03	Yes	Sm-147	3.56E-10	2.65E-13	
Cm-245	3.47E-02	2.57E-05		Sm-151	4.96E+01	3.68E-02	Yes
Cm-246	1.89E-02	1.40E-05		Sn-121	6.41E-03	4.76E-06	
Cm-247	5.65E-03	4.20E-06		Sn-121m	8.26E-03	6.13E-06	
Cm-248	5.91E-03	4.39E-06		Sn-126	3.24E-01	2.40E-04	Yes
Co-60	6.64E-07	4.93E-10		Sr-90	5.66E+02	4.20E-01	Yes
Cs-135	1.18E-03	8.76E-07		Tc-99	1.41E-01	1.05E-04	Yes
Cs-137	2.10E+01	1.56E-02	Yes	Te-125m	1.06E-13	7.87E-17	
Eu-154	2.52E-03	1.87E-06		Th-227	1.02E-06	7.60E-10	
Eu-155	3.91E-07	2.91E-10		Th-228	5.07E-05	3.76E-08	
Fr-221	1.92E-04	1.42E-07		Th-229	1.92E-04	1.43E-07	
Fr-223	1.43E-08	1.06E-11		Th-230	4.64E-05	3.45E-08	
I-129	5.20E-04	3.86E-07		Th-231	6.42E-04	4.77E-07	
Nb-93m	2.64E-01	1.96E-04	Yes	Th-232	5.07E-05	3.76E-08	
Ni-59	5.66E-01	4.21E-04	Yes	Th-234	1.77E-02	1.31E-05	
Ni-63	3.04E+01	2.26E-02	Yes	Tl-207	1.03E-06	7.68E-10	
Np-237	2.67E-02	1.98E-05		Tl-208	1.82E-05	1.35E-08	
Np-238	2.05E-04	1.52E-07		Tl-209	4.14E-06	3.08E-09	
Np-239	1.62E+00	1.21E-03		U-233	1.91E-02	1.42E-05	
Np-240m	4.86E-09	3.61E-12		U-234	5.90E-02	4.38E-05	
Pa-231	1.45E-06	1.08E-09		U-235	6.42E-04	4.77E-07	
Pa-233	2.67E-02	1.98E-05		U-236	8.27E-04	6.14E-07	
Pa-234	5.84E-05	4.33E-08		U-237	1.62E-05	1.20E-08	
Pa-234m	1.77E-02	1.31E-05		U-238	1.77E-02	1.31E-05	
Pb-209	1.92E-04	1.42E-07		U-240	4.86E-09	3.61E-12	
Pb-210	5.40E-07	4.01E-10		Y-90	5.66E+02	4.21E-01	
Pb-211	1.04E-06	7.70E-10		Zr-93	2.64E-01	1.96E-04	Yes
Pb-212	5.07E-05	3.76E-08		TOTAL	1.35E+03	1.00E+00	
Pb-214	9.70E-07	7.20E-10					
Pd-107	5.98E-04	4.44E-07					
Pm-147	7.60E-12	5.64E-15					
Po-210	5.32E-07	3.95E-10					
Po-211	2.90E-09	2.16E-12					
Po-212	3.25E-05	2.41E-08					
Po-213	1.88E-04	1.39E-07					

APPENDIX C. ACTIVITIES OF DRIED SLUDGE IN YEAR 2215 ($\mu\text{Ci/g}$)

Nuclide	Y 2215 μCi/g	Fraction of Activity	Reportable
Ac-225	3.70E-04	1.79E-06	
Ac-227	2.38E-06	1.15E-08	
Ac-228	5.07E-05	2.46E-07	
Am-241	1.53E+01	7.42E-02	Yes
Am-242	2.71E-02	1.31E-04	
Am-242m	2.72E-02	1.32E-04	Yes
Am-243	1.61E+00	7.80E-03	Yes
At-217	3.70E-04	1.79E-06	
At-218	8.22E-10	3.98E-12	
Ba-133	1.44E-07	7.00E-10	
Ba-137m	1.97E+00	9.57E-03	
Bi-210	2.96E-06	1.43E-08	
Bi-211	2.38E-06	1.15E-08	
Bi-212	5.07E-05	2.46E-07	
Bi-213	3.70E-04	1.79E-06	
Bi-214	4.11E-06	1.99E-08	
Bk-247	1.23E-02	5.94E-05	
Cd-113m	3.38E-05	1.64E-07	
Cf-249	4.91E-03	2.38E-05	
Cf-250	9.96E-07	4.83E-09	
Cf-251	1.60E-02	7.77E-05	
Cm-242	2.25E-02	1.09E-04	
Cm-243	3.88E-03	1.88E-05	
Cm-244	3.29E-02	1.59E-04	Yes
Cm-245	3.44E-02	1.67E-04	Yes
Cm-246	1.86E-02	9.01E-05	
Cm-247	5.65E-03	2.74E-05	
Cm-248	5.91E-03	2.86E-05	
Co-60	1.29E-12	6.26E-15	
Cs-135	1.18E-03	5.72E-06	
Cs-137	2.09E+00	1.01E-02	Yes
Eu-154	9.55E-07	4.63E-09	
Eu-155	3.34E-13	1.62E-15	
Fr-221	3.70E-04	1.79E-06	
Fr-223	3.29E-08	1.59E-10	
I-129	5.20E-04	2.52E-06	
Nb-93m	2.64E-01	1.28E-03	Yes
Ni-59	5.66E-01	2.74E-03	Yes
Ni-63	1.48E+01	7.16E-02	Yes
Np-237	2.72E-02	1.32E-04	Yes
Np-238	1.30E-04	6.29E-07	
Np-239	1.61E+00	7.80E-03	
Np-240m	9.40E-09	4.56E-11	
Pa-231	2.81E-06	1.36E-08	
Pa-233	2.72E-02	1.32E-04	
Pa-234	5.84E-05	2.83E-07	
Pa-234m	1.77E-02	8.57E-05	
Pb-209	3.70E-04	1.79E-06	
Pb-210	2.96E-06	1.43E-08	
Pb-211	2.38E-06	1.15E-08	
Pb-212	5.07E-05	2.46E-07	
Pb-214	4.11E-06	1.99E-08	
Pd-107	5.98E-04	2.90E-06	
Pm-147	2.55E-23	1.24E-25	
Po-210	2.94E-06	1.42E-08	
Po-211	6.66E-09	3.23E-11	
Po-212	3.25E-05	1.58E-07	
Po-213	3.62E-04	1.75E-06	

Nuclide	Y 2215 μCi/g	Fraction of Activity	Reportable
Po-214	4.11E-06	1.99E-08	
Po-215	2.38E-06	1.15E-08	
Po-216	5.07E-05	2.46E-07	
Po-218	4.11E-06	1.99E-08	
Pu-238	2.38E+01	1.15E-01	Yes
Pu-239	1.02E+01	4.97E-02	Yes
Pu-240	4.66E+00	2.26E-02	Yes
Pu-241	3.96E-02	1.92E-04	Yes
Pu-242	5.84E-03	2.83E-05	
Pu-243	5.65E-03	2.74E-05	
Pu-244	9.42E-09	4.57E-11	
Ra-223	2.38E-06	1.15E-08	
Ra-224	5.07E-05	2.46E-07	
Ra-225	3.70E-04	1.79E-06	
Ra-226	4.11E-06	1.99E-08	
Ra-228	5.07E-05	2.46E-07	
Rn-219	2.38E-06	1.15E-08	
Rn-220	5.07E-05	2.46E-07	
Rn-222	4.11E-06	1.99E-08	
Sb-125	5.95E-24	2.89E-26	
Sb-126	4.53E-02	2.20E-04	
Sb-126m	3.24E-01	1.57E-03	
Se-79	1.61E-02	7.79E-05	
Sm-147	3.56E-10	1.73E-12	
Sm-151	2.29E+01	1.11E-01	Yes
Sn-121	1.82E-03	8.81E-06	
Sn-121m	2.34E-03	1.14E-05	
Sn-126	3.24E-01	1.57E-03	Yes
Sr-90	5.24E+01	2.54E-01	Yes
Tc-99	1.41E-01	6.83E-04	Yes
Te-125m	1.44E-24	6.98E-27	
Th-227	2.35E-06	1.14E-08	
Th-228	5.07E-05	2.46E-07	
Th-229	3.70E-04	1.79E-06	
Th-230	1.05E-04	5.08E-07	
Th-231	6.43E-04	3.12E-06	
Th-232	5.07E-05	2.46E-07	
Th-234	1.77E-02	8.58E-05	
Tl-207	2.37E-06	1.15E-08	
Tl-208	1.82E-05	8.83E-08	
Tl-209	7.98E-06	3.87E-08	
U-233	1.91E-02	9.26E-05	
U-234	6.92E-02	3.36E-04	Yes
U-235	6.43E-04	3.12E-06	
U-236	8.41E-04	4.08E-06	
U-237	9.69E-07	4.70E-09	
U-238	1.77E-02	8.58E-05	
U-240	9.40E-09	4.56E-11	
Y-90	5.24E+01	2.54E-01	
Zr-93	2.64E-01	1.28E-03	Yes
TOTAL	2.06E+02	1.00E+00	

APPENDIX D. ACTIVITIES OF DRIED SLUDGE IN YEAR 2315 ($\mu\text{Ci/g}$)

Nuclide	Y 2315 μCi/g	Fraction of Activity	Reportable	Nuclide	Y 2315 μCi/g	Fraction of Activity	Reportable
Ac-225	5.46E-04	7.57E-06		Po-214	9.73E-06	1.35E-07	
Ac-227	3.73E-06	5.18E-08		Po-215	3.73E-06	5.18E-08	
Ac-228	5.07E-05	7.03E-07		Po-216	5.07E-05	7.03E-07	
Am-241	1.30E+01	1.81E-01	Yes	Po-218	9.74E-06	1.35E-07	
Am-242	1.72E-02	2.38E-04		Pu-238	1.08E+01	1.50E-01	Yes
Am-242m	1.73E-02	2.39E-04	Yes	Pu-239	1.02E+01	1.42E-01	Yes
Am-243	1.59E+00	2.21E-02	Yes	Pu-240	4.61E+00	6.39E-02	Yes
At-217	5.46E-04	7.57E-06		Pu-241	3.43E-02	4.75E-04	Yes
At-218	1.95E-09	2.70E-11		Pu-242	5.84E-03	8.10E-05	
Ba-133	2.27E-10	3.15E-12		Pu-243	5.65E-03	7.83E-05	
Ba-137m	1.96E-01	2.71E-03		Pu-244	1.40E-08	1.94E-10	
Bi-210	7.77E-06	1.08E-07		Ra-223	3.73E-06	5.18E-08	
Bi-211	3.73E-06	5.18E-08		Ra-224	5.07E-05	7.03E-07	
Bi-212	5.07E-05	7.03E-07		Ra-225	5.46E-04	7.57E-06	
Bi-213	5.46E-04	7.57E-06		Ra-226	9.74E-06	1.35E-07	
Bi-214	9.74E-06	1.35E-07		Ra-228	5.07E-05	7.03E-07	
Bk-247	1.17E-02	1.62E-04	Yes	Rn-219	3.73E-06	5.18E-08	
Cd-113m	2.07E-07	2.87E-09		Rn-220	5.07E-05	7.03E-07	
Cf-249	4.03E-03	5.58E-05		Rn-222	9.74E-06	1.35E-07	
Cf-250	4.97E-09	6.90E-11		Sb-125	8.07E-35	1.12E-36	
Cf-251	1.48E-02	2.06E-04	Yes	Sb-126	4.53E-02	6.28E-04	
Cm-242	1.42E-02	1.98E-04		Sb-126m	3.23E-01	4.48E-03	
Cm-243	3.41E-04	4.73E-06		Se-79	1.60E-02	2.23E-04	Yes
Cm-244	7.16E-04	9.92E-06		Sm-147	3.56E-10	4.94E-12	
Cm-245	3.42E-02	4.74E-04	Yes	Sm-151	1.06E+01	1.47E-01	Yes
Cm-246	1.83E-02	2.54E-04	Yes	Sn-121	5.15E-04	7.15E-06	
Cm-247	5.65E-03	7.83E-05		Sn-121m	6.64E-04	9.21E-06	
Cm-248	5.91E-03	8.19E-05		Sn-126	3.23E-01	4.48E-03	Yes
Co-60	2.51E-18	3.48E-20		Sr-90	4.85E+00	6.72E-02	Yes
Cs-135	1.18E-03	1.64E-05		Tc-99	1.41E-01	1.95E-03	Yes
Cs-137	2.07E-01	2.87E-03	Yes	Te-125m	1.95E-35	2.71E-37	
Eu-154	3.62E-10	5.02E-12		Th-227	3.68E-06	5.11E-08	
Eu-155	2.85E-19	3.95E-21		Th-228	5.07E-05	7.03E-07	
Fr-221	5.46E-04	7.57E-06		Th-229	5.46E-04	7.57E-06	
Fr-223	5.15E-08	7.15E-10		Th-230	1.69E-04	2.35E-06	
I-129	5.20E-04	7.21E-06		Th-231	6.44E-04	8.93E-06	
Nb-93m	2.64E-01	3.66E-03	Yes	Th-232	5.07E-05	7.03E-07	
Ni-59	5.65E-01	7.84E-03	Yes	Th-234	1.77E-02	2.45E-04	
Ni-63	7.17E+00	9.94E-02	Yes	Tl-207	3.72E-06	5.16E-08	
Np-237	2.76E-02	3.83E-04	Yes	Tl-208	1.82E-05	2.53E-07	
Np-238	8.22E-05	1.14E-06		Tl-209	1.18E-05	1.63E-07	
Np-239	1.59E+00	2.21E-02		U-233	1.91E-02	2.65E-04	Yes
Np-240m	1.39E-08	1.93E-10		U-234	7.39E-02	1.02E-03	Yes
Pa-231	4.16E-06	5.77E-08		U-235	6.44E-04	8.93E-06	
Pa-233	2.76E-02	3.83E-04		U-236	8.54E-04	1.18E-05	
Pa-234	5.84E-05	8.09E-07		U-237	8.40E-07	1.16E-08	
Pa-234m	1.77E-02	2.45E-04		U-238	1.77E-02	2.45E-04	Yes
Pb-209	5.46E-04	7.57E-06		U-240	1.39E-08	1.93E-10	
Pb-210	7.78E-06	1.08E-07		Y-90	4.85E+00	6.72E-02	
Pb-211	3.73E-06	5.18E-08		Zr-93	2.64E-01	3.66E-03	Yes
Pb-212	5.07E-05	7.03E-07		TOTAL	7.21E+01	1.00E+00	
Pb-214	9.73E-06	1.35E-07					
Pd-107	5.98E-04	8.29E-06					
Pm-147	8.54E-35	1.18E-36					
Po-210	7.74E-06	1.07E-07					
Po-211	1.05E-08	1.45E-10					
Po-212	3.25E-05	4.50E-07					
Po-213	5.34E-04	7.40E-06					

APPENDIX E. ACTIVITIES OF DRIED SLUDGE IN YEAR 2415 ($\mu\text{Ci/g}$)

Nuclide	Y 2415 μCi/g	Fraction of Activity	Reportable	Nuclide	Y 2415 μCi/g	Fraction of Activity	Reportable
Ac-225	7.20E-04	1.58E-05		Po-214	1.79E-05	3.93E-07	
Ac-227	5.09E-06	1.12E-07		Po-215	5.09E-06	1.12E-07	
Ac-228	5.07E-05	1.11E-06		Po-216	5.07E-05	1.11E-06	
Am-241	1.11E+01	2.44E-01	Yes	Po-218	1.79E-05	3.93E-07	
Am-242	1.09E-02	2.39E-04		Pu-238	4.91E+00	1.08E-01	Yes
Am-242m	1.09E-02	2.40E-04	Yes	Pu-239	1.02E+01	2.24E-01	Yes
Am-243	1.58E+00	3.46E-02	Yes	Pu-240	4.56E+00	1.00E-01	Yes
At-217	7.20E-04	1.58E-05		Pu-241	3.40E-02	7.45E-04	Yes
At-218	3.59E-09	7.86E-11		Pu-242	5.84E-03	1.28E-04	Yes
Ba-133	3.58E-13	7.85E-15		Pu-243	5.65E-03	1.24E-04	
Ba-137m	1.94E-02	4.26E-04		Pu-244	1.85E-08	4.06E-10	
Bi-210	1.51E-05	3.32E-07		Ra-223	5.09E-06	1.12E-07	
Bi-211	5.09E-06	1.12E-07		Ra-224	5.07E-05	1.11E-06	
Bi-212	5.07E-05	1.11E-06		Ra-225	7.20E-04	1.58E-05	
Bi-213	7.20E-04	1.58E-05		Ra-226	1.79E-05	3.93E-07	
Bi-214	1.79E-05	3.93E-07		Ra-228	5.07E-05	1.11E-06	
Bk-247	1.11E-02	2.43E-04	Yes	Rn-219	5.09E-06	1.12E-07	
Cd-113m	1.27E-09	2.77E-11		Rn-220	5.07E-05	1.11E-06	
Cf-249	3.31E-03	7.25E-05		Rn-222	1.79E-05	3.93E-07	
Cf-250	2.49E-11	5.45E-13		Sb-125	1.10E-45	2.41E-47	
Cf-251	1.37E-02	3.01E-04	Yes	Sb-126	4.52E-02	9.92E-04	
Cm-242	9.03E-03	1.98E-04		Sb-126m	3.23E-01	7.08E-03	
Cm-243	3.00E-05	6.57E-07		Se-79	1.60E-02	3.51E-04	Yes
Cm-244	1.56E-05	3.42E-07		Sm-147	3.56E-10	7.81E-12	
Cm-245	3.39E-02	7.44E-04	Yes	Sm-151	4.92E+00	1.08E-01	Yes
Cm-246	1.81E-02	3.96E-04	Yes	Sn-121	1.46E-04	3.20E-06	
Cm-247	5.65E-03	1.24E-04	Yes	Sn-121m	1.88E-04	4.13E-06	
Cm-248	5.91E-03	1.29E-04	Yes	Sn-126	3.23E-01	7.08E-03	Yes
Co-60	4.89E-24	1.07E-25		Sr-90	4.49E-01	9.84E-03	Yes
Cs-135	1.18E-03	2.59E-05		Tc-99	1.41E-01	3.09E-03	Yes
Cs-137	2.05E-02	4.50E-04	Yes	Te-125m	2.66E-46	5.82E-48	
Eu-154	1.38E-13	3.02E-15		Th-227	5.02E-06	1.10E-07	
Eu-155	2.43E-25	5.33E-27		Th-228	5.07E-05	1.11E-06	
Fr-221	7.20E-04	1.58E-05		Th-229	7.20E-04	1.58E-05	
Fr-223	7.02E-08	1.54E-09		Th-230	2.37E-04	5.19E-06	
I-129	5.20E-04	1.14E-05		Th-231	6.45E-04	1.41E-05	
Nb-93m	2.64E-01	5.79E-03	Yes	Th-232	5.07E-05	1.11E-06	
Ni-59	5.65E-01	1.24E-02	Yes	Th-234	1.77E-02	3.88E-04	
Ni-63	3.48E+00	7.64E-02	Yes	Tl-207	5.07E-06	1.11E-07	
Np-237	2.80E-02	6.15E-04	Yes	Tl-208	1.82E-05	3.99E-07	
Np-238	5.21E-05	1.14E-06		Tl-209	1.56E-05	3.41E-07	
Np-239	1.58E+00	3.46E-02		U-233	1.91E-02	4.19E-04	Yes
Np-240m	1.85E-08	4.05E-10		U-234	7.60E-02	1.67E-03	Yes
Pa-231	5.51E-06	1.21E-07		U-235	6.45E-04	1.41E-05	
Pa-233	2.80E-02	6.15E-04		U-236	8.68E-04	1.90E-05	
Pa-234	5.84E-05	1.28E-06		U-237	8.32E-07	1.83E-08	
Pa-234m	1.77E-02	3.87E-04		U-238	1.77E-02	3.88E-04	Yes
Pb-209	7.20E-04	1.58E-05		U-240	1.85E-08	4.05E-10	
Pb-210	1.51E-05	3.32E-07		Y-90	4.49E-01	9.84E-03	
Pb-211	5.09E-06	1.12E-07		Zr-93	2.64E-01	5.79E-03	Yes
Pb-212	5.07E-05	1.11E-06		TOTAL	4.56E+01	1.00E+00	
Pb-214	1.79E-05	3.93E-07					
Pd-107	5.98E-04	1.31E-05					
Pm-147	2.87E-46	6.29E-48					
Po-210	1.51E-05	3.31E-07					
Po-211	1.42E-08	3.12E-10					
Po-212	3.25E-05	7.12E-07					
Po-213	7.05E-04	1.54E-05					

APPENDIX F. ACTIVITIES OF DRIED SLUDGE IN YEAR 2515 ($\mu\text{Ci/g}$)

Nuclide	Y 2515 μCi/g	Fraction of Activity	Reportable
Ac-225	8.93E-04	2.49E-05	
Ac-227	6.44E-06	1.79E-07	
Ac-228	5.07E-05	1.41E-06	
Am-241	9.47E+00	2.64E-01	Yes
Am-242	6.90E-03	1.92E-04	
Am-242m	6.93E-03	1.93E-04	Yes
Am-243	1.56E+00	4.36E-02	Yes
At-217	8.93E-04	2.49E-05	
At-218	5.73E-09	1.60E-10	
Ba-133	5.63E-16	1.57E-17	
Ba-137m	1.93E-03	5.37E-05	
Bi-210	2.51E-05	6.98E-07	
Bi-211	6.44E-06	1.79E-07	
Bi-212	5.07E-05	1.41E-06	
Bi-213	8.93E-04	2.49E-05	
Bi-214	2.87E-05	7.99E-07	
Bk-247	1.05E-02	2.94E-04	Yes
Cd-113m	7.74E-12	2.16E-13	
Cf-249	2.71E-03	7.56E-05	
Cf-250	1.24E-13	3.46E-15	
Cf-251	1.27E-02	3.54E-04	Yes
Cm-242	5.72E-03	1.59E-04	
Cm-243	2.63E-06	7.33E-08	
Cm-244	3.39E-07	9.44E-09	
Cm-245	3.37E-02	9.38E-04	Yes
Cm-246	1.78E-02	4.96E-04	Yes
Cm-247	5.65E-03	1.57E-04	Yes
Cm-248	5.90E-03	1.64E-04	Yes
Co-60	9.50E-30	2.65E-31	
Cs-135	1.18E-03	3.29E-05	
Cs-137	2.04E-03	5.67E-05	
Eu-154	5.22E-17	1.45E-18	
Eu-155	2.07E-31	5.77E-33	
Fr-221	8.93E-04	2.49E-05	
Fr-223	8.89E-08	2.48E-09	
I-129	5.20E-04	1.45E-05	
Nb-93m	2.64E-01	7.35E-03	Yes
Ni-59	5.64E-01	1.57E-02	Yes
Ni-63	1.69E+00	4.71E-02	Yes
Np-237	2.84E-02	7.90E-04	Yes
Np-238	3.30E-05	9.20E-07	
Np-239	1.56E+00	4.36E-02	
Np-240m	2.30E-08	6.42E-10	
Pa-231	6.87E-06	1.91E-07	
Pa-233	2.84E-02	7.90E-04	
Pa-234	5.84E-05	1.63E-06	
Pa-234m	1.77E-02	4.92E-04	
Pb-209	8.93E-04	2.49E-05	
Pb-210	2.51E-05	6.98E-07	
Pb-211	6.44E-06	1.79E-07	
Pb-212	5.07E-05	1.41E-06	
Pb-214	2.87E-05	7.98E-07	
Pd-107	5.98E-04	1.67E-05	
Pm-147	9.59E-58	2.67E-59	
Po-210	2.50E-05	6.97E-07	
Po-211	1.80E-08	5.02E-10	
Po-212	3.25E-05	9.05E-07	
Po-213	8.74E-04	2.43E-05	

Nuclide	Y 2515 μCi/g	Fraction of Activity	Reportable
Po-214	2.87E-05	7.98E-07	
Po-215	6.44E-06	1.79E-07	
Po-216	5.07E-05	1.41E-06	
Po-218	2.87E-05	7.99E-07	
Pu-238	2.23E+00	6.22E-02	Yes
Pu-239	1.02E+01	2.83E-01	Yes
Pu-240	4.51E+00	1.26E-01	Yes
Pu-241	3.37E-02	9.40E-04	Yes
Pu-242	5.85E-03	1.63E-04	Yes
Pu-243	5.65E-03	1.57E-04	
Pu-244	2.31E-08	6.42E-10	
Ra-223	6.44E-06	1.79E-07	
Ra-224	5.07E-05	1.41E-06	
Ra-225	8.93E-04	2.49E-05	
Ra-226	2.87E-05	7.99E-07	
Ra-228	5.07E-05	1.41E-06	
Rn-219	6.44E-06	1.79E-07	
Rn-220	5.07E-05	1.41E-06	
Rn-222	2.87E-05	7.99E-07	
Sb-125	1.49E-56	4.14E-58	
Sb-126	4.52E-02	1.26E-03	
Sb-126m	3.23E-01	8.99E-03	
Se-79	1.60E-02	4.46E-04	Yes
Sm-147	3.56E-10	9.93E-12	
Sm-151	2.28E+00	6.34E-02	Yes
Sn-121	4.14E-05	1.15E-06	
Sn-121m	5.34E-05	1.49E-06	
Sn-126	3.23E-01	8.99E-03	Yes
Sr-90	4.15E-02	1.16E-03	Yes
Tc-99	1.41E-01	3.92E-03	Yes
Te-125m	3.59E-57	1.00E-58	
Th-227	6.35E-06	1.77E-07	
Th-228	5.07E-05	1.41E-06	
Th-229	8.93E-04	2.49E-05	
Th-230	3.05E-04	8.51E-06	
Th-231	6.46E-04	1.80E-05	
Th-232	5.07E-05	1.41E-06	
Th-234	1.77E-02	4.93E-04	
Tl-207	6.42E-06	1.79E-07	
Tl-208	1.82E-05	5.08E-07	
Tl-209	1.93E-05	5.37E-07	
U-233	1.91E-02	5.33E-04	Yes
U-234	7.69E-02	2.14E-03	Yes
U-235	6.46E-04	1.80E-05	
U-236	8.81E-04	2.46E-05	
U-237	8.26E-07	2.30E-08	
U-238	1.77E-02	4.93E-04	Yes
U-240	2.30E-08	6.42E-10	
Y-90	4.15E-02	1.16E-03	
Zr-93	2.64E-01	7.35E-03	Yes
TOTAL	3.59E+01	1.00E+00	

APPENDIX G. ACTIVITIES OF DRIED SLUDGE IN YEAR 2615 ($\mu\text{Ci/g}$)

Nuclide	Y 2615 μCi/g	Fraction of Activity	Reportable	Nuclide	Y 2615 μCi/g	Fraction of Activity	Reportable
Ac-225	1.06E-03	3.43E-05		Po-214	4.19E-05	1.35E-06	
Ac-227	7.79E-06	2.51E-07		Po-215	7.79E-06	2.51E-07	
Ac-228	5.07E-05	1.64E-06		Po-216	5.07E-05	1.64E-06	
Am-241	8.08E+00	2.61E-01	Yes	Po-218	4.19E-05	1.35E-06	
Am-242	4.37E-03	1.41E-04		Pu-238	1.02E+00	3.28E-02	Yes
Am-242m	4.40E-03	1.42E-04	Yes	Pu-239	1.02E+01	3.27E-01	Yes
Am-243	1.55E+00	5.00E-02	Yes	Pu-240	4.47E+00	1.44E-01	Yes
At-217	1.06E-03	3.43E-05		Pu-241	3.35E-02	1.08E-03	Yes
At-218	8.37E-09	2.70E-10		Pu-242	5.85E-03	1.89E-04	Yes
Ba-133	8.87E-19	2.86E-20		Pu-243	5.65E-03	1.82E-04	
Ba-137m	1.91E-04	6.17E-06		Pu-244	2.76E-08	8.90E-10	
Bi-210	3.75E-05	1.21E-06		Ra-223	7.79E-06	2.51E-07	
Bi-211	7.79E-06	2.51E-07		Ra-224	5.07E-05	1.64E-06	
Bi-212	5.07E-05	1.64E-06		Ra-225	1.06E-03	3.43E-05	
Bi-213	1.06E-03	3.43E-05		Ra-226	4.19E-05	1.35E-06	
Bi-214	4.19E-05	1.35E-06		Ra-228	5.07E-05	1.64E-06	
Bk-247	1.00E-02	3.23E-04	Yes	Rn-219	7.79E-06	2.51E-07	
Cd-113m	4.74E-14	1.53E-15		Rn-220	5.07E-05	1.64E-06	
Cf-249	2.23E-03	7.18E-05		Rn-222	4.19E-05	1.35E-06	
Cf-250	6.20E-16	2.00E-17		Sb-125	2.02E-67	6.52E-69	
Cf-251	1.18E-02	3.80E-04	Yes	Sb-126	4.52E-02	1.46E-03	
Cm-242	3.63E-03	1.17E-04		Sb-126m	3.23E-01	1.04E-02	
Cm-243	2.31E-07	7.46E-09		Se-79	1.60E-02	5.16E-04	Yes
Cm-244	7.38E-09	2.38E-10		Sm-147	3.56E-10	1.15E-11	
Cm-245	3.34E-02	1.08E-03	Yes	Sm-151	1.05E+00	3.40E-02	Yes
Cm-246	1.75E-02	5.66E-04	Yes	Sn-121	1.18E-05	3.79E-07	
Cm-247	5.65E-03	1.82E-04	Yes	Sn-121m	1.51E-05	4.89E-07	
Cm-248	5.90E-03	1.90E-04	Yes	Sn-126	3.23E-01	1.04E-02	Yes
Co-60	1.85E-35	5.97E-37		Sr-90	3.84E-03	1.24E-04	Yes
Cs-135	1.18E-03	3.81E-05		Tc-99	1.41E-01	4.54E-03	Yes
Cs-137	2.02E-04	6.52E-06		Te-125m	4.89E-68	1.58E-69	
Eu-154	1.98E-20	6.39E-22		Th-227	7.69E-06	2.48E-07	
Eu-155	1.77E-37	5.71E-39		Th-228	5.07E-05	1.64E-06	
Fr-221	1.06E-03	3.43E-05		Th-229	1.06E-03	3.43E-05	
Fr-223	1.08E-07	3.47E-09		Th-230	3.74E-04	1.21E-05	
I-129	5.20E-04	1.68E-05		Th-231	6.47E-04	2.09E-05	
Nb-93m	2.64E-01	8.52E-03	Yes	Th-232	5.07E-05	1.64E-06	
Ni-59	5.64E-01	1.82E-02	Yes	Th-234	1.77E-02	5.71E-04	
Ni-63	8.22E-01	2.65E-02	Yes	Tl-207	7.77E-06	2.51E-07	
Np-237	2.87E-02	9.24E-04	Yes	Tl-208	1.82E-05	5.88E-07	
Np-238	2.09E-05	6.75E-07		Tl-209	2.30E-05	7.42E-07	
Np-239	1.55E+00	5.00E-02		U-233	1.91E-02	6.17E-04	Yes
Np-240m	2.76E-08	8.89E-10		U-234	7.74E-02	2.50E-03	Yes
Pa-231	8.22E-06	2.65E-07		U-235	6.47E-04	2.09E-05	
Pa-233	2.87E-02	9.24E-04		U-236	8.95E-04	2.89E-05	
Pa-234	5.84E-05	1.88E-06		U-237	8.20E-07	2.65E-08	
Pa-234m	1.77E-02	5.70E-04		U-238	1.77E-02	5.71E-04	Yes
Pb-209	1.06E-03	3.43E-05		U-240	2.76E-08	8.89E-10	
Pb-210	3.75E-05	1.21E-06		Y-90	3.84E-03	1.24E-04	
Pb-211	7.79E-06	2.51E-07		Zr-93	2.64E-01	8.52E-03	Yes
Pb-212	5.07E-05	1.64E-06		TOTAL	3.10E+01	1.00E+00	
Pb-214	4.19E-05	1.35E-06					
Pd-107	5.98E-04	1.93E-05					
Pm-147	3.22E-69	1.04E-70					
Po-210	3.74E-05	1.21E-06					
Po-211	2.18E-08	7.04E-10					
Po-212	3.25E-05	1.05E-06					
Po-213	1.04E-03	3.36E-05					

APPENDIX H. ACTIVITIES OF DRIED SLUDGE IN YEAR 2715 ($\mu\text{Ci/g}$)

Nuclide	Y 2715 μCi/g	Fraction of Activity	Reportable	Nuclide	Y 2715 μCi/g	Fraction of Activity	Reportable
Ac-225	1.23E-03	4.38E-05		Po-214	5.74E-05	2.04E-06	
Ac-227	9.15E-06	3.25E-07		Po-215	9.14E-06	3.25E-07	
Ac-228	5.07E-05	1.80E-06		Po-216	5.07E-05	1.80E-06	
Am-241	6.88E+00	2.45E-01	Yes	Po-218	5.75E-05	2.04E-06	
Am-242	2.77E-03	9.85E-05		Pu-238	4.63E-01	1.64E-02	Yes
Am-242m	2.79E-03	9.90E-05		Pu-239	1.01E+01	3.60E-01	Yes
Am-243	1.54E+00	5.46E-02	Yes	Pu-240	4.42E+00	1.57E-01	Yes
At-217	1.23E-03	4.38E-05		Pu-241	3.32E-02	1.18E-03	Yes
At-218	1.15E-08	4.08E-10		Pu-242	5.85E-03	2.08E-04	Yes
Ba-133	1.40E-21	4.96E-23		Pu-243	5.65E-03	2.01E-04	
Ba-137m	1.90E-05	6.74E-07		Pu-244	3.21E-08	1.14E-09	
Bi-210	5.23E-05	1.86E-06		Ra-223	9.14E-06	3.25E-07	
Bi-211	9.14E-06	3.25E-07		Ra-224	5.07E-05	1.80E-06	
Bi-212	5.07E-05	1.80E-06		Ra-225	1.23E-03	4.39E-05	
Bi-213	1.23E-03	4.38E-05		Ra-226	5.75E-05	2.04E-06	
Bi-214	5.75E-05	2.04E-06		Ra-228	5.07E-05	1.80E-06	
Bk-247	9.53E-03	3.39E-04	Yes	Rn-219	9.14E-06	3.25E-07	
Cd-113m	2.89E-16	1.03E-17		Rn-220	5.07E-05	1.80E-06	
Cf-249	1.83E-03	6.49E-05		Rn-222	5.75E-05	2.04E-06	
Cf-250	3.10E-18	1.10E-19		Sb-125	2.73E-78	9.71E-80	
Cf-251	1.09E-02	3.87E-04	Yes	Sb-126	4.51E-02	1.60E-03	
Cm-242	2.30E-03	8.17E-05		Sb-126m	3.22E-01	1.15E-02	
Cm-243	2.03E-08	7.21E-10		Se-79	1.60E-02	5.68E-04	Yes
Cm-244	1.61E-10	5.71E-12		Sm-147	3.56E-10	1.27E-11	
Cm-245	3.32E-02	1.18E-03	Yes	Sm-151	4.88E-01	1.73E-02	Yes
Cm-246	1.73E-02	6.14E-04	Yes	Sn-121	3.33E-06	1.18E-07	
Cm-247	5.65E-03	2.01E-04	Yes	Sn-121m	4.29E-06	1.53E-07	
Cm-248	5.90E-03	2.10E-04	Yes	Sn-126	3.22E-01	1.15E-02	Yes
Co-60	3.59E-41	1.28E-42		Sr-90	3.55E-04	1.26E-05	
Cs-135	1.18E-03	4.19E-05		Tc-99	1.41E-01	5.00E-03	Yes
Cs-137	2.00E-05	7.12E-07		Te-125m	6.61E-79	2.35E-80	
Eu-154	7.51E-24	2.67E-25		Th-227	9.02E-06	3.20E-07	
Eu-155	1.51E-43	5.35E-45		Th-228	5.07E-05	1.80E-06	
Fr-221	1.23E-03	4.38E-05		Th-229	1.23E-03	4.39E-05	
Fr-223	1.26E-07	4.48E-09		Th-230	4.44E-04	1.58E-05	
I-129	5.20E-04	1.85E-05		Th-231	6.48E-04	2.30E-05	
Nb-93m	2.64E-01	9.38E-03	Yes	Th-232	5.07E-05	1.80E-06	
Ni-59	5.63E-01	2.00E-02	Yes	Th-234	1.77E-02	6.29E-04	
Ni-63	3.99E-01	1.42E-02	Yes	Tl-207	9.12E-06	3.24E-07	
Np-237	2.89E-02	1.03E-03	Yes	Tl-208	1.82E-05	6.47E-07	
Np-238	1.33E-05	4.71E-07		Tl-209	2.67E-05	9.47E-07	
Np-239	1.54E+00	5.46E-02		U-233	1.91E-02	6.80E-04	Yes
Np-240m	3.21E-08	1.14E-09		U-234	7.75E-02	2.75E-03	Yes
Pa-231	9.57E-06	3.40E-07		U-235	6.48E-04	2.30E-05	
Pa-233	2.89E-02	1.03E-03		U-236	9.08E-04	3.23E-05	
Pa-234	5.84E-05	2.07E-06		U-237	8.14E-07	2.89E-08	
Pa-234m	1.77E-02	6.28E-04		U-238	1.77E-02	6.29E-04	Yes
Pb-209	1.23E-03	4.38E-05		U-240	3.21E-08	1.14E-09	
Pb-210	5.23E-05	1.86E-06		Y-90	3.55E-04	1.26E-05	
Pb-211	9.14E-06	3.25E-07		Zr-93	2.64E-01	9.38E-03	Yes
Pb-212	5.07E-05	1.80E-06		TOTAL	2.81E+01	1.00E+00	
Pb-214	5.74E-05	2.04E-06					
Pd-107	5.98E-04	2.12E-05					
Pm-147	1.08E-80	3.82E-82					
Po-210	5.22E-05	1.85E-06					
Po-211	2.56E-08	9.10E-10					
Po-212	3.25E-05	1.15E-06					
Po-213	1.21E-03	4.29E-05					

APPENDIX I. ACTIVITIES OF DRIED SLUDGE IN YEAR 2815 ($\mu\text{Ci/g}$)

Nuclide	Y 2815 μCi/g	Fraction of Activity	Reportable	Nuclide	Y 2815 μCi/g	Fraction of Activity	Reportable
Ac-225	1.40E-03	5.33E-05		Po-214	7.53E-05	2.86E-06	
Ac-227	1.05E-05	3.99E-07		Po-215	1.05E-05	3.99E-07	
Ac-228	5.07E-05	1.93E-06		Po-216	5.07E-05	1.93E-06	
Am-241	5.87E+00	2.23E-01	Yes	Po-218	7.53E-05	2.86E-06	
Am-242	1.76E-03	6.68E-05		Pu-238	2.11E-01	8.02E-03	Yes
Am-242m	1.77E-03	6.71E-05		Pu-239	1.01E+01	3.84E-01	Yes
Am-243	1.52E+00	5.78E-02	Yes	Pu-240	4.37E+00	1.66E-01	Yes
At-217	1.40E-03	5.33E-05		Pu-241	3.30E-02	1.25E-03	Yes
At-218	1.51E-08	5.73E-10		Pu-242	5.85E-03	2.22E-04	Yes
Ba-133	2.20E-24	8.36E-26		Pu-243	5.65E-03	2.15E-04	
Ba-137m	1.88E-06	7.15E-08		Pu-244	3.67E-08	1.39E-09	
Bi-210	6.94E-05	2.64E-06		Ra-223	1.05E-05	3.99E-07	
Bi-211	1.05E-05	3.99E-07		Ra-224	5.07E-05	1.93E-06	
Bi-212	5.07E-05	1.93E-06		Ra-225	1.40E-03	5.33E-05	
Bi-213	1.40E-03	5.33E-05		Ra-226	7.53E-05	2.86E-06	
Bi-214	7.53E-05	2.86E-06		Ra-228	5.07E-05	1.93E-06	
Bk-247	9.07E-03	3.45E-04	Yes	Rn-219	1.05E-05	3.99E-07	
Cd-113m	1.77E-18	6.73E-20		Rn-220	5.07E-05	1.93E-06	
Cf-249	1.50E-03	5.70E-05		Rn-222	7.53E-05	2.86E-06	
Cf-250	1.55E-20	5.88E-22		Sb-125	3.72E-89	1.41E-90	
Cf-251	1.01E-02	3.83E-04	Yes	Sb-126	4.51E-02	1.71E-03	
Cm-242	1.46E-03	5.54E-05		Sb-126m	3.22E-01	1.22E-02	
Cm-243	1.78E-09	6.78E-11		Se-79	1.60E-02	6.07E-04	Yes
Cm-244	3.50E-12	1.33E-13		Sm-147	3.56E-10	1.35E-11	
Cm-245	3.29E-02	1.25E-03	Yes	Sm-151	2.26E-01	8.59E-03	Yes
Cm-246	1.70E-02	6.47E-04	Yes	Sn-121	9.45E-07	3.59E-08	
Cm-247	5.65E-03	2.15E-04	Yes	Sn-121m	1.22E-06	4.63E-08	
Cm-248	5.90E-03	2.24E-04	Yes	Sn-126	3.22E-01	1.22E-02	Yes
Co-60	7.00E-47	2.66E-48		Sr-90	3.29E-05	1.25E-06	
Cs-135	1.18E-03	4.48E-05		Tc-99	1.41E-01	5.35E-03	Yes
Cs-137	1.99E-06	7.56E-08		Te-125m	9.00E-90	3.42E-91	
Eu-154	2.85E-27	1.08E-28		Th-227	1.04E-05	3.93E-07	
Eu-155	1.29E-49	4.89E-51		Th-228	5.07E-05	1.93E-06	
Fr-221	1.40E-03	5.33E-05		Th-229	1.40E-03	5.33E-05	
Fr-223	1.45E-07	5.51E-09		Th-230	5.13E-04	1.95E-05	
I-129	5.20E-04	1.98E-05		Th-231	6.49E-04	2.47E-05	
Nb-93m	2.64E-01	1.00E-02	Yes	Th-232	5.07E-05	1.93E-06	
Ni-59	5.63E-01	2.14E-02	Yes	Th-234	1.77E-02	6.73E-04	
Ni-63	1.94E-01	7.37E-03	Yes	Tl-207	1.05E-05	3.98E-07	
Np-237	2.91E-02	1.11E-03	Yes	Tl-208	1.82E-05	6.92E-07	
Np-238	8.40E-06	3.19E-07		Tl-209	3.03E-05	1.15E-06	
Np-239	1.52E+00	5.78E-02		U-233	1.91E-02	7.27E-04	Yes
Np-240m	3.66E-08	1.39E-09		U-234	7.76E-02	2.95E-03	Yes
Pa-231	1.09E-05	4.15E-07		U-235	6.49E-04	2.47E-05	
Pa-233	2.91E-02	1.11E-03		U-236	9.21E-04	3.50E-05	
Pa-234	5.84E-05	2.22E-06		U-237	8.08E-07	3.07E-08	
Pa-234m	1.77E-02	6.71E-04		U-238	1.77E-02	6.73E-04	Yes
Pb-209	1.40E-03	5.33E-05		U-240	3.66E-08	1.39E-09	
Pb-210	6.94E-05	2.64E-06		Y-90	3.29E-05	1.25E-06	
Pb-211	1.05E-05	3.99E-07		Zr-93	2.64E-01	1.00E-02	Yes
Pb-212	5.07E-05	1.93E-06		TOTAL	2.63E+01	1.00E+00	
Pb-214	7.53E-05	2.86E-06					
Pd-107	5.98E-04	2.27E-05					
Pm-147	3.62E-92	1.38E-93					
Po-210	6.93E-05	2.63E-06					
Po-211	2.94E-08	1.12E-09					
Po-212	3.25E-05	1.23E-06					
Po-213	1.37E-03	5.22E-05					

APPENDIX J. ACTIVITIES OF DRIED SLUDGE IN YEAR 2915 ($\mu\text{Ci/g}$)

Nuclide	Y 2015 μCi/g	Fraction of Activity	Reportable	Nuclide	Y 2015 μCi/g	Fraction of Activity	Reportable
Ac-225	1.57E-03	6.27E-05		Po-214	9.53E-05	3.81E-06	
Ac-227	1.18E-05	4.74E-07		Po-215	1.18E-05	4.74E-07	
Ac-228	5.07E-05	2.03E-06		Po-216	5.07E-05	2.03E-06	
Am-241	5.00E+00	2.00E-01	Yes	Po-218	9.54E-05	3.81E-06	
Am-242	1.11E-03	4.45E-05		Pu-238	9.64E-02	3.86E-03	Yes
Am-242m	1.12E-03	4.48E-05		Pu-239	1.01E+01	4.03E-01	Yes
Am-243	1.51E+00	6.03E-02	Yes	Pu-240	4.33E+00	1.73E-01	Yes
At-217	1.57E-03	6.27E-05		Pu-241	3.27E-02	1.31E-03	Yes
At-218	1.91E-08	7.63E-10		Pu-242	5.86E-03	2.34E-04	Yes
Ba-133	3.46E-27	1.39E-28		Pu-243	5.65E-03	2.26E-04	
Ba-137m	1.87E-07	7.47E-09		Pu-244	4.12E-08	1.65E-09	
Bi-210	8.88E-05	3.55E-06		Ra-223	1.18E-05	4.74E-07	
Bi-211	1.18E-05	4.74E-07		Ra-224	5.07E-05	2.03E-06	
Bi-212	5.07E-05	2.03E-06		Ra-225	1.57E-03	6.27E-05	
Bi-213	1.57E-03	6.27E-05		Ra-226	9.54E-05	3.81E-06	
Bi-214	9.54E-05	3.81E-06		Ra-228	5.07E-05	2.03E-06	
Bk-247	8.62E-03	3.45E-04	Yes	Rn-219	1.18E-05	4.74E-07	
Cd-113m	1.08E-20	4.34E-22		Rn-220	5.07E-05	2.03E-06	
Cf-249	1.23E-03	4.92E-05		Rn-222	9.54E-05	3.81E-06	
Cf-250	7.74E-23	3.09E-24		Sb-125	5.07E-100	2.03E-101	
Cf-251	9.34E-03	3.73E-04	Yes	Sb-126	4.51E-02	1.80E-03	
Cm-242	9.24E-04	3.69E-05		Sb-126m	3.22E-01	1.29E-02	
Cm-243	1.57E-10	6.27E-12		Se-79	1.59E-02	6.38E-04	Yes
Cm-244	7.62E-14	3.05E-15		Sm-147	3.56E-10	1.43E-11	
Cm-245	3.27E-02	1.31E-03	Yes	Sm-151	1.05E-01	4.18E-03	Yes
Cm-246	1.68E-02	6.71E-04	Yes	Sn-121	2.68E-07	1.07E-08	
Cm-247	5.65E-03	2.26E-04	Yes	Sn-121m	3.45E-07	1.38E-08	
Cm-248	5.90E-03	2.36E-04	Yes	Sn-126	3.22E-01	1.29E-02	Yes
Co-60	1.36E-52	5.46E-54		Sr-90	3.04E-06	1.22E-07	
Cs-135	1.18E-03	4.72E-05		Tc-99	1.41E-01	5.62E-03	Yes
Cs-137	1.97E-07	7.89E-09		Te-125m	1.23E-100	4.90E-102	
Eu-154	1.08E-30	4.34E-32		Th-227	1.17E-05	4.67E-07	
Eu-155	1.10E-55	4.40E-57		Th-228	5.07E-05	2.03E-06	
Fr-221	1.57E-03	6.27E-05		Th-229	1.57E-03	6.28E-05	
Fr-223	1.63E-07	6.54E-09		Th-230	5.83E-04	2.33E-05	
I-129	5.20E-04	2.08E-05		Th-231	6.50E-04	2.60E-05	
Nb-93m	2.64E-01	1.06E-02	Yes	Th-232	5.07E-05	2.03E-06	
Ni-59	5.62E-01	2.25E-02	Yes	Th-234	1.77E-02	7.08E-04	
Ni-63	9.42E-02	3.77E-03	Yes	Tl-207	1.18E-05	4.72E-07	
Np-237	2.93E-02	1.17E-03	Yes	Tl-208	1.82E-05	7.28E-07	
Np-238	5.33E-06	2.13E-07		Tl-209	3.39E-05	1.36E-06	
Np-239	1.51E+00	6.03E-02		U-233	1.91E-02	7.65E-04	Yes
Np-240m	4.12E-08	1.65E-09		U-234	7.76E-02	3.10E-03	Yes
Pa-231	1.23E-05	4.91E-07		U-235	6.50E-04	2.60E-05	
Pa-233	2.93E-02	1.17E-03		U-236	9.34E-04	3.73E-05	
Pa-234	5.84E-05	2.33E-06		U-237	8.01E-07	3.20E-08	
Pa-234m	1.77E-02	7.06E-04		U-238	1.77E-02	7.08E-04	Yes
Pb-209	1.57E-03	6.27E-05		U-240	4.12E-08	1.65E-09	
Pb-210	8.88E-05	3.55E-06		Y-90	3.04E-06	1.22E-07	
Pb-211	1.18E-05	4.74E-07		Zr-93	2.64E-01	1.06E-02	Yes
Pb-212	5.07E-05	2.03E-06		TOTAL	2.50E+01	1.00E+00	
Pb-214	9.53E-05	3.81E-06					
Pd-107	5.98E-04	2.39E-05					
Pm-147	1.22E-103	4.87E-105					
Po-210	8.87E-05	3.55E-06					
Po-211	3.32E-08	1.33E-09					
Po-212	3.25E-05	1.30E-06					
Po-213	1.54E-03	6.14E-05					

APPENDIX K. ACTIVITIES OF DRIED SLUDGE IN YEAR 3015 ($\mu\text{Ci/g}$)

Nuclide	Y 3015 μCi/g	Fraction of Activity	Reportable	Nuclide	Y 3015 μCi/g	Fraction of Activity	Reportable
Ac-225	1.73E-03	7.22E-05		Po-214	1.17E-04	4.89E-06	
Ac-227	1.32E-05	5.50E-07		Po-215	1.32E-05	5.49E-07	
Ac-228	5.07E-05	2.11E-06		Po-216	5.07E-05	2.11E-06	
Am-241	4.27E+00	1.78E-01	Yes	Po-218	1.18E-04	4.89E-06	
Am-242	7.06E-04	2.94E-05		Pu-238	4.41E-02	1.84E-03	Yes
Am-242m	7.09E-04	2.95E-05		Pu-239	1.01E+01	4.19E-01	Yes
Am-243	1.49E+00	6.22E-02	Yes	Pu-240	4.28E+00	1.78E-01	Yes
At-217	1.73E-03	7.22E-05		Pu-241	3.25E-02	1.35E-03	Yes
At-218	2.35E-08	9.79E-10		Pu-242	5.86E-03	2.44E-04	Yes
Ba-133	5.45E-30	2.27E-31		Pu-243	5.65E-03	2.35E-04	
Ba-137m	1.85E-08	7.71E-10		Pu-244	4.58E-08	1.91E-09	
Bi-210	1.10E-04	4.59E-06		Ra-223	1.32E-05	5.49E-07	
Bi-211	1.32E-05	5.49E-07		Ra-224	5.07E-05	2.11E-06	
Bi-212	5.07E-05	2.11E-06		Ra-225	1.73E-03	7.22E-05	
Bi-213	1.73E-03	7.22E-05		Ra-226	1.18E-04	4.89E-06	
Bi-214	1.18E-04	4.89E-06		Ra-228	5.07E-05	2.11E-06	
Bk-247	8.20E-03	3.42E-04	Yes	Rn-219	1.32E-05	5.49E-07	
Cd-113m	6.63E-23	2.76E-24		Rn-220	5.07E-05	2.11E-06	
Cf-249	1.01E-03	4.20E-05		Rn-222	1.18E-04	4.89E-06	
Cf-250	3.86E-25	1.61E-26		Sb-125	6.85E-111	2.85E-112	
Cf-251	8.64E-03	3.60E-04	Yes	Sb-126	4.50E-02	1.88E-03	
Cm-242	5.85E-04	2.44E-05		Sb-126m	3.22E-01	1.34E-02	
Cm-243	1.38E-11	5.74E-13		Se-79	1.59E-02	6.63E-04	Yes
Cm-244	1.66E-15	6.90E-17		Sm-147	3.56E-10	1.48E-11	
Cm-245	3.24E-02	1.35E-03	Yes	Sm-151	4.84E-02	2.02E-03	Yes
Cm-246	1.65E-02	6.88E-04	Yes	Sn-121	7.60E-08	3.17E-09	
Cm-247	5.65E-03	2.35E-04	Yes	Sn-121m	9.79E-08	4.08E-09	
Cm-248	5.90E-03	2.46E-04	Yes	Sn-126	3.22E-01	1.34E-02	Yes
Co-60	2.65E-58	1.10E-59		Sr-90	2.81E-07	1.17E-08	
Cs-135	1.18E-03	4.91E-05		Tc-99	1.41E-01	5.85E-03	Yes
Cs-137	1.96E-08	8.15E-10		Te-125m	1.66E-111	6.90E-113	
Eu-154	4.11E-34	1.71E-35		Th-227	1.30E-05	5.42E-07	
Eu-155	9.36E-62	3.90E-63		Th-228	5.07E-05	2.11E-06	
Fr-221	1.73E-03	7.22E-05		Th-229	1.73E-03	7.22E-05	
Fr-223	1.82E-07	7.58E-09		Th-230	6.52E-04	2.72E-05	
I-129	5.20E-04	2.17E-05		Th-231	6.51E-04	2.71E-05	
Nb-93m	2.64E-01	1.10E-02	Yes	Th-232	5.07E-05	2.11E-06	
Ni-59	5.62E-01	2.34E-02	Yes	Th-234	1.77E-02	7.37E-04	
Ni-63	4.58E-02	1.91E-03	Yes	Tl-207	1.32E-05	5.48E-07	
Np-237	2.94E-02	1.23E-03	Yes	Tl-208	1.82E-05	7.59E-07	
Np-238	3.38E-06	1.41E-07		Tl-209	3.75E-05	1.56E-06	
Np-239	1.49E+00	6.22E-02		U-233	1.91E-02	7.97E-04	Yes
Np-240m	4.57E-08	1.90E-09		U-234	7.76E-02	3.23E-03	Yes
Pa-231	1.36E-05	5.67E-07		U-235	6.51E-04	2.71E-05	
Pa-233	2.94E-02	1.23E-03		U-236	9.46E-04	3.94E-05	
Pa-234	5.84E-05	2.43E-06		U-237	7.95E-07	3.31E-08	
Pa-234m	1.77E-02	7.36E-04		U-238	1.77E-02	7.37E-04	Yes
Pb-209	1.73E-03	7.22E-05		U-240	4.57E-08	1.90E-09	
Pb-210	1.10E-04	4.59E-06		Y-90	2.82E-07	1.17E-08	
Pb-211	1.32E-05	5.49E-07		Zr-93	2.64E-01	1.10E-02	Yes
Pb-212	5.07E-05	2.11E-06		TOTAL	2.40E+01	1.00E+00	
Pb-214	1.17E-04	4.89E-06					
Pd-107	5.98E-04	2.49E-05					
Pm-147	4.07E-115	1.69E-116					
Po-210	1.10E-04	4.59E-06					
Po-211	3.69E-08	1.54E-09					
Po-212	3.25E-05	1.35E-06					
Po-213	1.70E-03	7.07E-05					

APPENDIX L. ACTIVITIES OF DRIED SLUDGE IN YEAR 3115 ($\mu\text{Ci/g}$)

Nuclide	3115 μCi/g	Fraction of Activity	Reportable
Ac-225	1.90E-03	8.18E-05	
Ac-227	1.45E-05	6.27E-07	
Ac-228	5.07E-05	2.18E-06	
Am-241	3.64E+00	1.57E-01	Yes
Am-242	4.47E-04	1.93E-05	
Am-242m	4.50E-04	1.94E-05	
Am-243	1.48E+00	6.37E-02	Yes
At-217	1.90E-03	8.18E-05	
At-218	2.83E-08	1.22E-09	
Ba-133	8.59E-33	3.70E-34	
Ba-137m	1.84E-09	7.92E-11	
Bi-210	1.34E-04	5.76E-06	
Bi-211	1.45E-05	6.27E-07	
Bi-212	5.07E-05	2.18E-06	
Bi-213	1.90E-03	8.18E-05	
Bi-214	1.42E-04	6.10E-06	
Bk-247	7.80E-03	3.36E-04	Yes
Cd-113m	4.06E-25	1.75E-26	
Cf-249	8.28E-04	3.57E-05	
Cf-250	1.93E-27	8.32E-29	
Cf-251	8.00E-03	3.45E-04	Yes
Cm-242	3.71E-04	1.60E-05	
Cm-243	1.21E-12	5.22E-14	
Cm-244	3.61E-17	1.55E-18	
Cm-245	3.21E-02	1.38E-03	Yes
Cm-246	1.63E-02	7.02E-04	Yes
Cm-247	5.65E-03	2.43E-04	Yes
Cm-248	5.90E-03	2.54E-04	Yes
Co-60	5.16E-64	2.22E-65	
Cs-135	1.18E-03	5.08E-05	
Cs-137	1.94E-09	8.37E-11	
Eu-154	1.56E-37	6.73E-39	
Eu-155	7.99E-68	3.44E-69	
Fr-221	1.90E-03	8.18E-05	
Fr-223	2.01E-07	8.65E-09	
I-129	5.20E-04	2.24E-05	
Nb-93m	2.64E-01	1.14E-02	Yes
Ni-59	5.61E-01	2.42E-02	Yes
Ni-63	2.22E-02	9.58E-04	Yes
Np-237	2.95E-02	1.27E-03	Yes
Np-238	2.14E-06	9.22E-08	
Np-239	1.48E+00	6.37E-02	
Np-240m	5.02E-08	2.16E-09	
Pa-231	1.50E-05	6.45E-07	
Pa-233	2.95E-02	1.27E-03	
Pa-234	5.84E-05	2.51E-06	
Pa-234m	1.77E-02	7.61E-04	
Pb-209	1.90E-03	8.18E-05	
Pb-210	1.34E-04	5.76E-06	
Pb-211	1.45E-05	6.27E-07	
Pb-212	5.07E-05	2.18E-06	
Pb-214	1.42E-04	6.10E-06	
Pd-107	5.98E-04	2.58E-05	
Pm-147	1.37E-126	5.89E-128	
Po-210	1.34E-04	5.76E-06	
Po-211	4.07E-08	1.75E-09	
Po-212	3.25E-05	1.40E-06	

Nuclide	3115 μCi/g	Fraction of Activity	Reportable
Po-213	1.86E-03	8.00E-05	
Po-214	1.42E-04	6.10E-06	
Po-215	1.45E-05	6.27E-07	
Po-216	5.07E-05	2.18E-06	
Po-218	1.42E-04	6.10E-06	
Pu-238	2.03E-02	8.74E-04	Yes
Pu-239	1.00E+01	4.32E-01	Yes
Pu-240	4.23E+00	1.82E-01	Yes
Pu-241	3.22E-02	1.39E-03	Yes
Pu-242	5.86E-03	2.52E-04	Yes
Pu-243	5.65E-03	2.43E-04	
Pu-244	5.03E-08	2.17E-09	
Ra-223	1.45E-05	6.27E-07	
Ra-224	5.07E-05	2.18E-06	
Ra-225	1.90E-03	8.18E-05	
Ra-226	1.42E-04	6.10E-06	
Ra-228	5.07E-05	2.18E-06	
Rn-219	1.45E-05	6.27E-07	
Rn-220	5.07E-05	2.18E-06	
Rn-222	1.42E-04	6.10E-06	
Sb-125	9.33E-122	4.02E-123	
Sb-126	4.50E-02	1.94E-03	
Sb-126m	3.22E-01	1.39E-02	
Se-79	1.59E-02	6.85E-04	Yes
Sm-147	3.56E-10	1.54E-11	
Sm-151	2.24E-02	9.66E-04	Yes
Sn-121	2.16E-08	9.29E-10	
Sn-121m	2.78E-08	1.20E-09	
Sn-126	3.22E-01	1.39E-02	Yes
Sr-90	2.60E-08	1.12E-09	
Tc-99	1.40E-01	6.05E-03	Yes
Te-125m	2.26E-122	9.72E-124	
Th-227	1.43E-05	6.18E-07	
Th-228	5.07E-05	2.18E-06	
Th-229	1.90E-03	8.18E-05	
Th-230	7.21E-04	3.11E-05	
Th-231	6.52E-04	2.81E-05	
Th-232	5.07E-05	2.18E-06	
Th-234	1.77E-02	7.63E-04	
Tl-207	1.45E-05	6.25E-07	
Tl-208	1.82E-05	7.85E-07	
Tl-209	4.10E-05	1.77E-06	
U-233	1.91E-02	8.25E-04	Yes
U-234	7.76E-02	3.34E-03	Yes
U-235	6.52E-04	2.81E-05	
U-236	9.59E-04	4.13E-05	
U-237	7.89E-07	3.40E-08	
U-238	1.77E-02	7.63E-04	Yes
U-240	5.02E-08	2.16E-09	
Y-90	2.61E-08	1.12E-09	
Zr-93	2.64E-01	1.14E-02	Yes
TOTAL	2.32E+01	1.00E+00	

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Distribution:

J. E. Marra, 773-A
J. C. Griffin, 773-A
D. A. Crowley, 999-W
C. C. Herman, 999-W
A. B. Barnes, 999-W
B. J. Giddings, 786-5A
S. D. Fink, 773-A
D. J. McCabe, 773-42A
C. W. Gardner, 773-A
B. T. Butcher, Jr., 773-43A
N. E. Bibler, 773-A
J. M. Pareizs, 773-A
S. H. Reboul, 773-42A
D. K. Peeler, 999-W
D. C. Koopman, 999-W
M. E. Stone, 999-W
D. P. Lambert, 999-W
T. B. Edwards, 999-W

J. E. Occhipinti, 704-S
J. F. Iaukea, 704-30S
J. W. Ray, 704-S
R. T. McNew, 704-27S
B. A. Davis, 704-27S
T. L. Fellingner, 704-26S
H. H. Elder, 704-26S

H. B. Shah, 766-H
J. M. Gillam, 766-H
D. D. Larsen, 766-H
D. J. Martin, 703-H
T. J. Miller, 703-A