We put science to work.™

Savannah River National Laboratory™

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

A U.S. DEPARTMENT OF ENERGY NATIONAL LABORATORY • SAVANNAH RIVER SITE • AIKEN, SC

Determination of Reportable Radionuclides for DWPF Sludge Batch 8 (Macrobatch 10)

Christopher J. Bannochie, Ph.D.
David P. DiPrete, Ph.D.

June 2014

SRNL-STI-2014-00179

SRNL.DOE.GOV

DISCLAIMER

This work was prepared under an agreement with and funded by the U.S. Government. Neither the U.S. Government or its employees, nor any of its contractors, subcontractors or their employees, makes any express or implied:

1. warranty or assumes any legal liability for the accuracy, completeness, or for the use or results of such use of any information, product, or process disclosed; or
2. representation that such use or results of such use would not infringe privately owned rights; or
3. endorsement or recommendation of any specifically identified commercial product, process, or service.

Any views and opinions of authors expressed in this work do not necessarily state or reflect those of the United States Government, or its contractors, or subcontractors.

Printed in the United States of America

Prepared for
U.S. Department of Energy

Keywords: *DWPF, Sludge Batch 8, WAPS, Radionuclides*

Retention: *Permanent*

DETERMINATION OF REPORTABLE RADIONUCLIDES FOR DWPF SLUDGE BATCH 8 (MACROBATCH 10)

C. J. Bannochie
D. P. DiPrete

June 2014

Savannah River National Laboratory™
OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

Prepared for the U.S. Department of Energy
under contract number DE-AC09-08SR22470.

REVIEWS AND APPROVALS

AUTHORS:

____

C. J. Bannochie, Process Technology Programs   Date

____

D. P. DiPrete, Analytical Development   Date

TECHNICAL REVIEWS:

____

C. L. Crawford, Process Technology Programs, Reviewed per E7 2.60   Date

APPROVAL:

____

D. H. McGuire, Manager, Process Technology Programs   Date

____

S. L. Marra, Manager, E&CPT Research Programs   Date

____

E. J. Freed, Manager, DWPF & Saltstone Facility Engineering   Date

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the SRNL Shielded Cells technicians and supervision. Additionally, we would like to thank Ceci DiPrete (AD) and Mira Malek (AD) for assistance with the vast array of counting analyses.
.

LIST OF REVISIONS

Revision Number	Summary of Changes	Date
0	Initial Report	6/2014

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 comply with 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.[2] 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 heel from Sludge Batch 7b (SB7b) and Sludge Batch 8 (SB8) that was transferred to Tank 40 from Tank 51. The blend of sludge in Tank 40 is also referred to as Macrobatch 10 (MB10). This report develops the list of reportable radionuclides and associated 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 radionuclide inventory.

This work was initiated through Technical Task Request (TTR) HLW-DWPF-TTR-2012-0009, Rev. 2 entitled *Sludge Batch (SB) 8 Qualification Studies.*[4] Specifically, this report details results from performing Subtask II, Item 2 of the TTR and, in part, meets Deliverable 7 of the TTR. The work was performed following the Task Technical and Quality Assurance Plan (TTQAP), SRNL-RP-2012-00253, Rev. 1[5] and Analytical Study Plan (ASP), SRNL-RP-2012-00561, Rev. 0.[6]

In order to determine the reportable radionuclides for SB8 (MB10), 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 identified in WAPS 1.6 were included in the list. This list was then evaluated and some isotopes were excluded from the projection calculations.

Based on measurements and analytical detection limits, 30 radionuclides have been identified as reportable for DWPF SB8 as specified by WAPS 1.2. The 30 reportable radionuclides are:

Ni-59	**Ni-63**	**Se-79**	**Sr-90**	**Zr-93**	**Nb-93m**
Tc-99	**Cd-113m**	**Sn-126***	**Cs-135**	**Cs-137**	**Sm-151**
Th-229	**U-233**	**U-234**	**Np-237**	**Pu-238**	**U-238**
Pu-239	**Pu-240**	**Am-241**	**Pu-241**	**Am-242m**	**Pu-242***
Am-243	**Cm-244**	**Cm-245**	**Cm-246**	**Cf-249***	**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. For SB8, all of the radionuclides, which meet the half-life criteria, in the Design Basis glass are reportable except for two radionuclides: Pd-107 and Th-230. At no time during the 1100-year period between 2015 and 3115 did either of these two radionuclides contribute to more than 0.01% of the radioactivity on a Curie basis. This represents the first time Cs-135 has been reportable.

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 (Pu-238, -239, -240, -241, and -242) 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 SB8 to 32.

The radionuclide measurements made for SB8 are similar to those performed in the previous SB7b/MB9 work. 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. 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. For SB9 we are specifically looking to develop methods for Cd-113m (currently estimated from a FYSF calculation), Pb-210 (currently calculated), an improved detection limit for the Ra-226 analysis, and will compare a Pd-107 method developed for tank closure with the current calculation from Pd-105. A detection limit for Cd-113m below the current calculated value may remove this radionuclide from the reportable radionuclide list for subsequent sludge batches.

Since the WAPS 1.2[1] requires that the radionuclides be indexed to the year 2015, this may no longer be possible for SB9 and certainly will not be possible for SB10. Current schedule projections place the assay date for the SB9 WAPS radionuclide characterization in late 2015 or early 2016. SRNL and SRR should seek direction from DOE on whether to either, 1) Ignore the 2015 index year and begin with 2115 or 2) Revise WAPS 1.2 to a new index year set to after the expected end of DWPF operations.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

AD	Analytical Development
ASP	Analytical Study Plan
Ci	Curie
CST	Crystalline Silico-Titanate
DI	Deionized
DOE	Department of Energy
dpm	disintegrations per minute
DWPF	Defense Waste Processing Facility
FYSF	Fission Yield Scaling Factor
g	gram
gal	gallon
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
MB6	Macrobatch 6
MB7	Macrobatch 7
MB8	Macrobatch 8
MB9	Macrobatch 9
MB10	Macrobatch 10
MST	MonoSodium Titanate
μCi	micro-Curies
PHA	Pulse Height Analysis
PTP	Process Technology Programs
QA	Quality Assurance
SB1B	Sludge Batch 1B
SB2	Sludge Batch 2
SB3	Sludge Batch 3
SB4	Sludge Batch 4
SB5	Sludge Batch 5
SB6	Sludge Batch 6
SB7a	Sludge Batch 7a
SB7b	Sludge Batch 7b
SB8	Sludge Batch 8
SCO	SRNL Shielded Cells Operations
SpA	Specific Activity (Ci/g)
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
$t_{1/2}$	half-life
TTQAP	Task Technical and Quality Assurance Plan
TTR	Technical Task 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 comply with 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.[2] 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.

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 heel from Sludge Batch 7b (SB7b), and Sludge Batch 8 (SB8) that was transferred to Tank 40 from Tank 51. The blend of sludge in Tank 40 is also referred to as Macrobatch 10 (MB10). 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 radionuclide inventory.

This work was initiated through Technical Task Request (TTR) HLW-DWPF-TTR-2012-0009, Rev. 2 entitled *Sludge Batch (SB) 8 Qualification Studies.* [4] Specifically, this report details results from performing Subtask II, Item 2 of the TTR and, in part, meets Deliverable 7 of the TTR. The work was performed following the Task Technical and Quality Assurance Plan (TTQAP), SRNL-RP-2012-00253, Rev. 1[5] and Analytical Study Plan (ASP), SRNL-RP-2012-00561, Rev. 0.[6]
.

1.2 Radionuclides Identified For Consideration as Reportable

In order to determine the reportable radionuclides for Sludge Batch 8, 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. No new isotopes have been added to the list in Table 1-1 since the SB7a report.[7] 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 in Table 1-1 and the arguments that support that decision are presented in Table 1-2.

Table 1-1. List of Radioisotopes Considered for Sludge Batch 8

Radioisotope	Radioisotope	Radioisotope	Radioisotope
C-14 [a]	Sn-121m [b]	Ra-226 [d]	Pu-241 [a]
Cl-36 [a]	Sn-126 [b]	Ac-227 [d]	Am-241 [a]
Ni-59 [a]	I-129 [b]	Th-229 [d]	Pu-242 [a]
Co-60 [a]	Ba-133 [b]	Th-230 [d]	Am-242m [a]
Ni-63 [a]	Cs-135 [b]	Pa-231 [d]	Am-243 [a]
Se-79 [b]	Cs-137 [b]	Th-232 [c]	Cm-243 [a]
Rb-87 [b]	La-138 [b]	U-232 [a]	Cm-244 [a]
Sr-90 [b]	Ce-142 [b, c]	U-233 [a]	Cm-245 [a]
Zr-93 [b]	Nd-144 [b]	U-234 [d]	Cm-246 [a]
Nb-93m [b]	Pm-147 [b]	U-235 [c]	Cm-247 [a]
Nb-94 [b]	Sm-147 [b]	U-236 [a]	Bk-247 [a]
Zr-96 [b]	Sm-149 [b]	Np-236 [a]	Cm-248 [a]
Tc-99 [b]	Nd-150 [b]	Np-237 [a]	Cf-249 [a]
Cd-113 [b, c]	Sm-151 [b]	U-238 [c]	Cf-250 [a]
Pd-107 [b]	Eu-152 [b]	Pu-238 [a]	Cf-251 [a]
Cd-113m [b]	Eu-154 [b]	Pu-239 [a]	Cf-252 [a]
In-115 [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 8

Radioisotope	Radioisotope	Radioisotope
C-14[i]	In-115 [iii]	Sm-147 [iii]
Rb-87 [iii]	La-138 [iii]	Sm-149 [iii]
Nb-94 [ii]	Ce-142 [iii]	Eu-152[ii]
Zr-96[iii]	Nd-144 [iii]	Np-236 [iv]
Cd-113 [iii]	Nd-150 [iii]	U-232[v]

i. C-14 is volatilized during DWPF Chemical and Melt Cell processing and is not immobilized in the glass.[8]

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”.[9]

iii. Rb-87, 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 (> 4.9E10 years) make their activities negligible at all times.[9]

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”.[9]

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)”.[9]

2.0 EXPERIMENTAL

The details for sample acquisition from Tank 40 – SB8, preparation of the digestions, and measurement of the elemental composition have been published separately.[10] 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). Most of the separation methods were also performed by AD personnel except for the Se-79, I-129 and Am/Cm methods that were initially performed by Process Technology Programs (PTP) personnel with guidance from AD personnel and then submitted to AD personnel for further separations and/or counting.

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 the Tank 40 – SB8 dried solids described in a previous report.[10] 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 Reference 11. The isotopes obtained from direct ICP-MS measurements included: Zr-93, Tc-99, 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 alkali fusion (also known as "peroxide fusion") digestions of the Tank 40 – SB8 dried solids described in a previous report.[10] 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: Cs-134 (detection limit) and Cs-137.

2.1.3 Liquid Scintillation Counting

Liquid scintillation counting was performed on separate sub-samples of the alkali fusion digestions of the Tank 40 – SB8 dried solids described in a previous report.[10] 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. The techniques and methodology for these separations are maintained by SRNL AD and will only be summarized here. Aliquots of the alkali 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. For the special cases involving Se-79, I-129 and Am/Cm aliquots of the sludge slurry were initially treated in the shielded cells for various separation steps (via the methodology detailed below) and then submitted to AD for further separation and/or counting.

2.2.1 Cl-36 Method

Aliquots of Sludge Batch 8 aqua regia dissolution were initially rendered caustic and subjected to two Monosodium Titanate (MST) and Crystalline Silico-Titanate (CST) based decontamination steps. The resins and insoluble elements (i.e. Actinides, lanthanides, strontium and yttrium) were filtered off, decontaminating the solution. The solutions were then acidified with nitric acid and further decontaminated with Bio-Rad AMP and Eichrom Diphonix resins. The Cl in the samples was subsequently precipitated as AgCl. The AgCl precipitate was counted using gas flow proportional counter analysis. The AgCl precipitate was then activated by neutron activation analysis to determine Cl losses during the processes. The HCl used to digest the samples initially was used to trace Cl-36 throughout the processes. The chlorine yields were used to correct Cl-36 results for any losses.

2.2.2 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 alkali fusions 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.

2.2.3 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 and submission to AD. The Se traced decontaminated dissolutions were then further decontaminated with Bio-Rad AMP-1, Eichrom Sr and RE resin treatments. 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.

2.2.4 Sr-90 Method

Aliquots of each sample from the alkali fusions[10] 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.

2.2.5 Gamma Counting Following Cs-137 Removal

This method was used to determine Co-60, Ru-106, Sb-125, Sn-126, Ba-133, Ce-144, Eu-152, Eu-154, Eu-155, and Am-241. 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 alkali fusions[10] 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. A high purity coaxial germanium detector was utilized to detect the gamma rays from Co-60, Ru-106, Sb-125, Sn-126, Ba-133, Ce-144, Eu-152, Eu-154, Eu-155, and Am-241. Only Co-60, Eu-152, Eu-154, Eu-155, and Am-241 were 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 four hours or more. 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 and Ba-133 have half-lives 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 SB8 at the selected decay times except for Ru-106 and Ce-144 which are discussed in Section 3.1.

2.2.6 Sn-121m Method

Aliquots of alkali fusions[10] were spiked with Sn-113. The aliquots were converted to a chloride matrix with hydrochloric acid, and elemental tin was extracted from the matrix using anion exchange. Tin was eluted with dilute nitric acid, and the tin extract was analyzed by low energy gamma-ray spectrometry for Sn-121m and for the Sn-113 tracer. The Sn-121m results were then yielded with the results from the Sn-113 recovery

2.2.7 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. 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 traced samples were then rendered caustic, precipitating out the actinides, lanthanides, Sr-90 and Y-90, among some other radioactive species. MST was added to further decontaminate the caustic dissolutions from Sr-90, Y-90, the actinides and the lanthanides. CST was added to reduce levels of Cs-137. The treated solutions were filtered, and the decontaminated filtrate was then removed from the Shielded Cells for submission to AD. 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 photon spectrometry 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.

2.2.8 Sm-151/Pm-147 Method

Aliquots of each sample from the alkali fusions[10] 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 where 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.

2.2.9 Th-229/-230, Ac-227 Method

Aliquots of each sample from the alkali fusions[10] were run through a thorium separation procedure. The Th species were extracted from the matrix using two stages of a quaternary amine based solid phase extraction and purified further via co-precipitation with cerium. Th-229 and Th-230 concentrations were measured using passivated, implanted, planar silicon (PIPS) alpha spectrometers. The Th separation was yielded by measuring the Th-232 activities in the separated fractions, and comparing those activities to the Th-232 concentrations measured directly off aliquots of dissolution by the ICP-MS. The Th-232 yields were used to correct the various analytes for any Th losses from the radiochemical separations.

2.2.10 Pa-231 Method

Aliquots of each sample from the alkali fusions[10] were run through a Pa separation procedure in duplicate with the duplicate containing a Pa-233 tracer. The dissolutions were decontaminated with AMP and quaternary amine based resins. Protactinium species were then extracted from the matrix using a CMPO/TBP based extractant. Pa-233 tracer concentrations were measured using high purity germanium spectrometers to determine separation yields. Pa-231 was measured using the ICP-MS. The Pa-233 tracer yields were decay corrected and then used to correct the Pa-231 analyses for any losses from the radiochemical separations.

2.2.11 U Separation Method

To lower detection limits for U-234 from the ICP-MS analyses on peroxide fusion dissolution, aliquots of dissolution were purified with a DAAP based solid phase extraction. The purified aliquots were analyzed by the ICP-MS to measure U-234/U-238 mass ratios. Those ratios were applied to U-238 concentrations measured by the ICP-MS directly on aliquots of dissolution to quantify the U-234 concentration.

2.2.12 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 ($t_{1/2}$ =15 years). Its concentration, along with that for Pu-238, was determined by isolating the Pu from each solution by a 2-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.

2.2.13 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, Cm-248, Bk-247, Cf-249, Cf-250, Cf-251, and Cf-252. 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 extended gamma counting of the dissolved sludge (see Section 2.2.5). 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. Ascorbic acid is then added, followed by Bio-RAD AMP and U-TEVA to remove Cs-137, and the tetravalent and hexavalent actinides. This mixture is then filtered. The actinides are then extracted from the dissolution filtrate using a commercially available ion exchange resin (Eichrom RE). As Y-90 coextracts with the trivalent actinides on RE resin, the treated samples were held in the Shielded Cells for nine days to allow the Y-90 to decay before they were removed and submitted to AD. 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, Cm-244, and Cf-252 were measured by alpha spectroscopy, Am-241, Am-243, Cm-243, Cm-245, Cf-249, and Cf-251 were measured by low energy gamma spectroscopy, and Cm-245, Cm-246, Cm-247, Bk-247, Cm-248 and Cf-250 were 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 Am-242m, Am-243, Cm-242, Cm-244, Cm-245, 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-247, Bk-247, Cm-248, Cf-249, Cf-250, Cf-251 and Cf-252. For these, the detection limits were then used as the maximum concentrations or activities that could be present.

2.3 Calculated Activities of the Remaining Radionuclides

2.3.1 Nb-93m

The radionuclide Nb-93m ($t_{1/2}$ = 16.1 years)[13] 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.[22, 23, 24, 25,26,27,7,16] The concentration of Nb-93m during SB8 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 SB8 total solids, the concentration at mass 90 which is composed of Sr-90, Y-90, and Zr-90 was 0.0215 wt%. The concentration of Sr-90 determined by radioactive counting was 0.00722 wt% (see Section 2.2.4). The ratio of these two values representing the fraction of Sr-90 that remained in this sludge is 0.336. With the half-life of Sr-90 and standard equation for radioactive decay[12], the age of the sludge can be calculated to be 45 years. If one takes the same ratio of radioactive Sr-90 divided by the mass 90 predicted by the fission yield scaling factor (FYSF) (see Section 2.3.3) of 0.0301 wt% to find the fraction of Sr-90 remaining or 0.240, the calculated age of the sludge is older, giving 59 years. The more realistic age of waste equal to 45 years is used in this work to calculate various radioactive decay products.

The concentration of Zr-93 in SB8 measured by ICP-MS is 0.0279 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 12.

2.3.2 Pd-107

The noble metal Pd-107 is a pure beta emitter with a very long half-life ($t_{1/2}$ = 6.5E+06 years). This radionuclide could not be detected in the SB8 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/g,[11] Cd-113m may also qualify as a WAPS reportable radionuclide. However, Cd-113m primarily decays by ß 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 a half-life greater than 1.1E11 years[13]. This makes its activity negligible at all times[9]. Finally, the fission yield of Cd-113m is very small, 1.66E-04%[14], 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 FYSF[15]. 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:

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

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

$$FYSF_i = wt\%_i / (fy_i \text{ x } am_i) \quad (2)$$

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 15. In

SB8, there are 12 isotopes that have these six properties. The FYSF's calculated for these 12 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 SB8 total dried solids by the aqua regia method. The average of the FYSF's calculated for the 12 fission products is 5.79E-05 with a relative standard deviation of 16%.

Table 2-1. Calculated Values of the Fission Yield Scaling Factor (FYSF) for Twelve U-235 Fission Products in SB8

Isotope	Measured Wt% of Total Solids	Fission Yield	FYSF
Ru-101	2.86E-02	5.20	5.44E-05
Ru-102	2.62E-02	4.30	5.97E-05
Rh-103	1.51E-02	3.03	4.85E-05
Ru-104	1.45E-02	1.88	7.44E-05
La-139	5.18E-02	6.41	5.82E-05
Pr-141	4.56E-02	5.80	5.58E-05
Nd-143	4.48E-02	5.96	5.26E-05
Nd-144	4.86E-02	5.50	6.13E-05
Nd-145	3.07E-02	3.93	5.39E-05
Nd-146	2.53E-02	3.00	5.79E-05
Sm-147	1.70E-02	2.25	5.14E-05
Sm-148	1.53E-02	1.67	6.20E-05
Average	**-**	**-**	**5.79E-05**

With the FYSF for SB8, 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 barns[13]), 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:

$$\text{Concentration Cd-113m (wt\%)} = 5.79\text{E-}05 \times 1.66\text{E-}04 \times 113 = 1.09\text{E-}06 \text{ wt\%}.$$

2.3.4 Cs-135

Prior to the development of a Cs isolation method from Ba that was first used for SB7a, the Cs-135 values were calculated by ratioing the measured Cs-135 and Cs-137 ICP-MS values from supernate. This is possible because the Ba-135 and Ba-137 are insoluble in caustic 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. This calculated value for Cs-135 in SB8 was performed using the measured ICP-MS values for mass 135 and 137 from the supernate equal to 2.80E-05 wt% and 6.94E-05 wt%, respectively, giving a mass 135: mass 137 ratio of 0.4034. This ratio was used to calculate the Cs-135 in the sludge slurry by multiplying by the measured Cs-137 in the sludge slurry, giving 0.4034 x 9.80E-04 wt% = 3.95E-04 wt% Cs-135. When the calculated and analyzed values for SB7b were compared they differed by 2%, far less than the method uncertainty,[16] hence there is a high degree of confidence in either method of determination.

2.3.5 Pb-210 and Ra-226

Calculation of the quantities of radioactive decay products Pb-210 and Ra-226 were performed based on the calculated value that the waste is 45 years old. Two of the parent radionuclides (U-234 and Pu-238) used in these calculations are indicated below in Table 3-1 of Section 3.1. The third parent radionuclide, Th-230 is long-lived alpha emitting radionuclide ($t_{1/2}$ = 7.5E+04 years) that is a decay product of U-234 and Pu-238. It is also an impurity in Thoria (ThO_2), the source material used for generating U-233. Based on the SRS Thoria specifications[7], the concentration of Th-230 in Thoria is assumed to be a maximum of 1 ppm. Coupling this concentration with the mass concentration of Th-232 provides a basis for calculating the concentration of Th-230 introduced by the Thoria. In SB8, this is the primary source of Th-230.

In calculating the concentrations of decay products, the first step was to calculate the concentrations of the parent radionuclides 45 years ago. Utilizing the standard activity decay relationship,[12] the parent concentration in 1968 was calculated as the product of the current concentration (in 2013) and the term [exp(0.693*45/ $t_{1/2}$)], where $t_{1/2}$ is the half-life of the parent radionuclide in units of years. The second step was to determine the decay product concentration in 2014, utilizing a decay/ingrowth calculation to quantify the progeny arising from 45 years of decay of the 1969 parent concentrations. RadDecay v4.01 software (see Section 3.2 below) was utilized for these calculations.

The calculated Ra-226 activity was four orders of magnitude lower than the detection limit measured for this radionuclide; therefore, the calculated value was employed in the decay calculations so as not to artificially inflate the contribution from this radionuclide.

2.4 Quality Assurance

Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2.

3.0 RESULTS AND DISCUSSION

3.1 Summary of the Activities and Radionuclides for Input

The complete list of radionuclides and their activities,[11] 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: $A_o = M_o \times SpA$, 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 μCi/g, activity in Ci/gal and the method used to determine or estimate the value. The assay date for this data is November 4, 2013. The % relative standard deviations (%RSD) are given for the quadruplicate analyses with 'NA' indicated for those radionuclides that were below the detection limit and for the calculated values. As indicated in the footnotes to Table 3-1 only two analyses were performed for Se-79 and three detectable values were obtained for Pu-241 (one of the quadruplicate values was below the method quantification limits).

The total measured alpha activity of the digested samples was <260 μCi/g of total dried solids. Total measured beta activity was measured at 2.51E+04 μCi/g of total dried solids with a %RSD of 2.19.

Table 3-1. List of Radionuclides and Activities Used as Input to the *RadDecay* v. 4.01 Program

Radionuclide	Specific Activity (Ci/g)	Wt% of Total Solids	Activity (μCi/g)[ŧ]	Activity (Ci/gal)	% RSD	Method
Cl-36	3.30E-02	<4.00E-07	<1.32E-04	<9.94E-08	NA	Cl-36
Ni-59	8.08E-02	9.33E-04	7.53E-01	5.67E-04	9.19	Ni-59/-63
Co-60	1.13E+03	1.10E-07	1.25E+00	9.40E-04	2.13	Cs-Removed Gamma Counting
Ni-63	6.17E+01	1.51E-04	9.34E+01	7.03E-02	3.99	Ni-59/-63
Se-79	6.97E-02	1.49E-05	1.04E-02	7.82E-06	15.9**	Se-79
Sr-90	1.36E+02	7.22E-03	9.85E+03	7.42E+00	5.26	Sr-90
Y-90*	5.44E+05	1.81E-06	9.85E+03	7.42E+00	5.26	Secular equilibrium w/ Sr-90
Zr-93	2.51E-03	2.79E-02	7.02E-01	5.29E-04	9.24	ICP-MS
Nb-93m	2.83E+02	2.18E-07	6.15E-01	4.63E-04	NA	Calculated from Zr-93 and Waste Age
Tc-99	1.70E-02	2.02E-03	3.43E-01	2.58E-04	4.56	ICP-MS
Pd-107	5.14E-04	2.95E-04	1.52E-03	1.14E-06	NA	Calculated from Pd-105
Cd-113m	2.17E+02	1.09E-06	2.35E+00	1.77E-03	NA	Based on Fission Yield
Sn-121m	5.91E+01	6.25E-07	3.70E-01	2.78E-04	19.5	Sn-121m
Sb-125	1.03E+03	<1.24E-08	<1.28E-01	<9.63E-05	NA	Cs-Removed Gamma Counting
Te-125m*	1.80E+04	<7.10E-10	<1.28E-01	<9.63E-05	NA	Secular equilibrium w/ Sb-125
Sn-126	2.84E-02	<9.94E-04	<2.82E-01	<2.12E-04	NA	Cs-Removed Gamma Counting
I-129	1.77E-04	1.15E-03	2.04E-03	1.53E-06	4.44	I-129
Ba-133	2.50E+02	<2.67E-08	<6.67E-02	<5.02E-05	NA	Cs-Removed Gamma Counting
Cs-135	1.15E-03	3.95E-04	4.55E-03	3.43E-06	3.32	Ratio of Cs-135:Cs-137 supernate applied to Cs-137 slurry
Cs-137	8.70E+01	9.80E-04	8.52E+02	6.42E-01	1.75	Direct Gamma Counting
Ba-137m*	5.38E+08	1.50E-10	8.06E+02	6.07E-01	1.75	Calculated from 0.946 x Cs-137 activity
Pm-147	9.27E+02	<1.35E-05	<1.25E+02	<9.43E-02	NA	Pm-147/Sm-151
Sm-151	2.63E+01	6.20E-04	1.63E+02	1.23E-01	2.40	Pm-147/Sm-151
Eu-152	1.73E+02	1.66E-07	2.87E-01	2.16E-04	1.85	Cs-Removed Gamma Counting
Eu-154	2.70E+02	4.11E-06	1.11E+01	8.34E-03	1.85	Cs-Removed Gamma Counting
Eu-155	4.65E+02	3.43E-07	1.59E+00	1.20E-03	29.3	Cs-Removed Gamma Counting
Pb-210	7.63E+01	2.05E-12	1.56E-06	1.18E-09	NA	Calculated from Pu-238, U-234, Thoria Impurity and Waste Age
Ra-226	9.89E-01	3.45E-10	3.42E-06	2.57E-09	NA	Calculated from Pu-238, U-234, Thoria Impurity and Waste Age
Ac-227	7.23E+01	1.25E-09	9.02E-04	6.79E-07	1.31	Th-229/-230
Th-229	2.13E-01	1.10E-07	2.35E-04	1.77E-07	1.28	Th-229/-230
Th-230	2.11E-02	3.46E-07	7.30E-05	5.49E-08	1.33	Th-229/-230
Pa-231	4.72E-02	<9.19E-07	<4.34E-04	<3.27E-07	NA	Pa-231
Th-232	1.10E-07	8.16E-01	8.95E-04	6.74E-07	1.29	ICP-MS
U-233	9.68E-03	6.20E-04	6.00E-02	4.52E-05	1.28	U – ICP-MS
U-234	6.25E-03	7.02E-04	4.39E-02	3.30E-05	1.62	U – ICP-MS
U-235	2.16E-06	2.50E-02	5.41E-04	4.07E-07	1.18	U – ICP-MS
U-236	6.47E-05	1.55E-03	1.01E-03	7.57E-07	2.41	U – ICP-MS
Np-237	7.05E-04	3.54E-03	2.50E-02	1.88E-05	9.13	ICP-MS
U-238	3.36E-07	3.72E+00	1.25E-02	9.41E-06	0.638	ICP-MS
Pu-238	1.71E+01	1.16E-03	1.99E+02	1.50E-01	3.26	Pu-238/-241
Pu-239	6.22E-02	1.25E-02	7.78E+00	5.86E-03	3.42	ICP-MS
Pu-240	2.28E-01	1.24E-03	2.82E+00	2.13E-03	15.6	ICP-MS
Pu-241	1.03E+02	4.19E-05	4.32E+01	3.25E-02	0.542***	Pu-238/-241
Pu-242	3.82E-03	<1.92E-04	<7.31E-03	<5.51E-06	NA	ICP-MS
Am-241	3.43E+00	7.99E-04	2.74E+01	2.06E-02	3.74	Cs-Removed Gamma Counting
Am-242m	9.72E+00	1.47E-06	1.42E-01	1.07E-04	36.6	Am/Cm
Am-243	1.99E-01	9.46E-04	1.88E+00	1.42E-03	13.4	Am/Cm
Cm-242	3.31E+03	3.56E-09	1.18E-01	8.86E-05	36.6	Am/Cm
Cm-243	5.16E+01	<1.42E-07	<7.33E-02	<5.52E-05	NA	Am/Cm
Cm-244	8.09E+01	8.42E-05	6.81E+01	5.13E-02	15.2	Am/Cm
Cm-245	1.72E-01	6.30E-06	1.08E-02	8.15E-06	18.7	Am/Cm – ICP-MS
Cm-246	3.07E-01	1.01E-05	3.10E-02	2.34E-05	24.9	Am/Cm – ICP-MS
Cm-247	9.28E-05	<1.50E-07	<1.40E-07	<1.05E-10	NA	Am/Cm – ICP-MS
Bk-247	1.03E+00	<1.51E-07	<1.55E-03	<1.17E-06	NA	Am/Cm – ICP-MS
Cm-248	4.25E-03	<1.98E-07	<8.43E-06	<6.35E-09	NA	Am/Cm – ICP-MS
Cf-249	4.38E+00	<3.87E-07	<1.69E-02	<1.28E-05	NA	Am/Cm
Cf-250	1.09E+02	<5.96E-11	<6.52E-05	<4.91E-08	NA	Am/Cm – ICP-MS
Cf-251	1.86E+00	<2.58E-06	<4.79E-02	<3.61E-05	NA	Am/Cm
Cf-252	5.38E+02	<1.54E-08	<8.30E-02	<6.25E-05	NA	Am/Cm

* Included because this isotope is in secular equilibrium with a parent for which a measured value was available; [ŧ] Less than values represent the minimum detection limit value and hence are an upper bound for that isotope's activity. ** Se-79 calculated from two replicates. *** Pu-241 calculated from three replicates.

3.1 Additional Radionuclides Requested

The following radionuclides listed in Table 3-2 were not used in the WAPS radionuclide decay calculations, but are being reported as requested in the TTR.

Table 3-2. List of Additional Radionuclides and Activities Requested by DWPF in the TTR

Radionuclide	Specific Activity (Ci/g)	Wt% of Total Solids	Activity (μCi/g) [t]	Activity (Ci/gal)	Method
Ru-106	3.35E+03	<4.39E-09	<1.47E-01	<1.11E-04	Cs-Removed Gamma Counting
Rh-106*	3.56E+09	<4.12E-15	<1.47E-01	<1.11E-04	Secular equilibrium w/ Ru-106
Sb-126*	8.36E+04	<3.37E-10	<2.82E-01	<2.12E-04	Secular equilibrium w/ Sn-126
Cs-134	1.29E+03	<2.97E-08	<3.84E-01	<2.89E-04	Gamma Counting
Ce-144	3.19E+03	<2.02E-08	<6.44E-01	<4.85E-04	Cs-Removed Gamma Counting
Pr-144*	7.56E+07	<8.53E-13	<6.44E-01	<4.85E-04	Secular equilibrium w/ Ce-144

* Included because this isotope is in secular equilibrium with a parent for which a detection limit value was available.
[t] 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, *RadDecay* v. 4.01 [17], was used to identify which radionuclides were reportable through calendar year 3115. The initial activities for 59 isotopes were entered into *RadDecay* v. 4.01 and the results of two calculations with the index years 2015 and 3115 (1100 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 μCi/g of dried sludge solids at each time and the percent of the activity that each of the radionuclides contributed.[18]

Use of *RadDecay*® v. 4.01 is controlled by a Software Quality Assurance Plan[19] recently updated to take into consideration a new computer chip set and the SRS Standard Windows 7 operating system. The calculations performed using *RadDecay*® v. 4.01 were verified against a separate program called *RadCalc* v. 4.1.[20] Comparison between the two independent calculations are detailed in SRNL Electronic Laboratory.[21] Certain radionuclides were identified in the *RadCalc* v. 4.1 calculations that were not present in the *RadDecay*® v. 4.01 calculation output. These are Sb-126m2, Nd-144, Hg-206, Tl-206, Bi-209, Tl-210, Bi-215, At-215, At-219, Rn-217, Rn-218, and U-235m. All of these radionuclides, except Nd-144 and Bi-209, have very short half-lives of minutes or less, and only the Sb-126m2 and U-235m contributed significantly to the total activity. For instance at the year 3115 projection, the Sb-126m2 and U-235m contributed 0.63% and 25.28% of the total activity, respectively.[21] The Nd-144 and Bi-209 never contribute significantly to the activity throughout the evaluaton period.

The total Curie content of the dried sludge in the year 2015 is 2.11E+04 μCi/g. This value is greater than the 1.08E+04 μCi/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. The activity of Y-90 accounts for nearly the entire difference, with the balance attributable primarily to Ba-137m.

Appendix L presents the reportable radionuclides indexed to the year 3115. The total Curie content of the dried sludge in 3115 is 2.22E+01 μCi/g. This value is greater than the 2.01E+01 μCi/g total represented by the radionuclides identified as reportable. The difference is due primarily to the 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, and Pa-234m.

Thirty radionuclides have been identified as reportable for DWPF SB8 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 30 reportable radionuclides are given in Table 3-3. Examination of the calculations at every one hundred year interval out to 1100 years indicated two radionuclides became reportable at some point during this time period but were not reportable in either 2015 or 3115: Am-242m (reportable 2215-2815) and Cf-249 (reportable 2415-3015). One radionuclide, Pu-241, was reportable for each one hundred year interval except around 2215, a behavior not previously observed, but consistent with the decay of Pu-241 produced in the reactors and the ingrowth of new Pu-241 from the decay of Cm-245. Figure 3-1 shows the projected behavior of Pu-241 and some other select radionuclides during the decay of SB8 material. The data for these intermediate year calculations can be found in Appendices B-K.

Table 3-3. Reportable Radionuclides in DWPF Sludge Batch 8

Ni-59	**Ni-63**	**Se-79**	**Sr-90**	**Zr-93**	**Nb-93m**
Tc-99	**Cd-113m**	**Sn-126***	**Cs-135**	**Cs-137**	**Sm-151**
Th-229	**U-233**	**U-234**	**Np-237**	**Pu-238**	**U-238**
Pu-239	**Pu-240**	**Am-241**	**Pu-241**	**Am-242m**	**Pu-242***
Am-243	**Cm-244**	**Cm-245**	**Cm-246**	**Cf-249***	**Cf-251***

* Based upon an analytical detection limit.

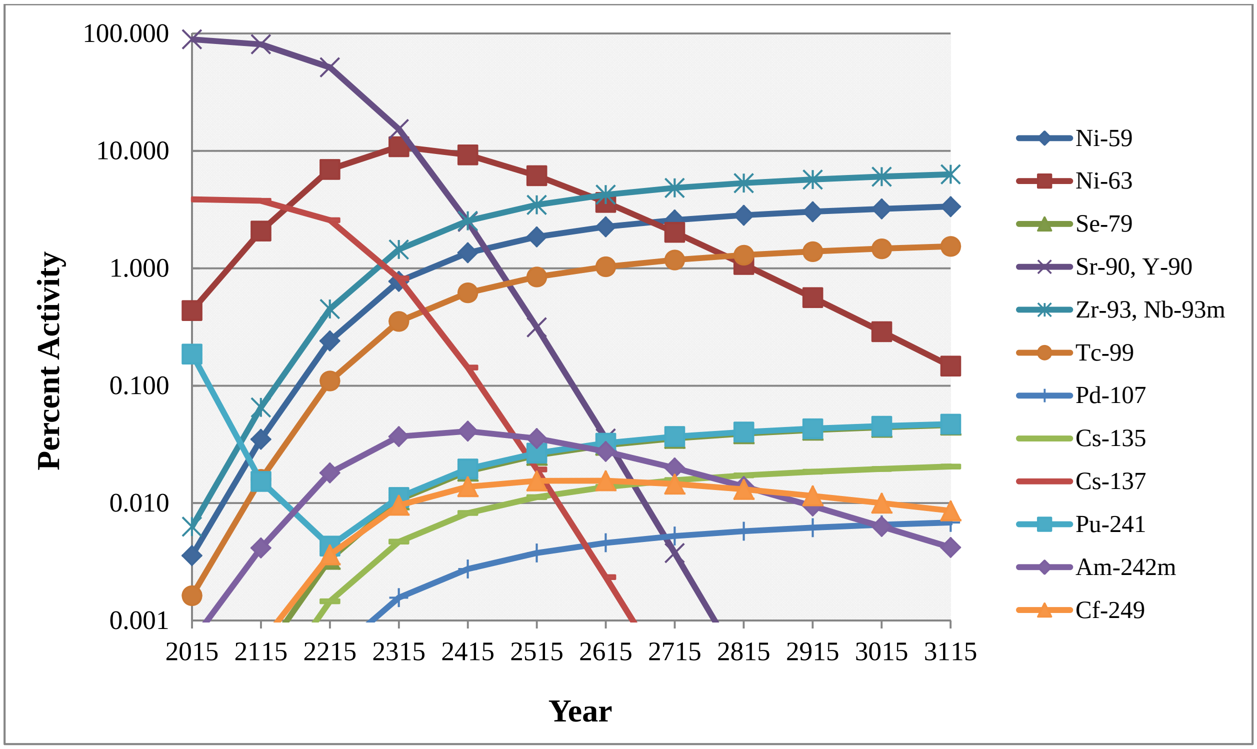

Figure 3-1 Percent of Total Activity for Select Radionuclides in DWPF Sludge Batch 8 Over the Index Years 2015 through 3115.

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, which meet the half-life criteria, in the Design Basis glass are reportable except for two radionuclides: Pd-107 and Th-230. At no time during the 1100-year period between 2015 and 3115 did either of these two radionuclides contribute to more than 0.01% of the radioactivity on a Curie basis.

Seven of the 30 reportable radionuclides for SB8 are not part of either the design-basis list of radionuclides[2] or the list of Pu and U isotopes identified in WAPS 1.6. These radionuclides are Nb-93m, Cd-113m, Th-229, Cm-245, Cm-246, Cf-249, and Cf-251.

The list of reportable radionuclides that were determined for SB1B [22] contained two radionuclides that were not reportable for SB2 through SB5. These radionuclides were I-129 and Th-229. The I-129 continues to not be reportable for SB6 through SB8, whereas the Th-229 has been reportable for these last four sludge batches. Sn-121m was reportable for SB1B, SB2, and SB3, but due to an improved detection limit was not reportable for SB4 or SB5, it was reportable again for SB6, but then not reportable for SB7a. For each sludge batch prior to SB7b, the values for Sn-121m have been based on detection limits, however the last two sludge batches have produced a detectable value for Sn-121m. For Sb7b it was reportable, but for SB8 it is not. Similarly, Cf-249 was reportable for SB3, but due to an improved detection limit for the input value, it has not been reportable for SB4 through SB7b; it is once again reportable for SB8. Cm-247, Cm-248, and Bk-247 were reportable for SB4, but improved detection limits for these input values made all of them unreportable for SB5 through SB7b, but Cm-248 was reportable for SB6. None of these three radionuclides are reportable for SB8. For earlier sludge batches and for SB6 through SB8, the Se-79 input value was not a detection limit value as it was for SB5. The detection limit was low enough in SB5 that the radionuclide was not reportable. C-14, reported in the first two batch analyses, has been excluded from consideration for future sludge batches.[8]

SB8 is the first sludge batch where Cs-135, included in the Design Basis Glass, became reportable. This is likely a result of the four-fold increase in the fraction of activity due to Cs as a result of MCU operations since SB6.[7,16,27] Figure 3-2 shows this increase in Cs-activity between SB6 and SB8.

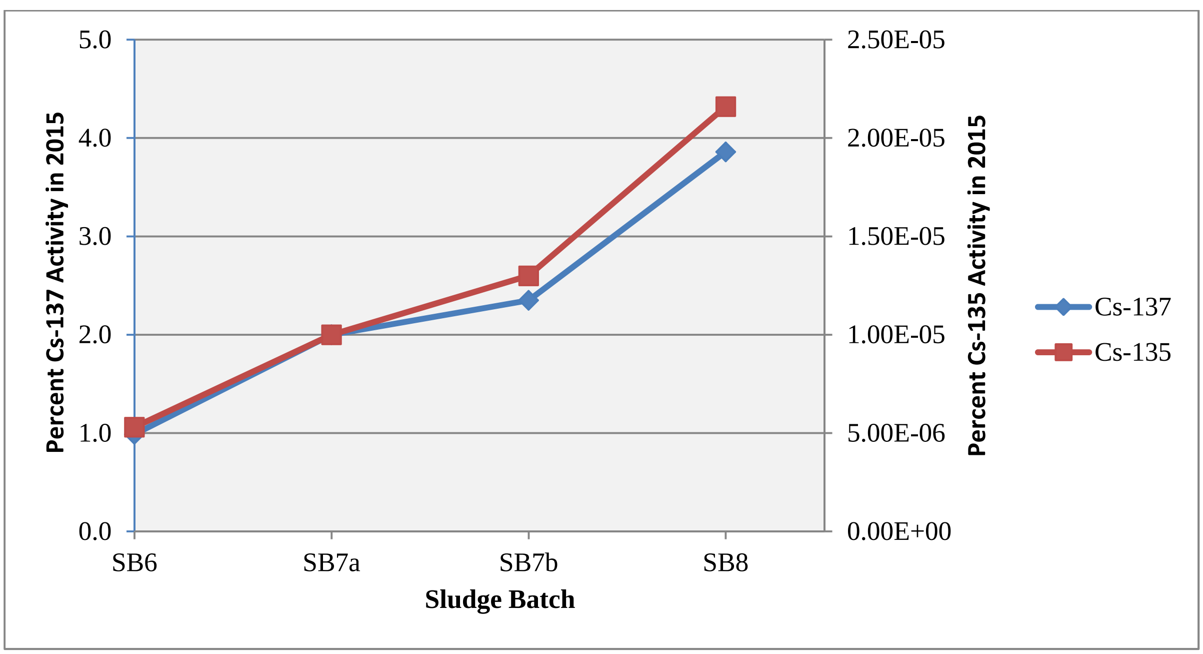

Figure 3-2 Percent of Total Activity Due to Cs-135 and Cs-137 in 2015 for Sludge Batches 6 through 8

For easier comparison, the reportable nuclides for SB1B through SB8 have been reproduced in Table 3-4.

Table 3-4. Reportable Radionuclides in DWPF Sludge Batch 1B through 8

Isotope	SB1B (MB2)[22]	SB2 (MB3)[23]	SB3 (MB4)[24]	SB4 (MB5)[25]	SB 5 (MB6)[26]	SB6 (MB7)[27]	SB7a (MB8)[7]	SB7b (MB9)[16]	SB8 (MB10)
C-14	X	X							
Cl-36					X			X	
Ni-59	X	X	X	X	X	X	X	X	X
Ni-63	X	X	X	X	X	X	X	X	X
Se-79	X	X	X	X		X	X	X	X
Sr-90	X	X	X	X	X	X	X	X	X
Zr-93	X	X	X	X	X	X	X	X	X
Nb-93m	X	X	X	X	X	X	X	X	X
Tc-99	X	X	X	X	X	X	X	X	X
Cd-113m								X	X
Sn-121m	X	X	X			X		X	
Sn-126	X	X	X	X	X	X	X	X	X
I-129	X								
Cs-135									X
Cs-137	X	X	X	X	X	X	X	X	X
Sm-151	X	X	X	X	X	X	X	X	X
Th-229	X					X	X	X	X
U-233	X	X	X	X	X	X	X	X	X
U-234	X	X	X	X	X	X	X	X	X
Np-237	X	X	X	X	X	X	X	X	X
U-238	X	X	X	X	X	X	X	X	X
Pu-238	X	X	X	X	X	X	X	X	X
Pu-239	X	X	X	X	X	X	X	X	X
Pu-240	X	X	X	X	X	X	X	X	X
Am-241	X	X	X	X	X	X	X	X	X
Pu-241	X	X	X	X	X	X	X	X	X
Pu-242	X	X	X	X	X	X	X	X	X
Am-242m			X	X	X	X			X
Am-243	X	X	X	X	X	X	X	X	X
Cm-244	X	X	X	X	X	X	X	X	X
Cm-245		X	X	X	X	X			X
Cm-246	X	X	X	X	X	X	X	X	X
Bk-247				X					
Cm-247			X	X					
Cm-248			X	X		X			
Cf-249			X			X			X
Cf-251		X	X	X	X	X	X		X

[7] Reboul, S. H., Diprete, D. P., Click, D. R., Bannochie, C. J., *Determination of Radionuclides in DWPF Sludge Batch 7a (Macrobatch 8)*, SRNL-STI-2011-00720, Rev. 0, Savannah River Site, December, 2011.

[16] Crawford, C. L., DiPrete, D. P., *Determination of Reportable Radionuclides in DWPF Sludge Batch 7b (Macrobatch 9)*, SRNL-STI-2012-00294, Rev. 2, Savannah River Site, May 2014.

[22] Fellinger, 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.

[23] 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.

[24] Bannochie, 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.

[25] Bannochie, C. J., Bibler, N. E., and DiPrete, D. P., *Determination of Reportable Radionuclides for DWPF Sludge Batch 4 (Macrobatch 5)*, WSRC-STI-2008-00142, Rev. 0, Savannah River Site, May 2008.

[26] Bannochie, C. J., Bibler, N. E., and DiPrete, D. P., *Determination of Reportable Radionuclides for DWPF Sludge Batch 5 (Macrobatch 6)*, SRNL-STI-2009-00821, Rev. 0, Savannah River Site, February 2010.

[27] Bannochie, C. J. and DiPrete, D. P., *Determination of Reportable Radionuclides for DWPF Sludge Batch 6 (Macrobatch 7)*, SRNL-STI-2011-00189, Rev. 0, Savannah River Site, May 2011.

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 MB10 – Sludge Batch 8) in order to meet the WAPS IAEA Safeguards Reporting for HLW Specification (WAPS 1.6). The data for uranium isotopes are given in Table 3-5.

Table 3-5. Uranium Isotope Distribution in DWPF Sludge Batch 8

Isotope	Wt% Total Solids	Percent Distribution
U-233	6.20E-04	0.0166
U-234	7.02E-04	0.0188
U-235	2.50E-02	0.668
U-236	1.55E-03	0.0415
U-238	3.72E+00	99.3
Total	3.74E+00	100

The data for the plutonium isotopes is given in Table 3-6.

Table 3-6. Plutonium Isotope Distribution in DWPF Sludge Batch 8

Isotope	Wt% Total Solids	Percent Distribution
Pu-238	1.16E-03	7.68
Pu-239	1.25E-02	82.6
Pu-240	1.24E-03	8.18
Pu-241	4.19E-05	0.277
Pu-242	<1.92E-04	<1.26
Total	1.52E-02	100

All of the Pu isotopes, as well as U-233, U-234, and U-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 0.002% and U-236 at 0.005% in 3115).

4.0 CONCLUSIONS

Thirty radionuclides have been identified as reportable for DWPF SB8 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 30 reportable radionuclides are:

Ni-59	**Ni-63**	**Se-79**	**Sr-90**	**Zr-93**	**Nb-93m**
Tc-99	**Cd-113m**	**Sn-126***	**Cs-135**	**Cs-137**	**Sm-151**
Th-229	**U-233**	**U-234**	**Np-237**	**Pu-238**	**U-238**
Pu-239	**Pu-240**	**Am-241**	**Pu-241**	**Am-242m**	**Pu-242***
Am-243	**Cm-244**	**Cm-245**	**Cm-246**	**Cf-249***	**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. For SB8, all of the radionuclides, which meet the half-life criteria, in the Design Basis glass are reportable except for two radionuclides: Pd-107 and Th-230. At no time during the 1100-year period between 2015 and 3115 did either of these two radionuclides contribute to more than 0.01% of the radioactivity on a Curie basis. This represents the first time Cs-135 has been reportable.

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 (Pu-238, -239, -240, -241, and -242) 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 SB8 to 32.

The radionuclide measurements made for SB8 are similar to those performed in the previous SB7b/MB9 work. 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. 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.

5.0 RECOMMENDATIONS

The radionuclide measurements made for SB8 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. 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. For SB9 we are specifically looking to develop methods for Cd-113m (currently estimated from a FYSF calculation), Pb-210 (currently calculated), an improved detection limit for the Ra-226 analysis, and will compare a Pd-107 method developed for tank closure with the current calculation from Pd-105. A detection limit for Cd-113m below the current calculated value may remove this radionuclide from the reportable radionuclide list for subsequent sludge batches.

Since the WAPS 1.2[1] requires that the radionuclides be indexed to the year 2015, this may no longer be possible for SB9 and certainly will not be possible for SB10. Current schedule projections place the assay date for the SB9 WAPS radionuclide characterization in late 2015 or early 2016. SRNL and SRR should seek direction from DOE on whether to either, 1) Ignore the 2015 index year and begin with 2115 or 2) Revise WAPS 1.2 to a new index year set to after the expected end of DWPF operations.

6.0 REFERENCES

[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] Savannah River Remediation, *DWPF Waste Form Compliance Plan*, WSRC-IM-91-116-0, Rev. 9, Savannah River Site, June 2012.

[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, March 2006.

[4] Samadi, A., *Technical Task Request: Sludge Batch (SB) 8 Qualification Studies*, HLW-DWPF-TTR-2012-0009, Rev. 2, Savannah River Site, April 2013.

[5] Pareizs, J. M., *Task Technical and Quality Assurance Plan for Sludge Batch 8 Qualification in the Shielded Cells*, SRNL-RP-2012-00253, Rev. 1, Savannah River Site, September 2013.

[6] Pareizs, J. M. and Click, D. R., *Analytical Study Plan for Sludge Batch 8 Qualification in the Shielded Cells*, SRNL-RP-2012-00561, Rev. 0, Savannah National Laboratory, August 2012.

[7] Reboul, S. H., Diprete, D. P., Click, D. R., Bannochie, C. J., *Determination of Radionuclides in DWPF Sludge Batch 7a (Macrobatch 8)*, SRNL-STI-2011-00720, Rev. 0, Savannah River Site, December, 2011.

[8] Bibler, N. E. and Fowler, J. R., *Technical Basis for Eliminating Carbon-14 as a Reportable Radionuclide In DWPF Glass*, WSRC-TR-2004-00629, Rev. 0, Savannah River Site, December 2004.

[9] Hyder, M. L., *Waste Acceptance Radionuclides to be Reported in Tank 51 Sludge Only Glass*, WSRC-TR-95-0485, Rev. 0, Savannah River Site, December 1995.

[10] Bannochie, C. J., *Tank 40 Final SB8 Chemical Characterization Results*, SRNL-STI-2013-00504, Rev. 0, Savannah River Site, September 2013.

[11] Oak Ridge National Laboratory, *Integrated Data Base Report – 1996: U. S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, USDOE Document DOE/RW-0006, Rev. 13, Oak Ridge National Laboratory, December 1997.

[12] Friedlander, G. and Kennedy, J. W., *Nuclear and Radiochemistry*; John Wiley & Sons, Inc: New York, 1957; p7.

[13] Baum, E. M., Knox, H. D., and Miller, T. R., *Nuclides and Isotopes (Chart of the Nuclides),* 16th Edition, KAPL, Inc. and Lockheed Martin, 2002.

[14] England, T. R. and Rider, B. F., *ENDF-349, Evaluation and Compilation of Fission Product Yields*, LA-UR-3106, Los Alamos National Laboratory, 1994.

[15] Bibler, N. E., Fellinger, T. L., and Hobbs, D. T., *Technetium-99 Behavior in Savannah River Site HLW Sludges During Waste Processing*, WSRC-MS-2004-00614, Savannah River Site, Published as Paper No. 4 in Session 43 of WM'06 Proceedings, WM Symposium, Tucson, AZ, February 2006.

[16] Crawford, C. L, DiPrete, D. P., Determination of Reportable Radionuclides for DWPF Sludge Batch 7B (Macrobatch 9), Savannah River National Laboratory, SRNL-STI-2012-00294, Rev. 2, Savannah River Site, May 2014.

[17] *RadDecay*, Version 4.01, Grove Software, Inc. Lynchburg, VA 24502.

[18] Bannochie, C. J., "DWPF SB8 WAPS Radioactive Decay Calculations", SRNL E-Notebook (Production), L2320-00016-18, Savannah River National Laboratory, August 2013.

[19] Bannochie, C. J., *Software Quality Assurance Plan and Acceptance Testing for Commercial Radioactive Decay Calculation Packages Utilized by Process Technology Programs*, Savannah River National Laboratory, G-SQP-A-00006, Rev. 4, December 2013.

[20] *Radcalc*, Version 4.1, U.S. Department of Energy Office of Packaging and Transportation, Energy Solutions Federal Services, Inc., Salt Lake City, UT 84101.

[21] Crawford, C. L., "SB8 WAPS Radioactive Decay Calculations", SRNL E-Notebook (Production), B9108-00026-12, Savannah River National Laboratory, February 2014.

[22] Fellinger, T. L, Bibler, N. E., and Harbour, J. R., *Characterization of and Waste Acceptance Radionuclides to be Reported for DWPF Macro Batch 2 (ESP 215 – ESP 221)*, WSRC-RP-99-00436, Rev. 1, Savannah River Site, March 2004.

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

[24] Bannochie, 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.

[25] Bannochie, C. J., Bibler, N. E., and DiPrete, D. P., *Determination of Reportable Radionuclides for DWPF Sludge Batch 4 (Macrobatch 5)*, WSRC-STI-2008-00142, Rev. 0, Savannah River Site, May 2008.

[26] Bannochie, C. J., Bibler, N. E., and DiPrete, D. P., *Determination of Reportable Radionuclides for DWPF Sludge Batch 5 (Macrobatch 6)*, SRNL-STI-2009-00821, Rev. 0, Savannah River Site, February 2010.

[27] Bannochie, C. J. and DiPrete, D. P., *Determination of Reportable Radionuclides for DWPF Sludge Batch 6 (Macrobatch 7)*, SRNL-STI-2011-00189, Rev. 0, Savannah River Site, May 2011.

APPENDIX A. ACTIVITIES OF DRIED SLUDGE IN YEAR 2015 (μCi/g)

Nuclide	Y 2015 µCi/g	Fraction of Activity	Reportable
Ac-225	2.46E-04	1.17E-08	
Ac-227	8.73E-04	4.15E-08	
Ac-228	1.92E-04	9.10E-09	
Am-241	2.74E+01	1.30E-03	Yes
Am-242	1.40E-01	6.65E-06	
Am-242m	1.41E-01	6.68E-06	
Am-243	1.88E+00	8.93E-05	
At-217	2.46E-04	1.17E-08	
At-218	6.96E-10	3.31E-14	
Ba-133	5.86E-02	2.78E-06	
Ba-137m	7.70E+02	3.66E-02	
Bi-210	1.67E-06	7.94E-11	
Bi-211	8.75E-04	4.15E-08	
Bi-212	5.64E-05	2.68E-09	
Bi-213	2.46E-04	1.17E-08	
Bi-214	3.48E-06	1.65E-10	
Bk-247	1.55E-03	7.35E-08	
Cd-113m	2.12E+00	1.01E-04	Yes
Cf-249	1.68E-02	7.99E-07	
Cf-250	5.86E-05	2.79E-09	
Cf-251	4.78E-02	2.27E-06	
Cf-252	4.91E-02	2.33E-06	
Cl-36	1.32E-04	6.27E-09	
Cm-242	1.16E-01	5.52E-06	
Cm-243	6.98E-02	3.32E-06	
Cm-244	6.31E+01	3.00E-03	Yes
Cm-245	1.08E-02	5.13E-07	
Cm-246	3.10E-02	1.47E-06	
Cm-247	1.44E-07	6.85E-12	
Cm-248	8.69E-06	4.13E-10	
Co-60	9.61E-01	4.56E-05	
Cs-135	4.55E-03	2.16E-07	
Cs-137	8.14E+02	3.86E-02	Yes
Eu-152	2.59E-01	1.23E-05	
Eu-154	9.48E+00	4.50E-04	
Eu-155	1.20E+00	5.71E-05	
Fr-221	2.46E-04	1.17E-08	
Fr-223	1.20E-05	5.72E-10	
Gd-152	9.76E-16	4.64E-20	
I-129	2.04E-03	9.69E-08	
Nb-93m	6.23E-01	2.96E-05	
Ni-59	7.53E-01	3.58E-05	
Ni-63	9.21E+01	4.37E-03	Yes
Np-237	2.50E-02	1.19E-06	
Np-238	6.70E-04	3.18E-08	
Np-239	1.88E+00	8.93E-05	
Np-240m	1.32E-13	6.25E-18	
Pa-231	4.34E-04	2.06E-08	
Pa-233	2.50E-02	1.19E-06	
Pa-234	4.12E-05	1.96E-09	
Pa-234m	1.25E-02	5.92E-07	
Pb-209	2.46E-04	1.17E-08	
Pb-210	1.67E-06	7.94E-11	
Pb-211	8.75E-04	4.15E-08	
Pb-212	5.64E-05	2.68E-09	
Pb-214	3.48E-06	1.65E-10	
Pd-107	1.52E-03	7.22E-08	
Pm-147	7.37E+01	3.50E-03	
Po-210	1.60E-06	7.60E-11	
Po-211	2.45E-06	1.16E-10	

Nuclide	Y 2015 µCi/g	Fraction of Activity	Reportable
Po-212	3.61E-05	1.72E-09	
Po-213	2.40E-04	1.14E-08	
Po-214	3.48E-06	1.65E-10	
Po-215	8.75E-04	4.15E-08	
Po-216	5.65E-05	2.68E-09	
Po-218	3.48E-06	1.65E-10	
Pu-238	1.96E+02	9.30E-03	Yes
Pu-239	7.78E+00	3.69E-04	Yes
Pu-240	2.83E+00	1.35E-04	Yes
Pu-241	3.92E+01	1.86E-03	Yes
Pu-242	7.31E-03	3.47E-07	
Pu-243	1.44E-07	6.85E-12	
Pu-244	1.32E-13	6.26E-18	
Ra-223	8.75E-04	4.15E-08	
Ra-224	5.65E-05	2.68E-09	
Ra-225	2.46E-04	1.17E-08	
Ra-226	3.48E-06	1.65E-10	
Ra-228	1.92E-04	9.10E-09	
Rn-219	8.75E-04	4.15E-08	
Rn-220	5.65E-05	2.68E-09	
Rn-222	3.48E-06	1.65E-10	
Sb-125	7.76E-02	3.69E-06	
Sb-126	3.95E-02	1.88E-06	
Sb-126m	2.82E-01	1.34E-05	
Se-79	1.04E-02	4.94E-07	
Sm-147	1.27E-09	6.03E-14	
Sm-151	1.61E+02	7.62E-03	Yes
Sn-121	2.80E-01	1.33E-05	
Sn-121m	3.61E-01	1.71E-05	
Sn-126	2.82E-01	1.34E-05	
Sr-90	9.39E+03	4.46E-01	Yes
Tc-99	3.43E-01	1.63E-05	
Te-125m	1.88E-02	8.92E-07	
Th-227	8.62E-04	4.09E-08	
Th-228	5.72E-05	2.72E-09	
Th-229	2.46E-04	1.17E-08	
Th-230	7.38E-05	3.51E-09	
Th-231	5.41E-04	2.57E-08	
Th-232	8.95E-04	4.25E-08	
Th-234	1.25E-02	5.94E-07	
Tl-207	8.72E-04	4.14E-08	
Tl-208	2.03E-05	9.62E-10	
Tl-209	5.31E-06	2.52E-10	
U-233	6.00E-02	2.85E-06	
U-234	4.50E-02	2.14E-06	
U-235	5.41E-04	2.57E-08	
U-236	1.01E-03	4.80E-08	
U-237	9.63E-04	4.57E-08	
U-238	1.25E-02	5.94E-07	
U-240	1.32E-13	6.25E-18	
Y-90	9.39E+03	4.46E-01	
Zr-93	7.02E-01	3.33E-05	
TOTAL	**2.11E+04**	1.00E+00	

APPENDIX B. ACTIVITIES OF DRIED SLUDGE IN YEAR 2115 (μCi/g)

Nuclide	Y 2115 µCi/g	Fraction of Activity	Reportable
Ac-225	8.07E-04	3.76E-07	
Ac-227	4.52E-04	2.11E-07	
Ac-228	8.95E-04	4.17E-07	
Am-241	2.45E+01	1.14E-02	Yes
Am-242	8.87E-02	4.13E-05	
Am-242m	8.92E-02	4.15E-05	
Am-243	1.86E+00	8.67E-04	Yes
At-217	8.07E-04	3.76E-07	
At-218	1.52E-09	7.10E-13	
Ba-133	9.23E-05	4.30E-08	
Ba-137m	7.64E+01	3.55E-02	
Bi-210	6.09E-06	2.84E-09	
Bi-211	4.52E-04	2.11E-07	
Bi-212	8.95E-04	4.17E-07	
Bi-213	8.07E-04	3.76E-07	
Bi-214	7.62E-06	3.55E-09	
Bk-247	1.47E-03	6.86E-07	
Cd-113m	1.30E-02	6.05E-06	
Cf-249	1.38E-02	6.43E-06	
Cf-250	2.93E-07	1.36E-10	
Cf-251	4.43E-02	2.06E-05	
Cf-252	1.91E-13	8.87E-17	
Cl-36	1.32E-04	6.14E-08	
Cm-242	7.36E-02	3.43E-05	
Cm-243	6.13E-03	2.86E-06	
Cm-244	1.37E+00	6.39E-04	Yes
Cm-245	1.08E-02	5.05E-06	
Cm-246	3.05E-02	1.42E-05	
Cm-247	3.49E-07	1.62E-10	
Cm-248	9.05E-06	4.22E-09	
Co-60	1.87E-06	8.71E-10	
Cs-135	4.55E-03	2.12E-06	
Cs-137	8.07E+01	3.76E-02	Yes
Eu-152	1.43E-03	6.64E-07	
Eu-154	3.60E-03	1.68E-06	
Eu-155	1.03E-06	4.78E-10	
Fr-221	8.07E-04	3.76E-07	
Fr-223	6.24E-06	2.91E-09	
Gd-152	9.84E-15	4.58E-18	
I-129	2.04E-03	9.50E-07	
Nb-93m	7.01E-01	3.27E-04	Yes
Ni-59	7.52E-01	3.50E-04	Yes
Ni-63	4.47E+01	2.08E-02	Yes
Np-237	2.59E-02	1.20E-05	
Np-238	4.25E-04	1.98E-07	
Np-239	1.86E+00	8.67E-04	
Np-240m	7.08E-12	3.30E-15	
Pa-231	4.34E-04	2.02E-07	
Pa-233	2.59E-02	1.20E-05	
Pa-234	4.12E-05	1.92E-08	
Pa-234m	1.25E-02	5.81E-06	
Pb-209	8.07E-04	3.76E-07	
Pb-210	6.09E-06	2.84E-09	
Pb-211	4.52E-04	2.11E-07	
Pb-212	8.95E-04	4.17E-07	
Pb-214	7.62E-06	3.55E-09	
Pd-107	1.52E-03	7.08E-07	
Pm-147	2.47E-10	1.15E-13	
Po-210	6.07E-06	2.82E-09	
Po-211	1.27E-06	5.90E-10	
Po-212	5.73E-04	2.67E-07	
Po-213	7.90E-04	3.68E-07	
Po-214	7.62E-06	3.55E-09	
Po-215	4.52E-04	2.11E-07	
Po-216	8.95E-04	4.17E-07	
Po-218	7.62E-06	3.55E-09	
Pu-238	8.90E+01	4.14E-02	Yes
Pu-239	7.76E+00	3.61E-03	Yes
Pu-240	2.97E+00	1.38E-03	Yes
Pu-241	3.29E-01	1.53E-04	Yes
Pu-242	7.32E-03	3.41E-06	
Pu-243	3.49E-07	1.62E-10	
Pu-244	7.09E-12	3.30E-15	
Ra-223	4.52E-04	2.11E-07	
Ra-224	8.95E-04	4.17E-07	
Ra-225	8.07E-04	3.76E-07	
Ra-226	7.62E-06	3.55E-09	
Ra-228	8.95E-04	4.17E-07	
Rn-219	4.52E-04	2.11E-07	
Rn-220	8.95E-04	4.17E-07	
Rn-222	7.62E-06	3.55E-09	
Sb-125	1.05E-12	4.91E-16	
Sb-126	3.95E-02	1.84E-05	
Sb-126m	2.82E-01	1.31E-04	
Se-79	1.04E-02	4.84E-06	
Sm-147	3.09E-09	1.44E-12	
Sm-151	7.43E+01	3.46E-02	Yes
Sn-121	7.94E-02	3.70E-05	
Sn-121m	1.02E-01	4.76E-05	
Sn-126	2.82E-01	1.31E-04	Yes
Sr-90	8.69E+02	4.05E-01	Yes
Tc-99	3.43E-01	1.60E-04	Yes
Te-125m	2.55E-13	1.19E-16	
Th-227	4.46E-04	2.08E-07	
Th-228	8.95E-04	4.17E-07	
Th-229	8.08E-04	3.76E-07	
Th-230	1.34E-04	6.23E-08	
Th-231	5.42E-04	2.52E-07	
Th-232	8.95E-04	4.17E-07	
Th-234	1.25E-02	5.82E-06	
Tl-207	4.51E-04	2.10E-07	
Tl-208	3.22E-04	1.50E-07	
Tl-209	1.74E-05	8.12E-09	
U-233	6.00E-02	2.79E-05	
U-234	8.34E-02	3.88E-05	
U-235	5.42E-04	2.52E-07	
U-236	1.02E-03	4.74E-07	
U-237	8.08E-06	3.76E-09	
U-238	1.25E-02	5.82E-06	
U-240	7.08E-12	3.30E-15	
Y-90	8.69E+02	4.05E-01	
Zr-93	7.02E-01	3.27E-04	Yes
TOTAL	**2.15E+03**	1.00E+00	

APPENDIX C. ACTIVITIES OF DRIED SLUDGE IN YEAR 2215 (μCi/g)

Nuclide	Y 2215 µCi/g	Fraction of Activity	Reportable
Ac-225	1.36E-03	4.37E-06	
Ac-227	4.35E-04	1.39E-06	
Ac-228	8.95E-04	2.87E-06	
Am-241	2.09E+01	6.70E-02	Yes
Am-242	5.62E-02	1.80E-04	
Am-242m	5.65E-02	1.81E-04	Yes
Am-243	1.84E+00	5.91E-03	Yes
At-217	1.36E-03	4.37E-06	
At-218	2.94E-09	9.42E-12	
Ba-133	1.45E-07	4.66E-10	
Ba-137m	7.58E+00	2.43E-02	
Bi-210	1.22E-05	3.92E-08	
Bi-211	4.35E-04	1.39E-06	
Bi-212	8.95E-04	2.87E-06	
Bi-213	1.36E-03	4.37E-06	
Bi-214	1.47E-05	4.71E-08	
Bk-247	1.40E-03	4.49E-06	
Cd-113m	7.94E-05	2.55E-07	
Cf-249	1.13E-02	3.63E-05	
Cf-250	1.46E-09	4.69E-12	
Cf-251	4.10E-02	1.31E-04	Yes
Cf-252	7.40E-25	2.37E-27	
Cl-36	1.32E-04	4.23E-07	
Cm-242	4.67E-02	1.50E-04	
Cm-243	5.39E-04	1.73E-06	
Cm-244	2.99E-02	9.58E-05	
Cm-245	1.09E-02	3.48E-05	
Cm-246	3.01E-02	9.65E-05	
Cm-247	5.38E-07	1.72E-09	
Cm-248	9.05E-06	2.90E-08	
Co-60	3.64E-12	1.17E-14	
Cs-135	4.55E-03	1.46E-05	
Cs-137	8.01E+00	2.57E-02	Yes
Eu-152	7.88E-06	2.52E-08	
Eu-154	1.37E-06	4.38E-09	
Eu-155	8.75E-13	2.81E-15	
Fr-221	1.36E-03	4.37E-06	
Fr-223	6.01E-06	1.92E-08	
Gd-152	9.89E-15	3.17E-17	
I-129	2.04E-03	6.54E-06	
Nb-93m	7.02E-01	2.25E-03	Yes
Ni-59	7.52E-01	2.41E-03	Yes
Ni-63	2.17E+01	6.96E-02	Yes
Np-237	2.66E-02	8.53E-05	
Np-238	2.69E-04	8.62E-07	
Np-239	1.84E+00	5.91E-03	
Np-240m	1.40E-11	4.50E-14	
Pa-231	4.34E-04	1.39E-06	
Pa-233	2.66E-02	8.53E-05	
Pa-234	4.12E-05	1.32E-07	
Pa-234m	1.25E-02	4.00E-05	
Pb-209	1.36E-03	4.37E-06	
Pb-210	1.22E-05	3.92E-08	
Pb-211	4.35E-04	1.39E-06	
Pb-212	8.95E-04	2.87E-06	
Pb-214	1.47E-05	4.71E-08	
Pd-107	1.52E-03	4.87E-06	
Pm-147	8.29E-22	2.66E-24	
Po-210	1.22E-05	3.90E-08	
Po-211	1.22E-06	3.91E-09	

Nuclide	Y 2215 µCi/g	Fraction of Activity	Reportable
Po-212	5.73E-04	1.84E-06	
Po-213	1.33E-03	4.28E-06	
Po-214	1.47E-05	4.71E-08	
Po-215	4.35E-04	1.39E-06	
Po-216	8.95E-04	2.87E-06	
Po-218	1.47E-05	4.71E-08	
Pu-238	4.04E+01	1.30E-01	Yes
Pu-239	7.75E+00	2.48E-02	Yes
Pu-240	2.95E+00	9.44E-03	Yes
Pu-241	1.34E-02	4.31E-05	
Pu-242	7.32E-03	2.35E-05	
Pu-243	5.38E-07	1.72E-09	
Pu-244	1.41E-11	4.51E-14	
Ra-223	4.35E-04	1.39E-06	
Ra-224	8.95E-04	2.87E-06	
Ra-225	1.36E-03	4.37E-06	
Ra-226	1.47E-05	4.71E-08	
Ra-228	8.95E-04	2.87E-06	
Rn-219	4.35E-04	1.39E-06	
Rn-220	8.95E-04	2.87E-06	
Rn-222	1.47E-05	4.71E-08	
Sb-125	1.43E-23	4.59E-26	
Sb-126	3.94E-02	1.26E-04	
Sb-126m	2.82E-01	9.03E-04	
Se-79	1.04E-02	3.33E-05	
Sm-147	3.09E-09	9.92E-12	
Sm-151	3.44E+01	1.10E-01	Yes
Sn-121	2.25E-02	7.22E-05	
Sn-121m	2.90E-02	9.30E-05	
Sn-126	2.82E-01	9.03E-04	Yes
Sr-90	8.04E+01	2.58E-01	Yes
Tc-99	3.43E-01	1.10E-03	Yes
Te-125m	3.46E-24	1.11E-26	
Th-227	4.29E-04	1.38E-06	
Th-228	8.95E-04	2.87E-06	
Th-229	1.36E-03	4.37E-06	
Th-230	2.18E-04	6.97E-07	
Th-231	5.43E-04	1.74E-06	
Th-232	8.95E-04	2.87E-06	
Th-234	1.25E-02	4.01E-05	
Tl-207	4.34E-04	1.39E-06	
Tl-208	3.22E-04	1.03E-06	
Tl-209	2.94E-05	9.44E-08	
U-233	6.00E-02	1.92E-04	Yes
U-234	1.01E-01	3.23E-04	Yes
U-235	5.43E-04	1.74E-06	
U-236	1.03E-03	3.29E-06	
U-237	3.29E-07	1.06E-09	
U-238	1.25E-02	4.01E-05	
U-240	1.40E-11	4.50E-14	
Y-90	8.04E+01	2.58E-01	
Zr-93	7.02E-01	2.25E-03	Yes
TOTAL	**3.12E+02**	1.00E+00	

APPENDIX D. ACTIVITIES OF DRIED SLUDGE IN YEAR 2315 (μCi/g)

Nuclide	Y 2315 µCi/g	Fraction of Activity	Reportable
Ac-225	1.91E-03	1.97E-05	
Ac-227	4.35E-04	4.48E-06	
Ac-228	8.95E-04	9.23E-06	
Am-241	1.78E+01	1.84E-01	Yes
Am-242	3.56E-02	3.68E-04	
Am-242m	3.58E-02	3.69E-04	Yes
Am-243	1.83E+00	1.88E-02	Yes
At-217	1.91E-03	1.97E-05	
At-218	5.06E-09	5.22E-11	
Ba-133	2.29E-10	2.36E-12	
Ba-137m	7.52E-01	7.75E-03	
Bi-210	2.17E-05	2.23E-07	
Bi-211	4.35E-04	4.48E-06	
Bi-212	8.95E-04	9.23E-06	
Bi-213	1.91E-03	1.97E-05	
Bi-214	2.53E-05	2.61E-07	
Bk-247	1.33E-03	1.37E-05	
Cd-113m	4.86E-07	5.01E-09	
Cf-249	9.30E-03	9.59E-05	
Cf-250	7.31E-12	7.54E-14	
Cf-251	3.79E-02	3.91E-04	Yes
Cf-252	2.87E-36	2.96E-38	
Cl-36	1.32E-04	1.36E-06	
Cm-242	2.96E-02	3.05E-04	
Cm-243	4.74E-05	4.88E-07	
Cm-244	6.51E-04	6.71E-06	
Cm-245	1.08E-02	1.12E-04	Yes
Cm-246	2.97E-02	3.06E-04	Yes
Cm-247	7.13E-07	7.35E-09	
Cm-248	9.05E-06	9.33E-08	
Co-60	7.08E-18	7.30E-20	
Cs-135	4.55E-03	4.69E-05	
Cs-137	7.95E-01	8.19E-03	Yes
Eu-152	4.35E-08	4.48E-10	
Eu-154	5.19E-10	5.35E-12	
Eu-155	7.47E-19	7.70E-21	
Fr-221	1.91E-03	1.97E-05	
Fr-223	6.00E-06	6.18E-08	
Gd-152	9.89E-15	1.02E-16	
I-129	2.04E-03	2.10E-05	
Nb-93m	7.02E-01	7.24E-03	Yes
Ni-59	7.51E-01	7.74E-03	Yes
Ni-63	1.06E+01	1.09E-01	Yes
Np-237	2.72E-02	2.81E-04	Yes
Np-238	1.71E-04	1.76E-06	
Np-239	1.83E+00	1.88E-02	
Np-240m	2.10E-11	2.17E-13	
Pa-231	4.35E-04	4.48E-06	
Pa-233	2.72E-02	2.81E-04	
Pa-234	4.12E-05	4.25E-07	
Pa-234m	1.25E-02	1.29E-04	
Pb-209	1.91E-03	1.97E-05	
Pb-210	2.17E-05	2.23E-07	
Pb-211	4.35E-04	4.48E-06	
Pb-212	8.95E-04	9.23E-06	
Pb-214	2.53E-05	2.61E-07	
Pd-107	1.52E-03	1.57E-05	
Pm-147	2.78E-33	2.87E-35	
Po-210	2.16E-05	2.23E-07	
Po-211	1.22E-06	1.25E-08	

Nuclide	Y 2315 µCi/g	Fraction of Activity	Reportable
Po-212	5.73E-04	5.91E-06	
Po-213	1.87E-03	1.93E-05	
Po-214	2.53E-05	2.61E-07	
Po-215	4.35E-04	4.48E-06	
Po-216	8.95E-04	9.23E-06	
Po-218	2.53E-05	2.61E-07	
Pu-238	1.84E+01	1.89E-01	Yes
Pu-239	7.73E+00	7.97E-02	Yes
Pu-240	2.91E+00	3.00E-02	Yes
Pu-241	1.09E-02	1.12E-04	Yes
Pu-242	7.33E-03	7.56E-05	
Pu-243	7.13E-07	7.35E-09	
Pu-244	2.10E-11	2.17E-13	
Ra-223	4.35E-04	4.48E-06	
Ra-224	8.95E-04	9.23E-06	
Ra-225	1.91E-03	1.97E-05	
Ra-226	2.53E-05	2.61E-07	
Ra-228	8.95E-04	9.23E-06	
Rn-219	4.35E-04	4.48E-06	
Rn-220	8.95E-04	9.23E-06	
Rn-222	2.53E-05	2.61E-07	
Sb-125	1.94E-34	2.00E-36	
Sb-126	3.94E-02	4.06E-04	
Sb-126m	2.81E-01	2.90E-03	
Se-79	1.04E-02	1.07E-04	Yes
Sm-147	3.09E-09	3.19E-11	
Sm-151	1.59E+01	1.64E-01	Yes
Sn-121	6.39E-03	6.58E-05	
Sn-121m	8.23E-03	8.48E-05	
Sn-126	2.81E-01	2.90E-03	Yes
Sr-90	7.44E+00	7.67E-02	Yes
Tc-99	3.43E-01	3.53E-03	Yes
Te-125m	4.70E-35	4.84E-37	
Th-227	4.29E-04	4.42E-06	
Th-228	8.95E-04	9.23E-06	
Th-229	1.91E-03	1.97E-05	
Th-230	3.12E-04	3.22E-06	
Th-231	5.43E-04	5.60E-06	
Th-232	8.95E-04	9.23E-06	
Th-234	1.25E-02	1.29E-04	
Tl-207	4.33E-04	4.47E-06	
Tl-208	3.22E-04	3.32E-06	
Tl-209	4.13E-05	4.26E-07	
U-233	6.00E-02	6.18E-04	Yes
U-234	1.09E-01	1.12E-03	Yes
U-235	5.43E-04	5.60E-06	
U-236	1.04E-03	1.07E-05	
U-237	2.66E-07	2.75E-09	
U-238	1.25E-02	1.29E-04	Yes
U-240	2.10E-11	2.17E-13	
Y-90	7.44E+00	7.67E-02	
Zr-93	7.02E-01	7.24E-03	Yes
TOTAL	**9.70E+01**	1.00E+00	

APPENDIX E. ACTIVITIES OF DRIED SLUDGE IN YEAR 2415 (μCi/g)

Nuclide	Y 2415 µCi/g	Fraction of Activity	Reportable
Ac-225	2.46E-03	4.44E-05	
Ac-227	4.35E-04	7.86E-06	
Ac-228	8.95E-04	1.62E-05	
Am-241	1.52E+01	2.74E-01	Yes
Am-242	2.26E-02	4.08E-04	
Am-242m	2.27E-02	4.10E-04	Yes
Am-243	1.81E+00	3.27E-02	Yes
At-217	2.46E-03	4.44E-05	
At-218	7.91E-09	1.43E-10	
Ba-133	3.60E-13	6.51E-15	
Ba-137m	7.46E-02	1.35E-03	
Bi-210	3.48E-05	6.28E-07	
Bi-211	4.35E-04	7.86E-06	
Bi-212	8.95E-04	1.62E-05	
Bi-213	2.46E-03	4.44E-05	
Bi-214	3.96E-05	7.15E-07	
Bk-247	1.27E-03	2.29E-05	
Cd-113m	2.97E-09	5.37E-11	
Cf-249	7.63E-03	1.38E-04	Yes
Cf-250	3.65E-14	6.60E-16	
Cf-251	3.51E-02	6.35E-04	Yes
Cf-252	1.11E-47	2.01E-49	
Cl-36	1.32E-04	2.38E-06	
Cm-242	1.87E-02	3.39E-04	
Cm-243	4.16E-06	7.52E-08	
Cm-244	1.42E-05	2.56E-07	
Cm-245	1.08E-02	1.96E-04	Yes
Cm-246	2.92E-02	5.28E-04	Yes
Cm-247	8.76E-07	1.58E-08	
Cm-248	9.05E-06	1.63E-07	
Co-60	1.38E-23	2.49E-25	
Cs-135	4.55E-03	8.22E-05	
Cs-137	7.88E-02	1.42E-03	Yes
Eu-152	2.40E-10	4.33E-12	
Eu-154	1.97E-13	3.56E-15	
Eu-155	6.37E-25	1.15E-26	
Fr-221	2.46E-03	4.44E-05	
Fr-223	6.00E-06	1.08E-07	
Gd-152	9.89E-15	1.79E-16	
I-129	2.04E-03	3.69E-05	
Nb-93m	7.02E-01	1.27E-02	Yes
Ni-59	7.50E-01	1.36E-02	Yes
Ni-63	5.13E+00	9.26E-02	Yes
Np-237	2.78E-02	5.02E-04	Yes
Np-238	1.08E-04	1.95E-06	
Np-239	1.81E+00	3.27E-02	
Np-240m	2.80E-11	5.05E-13	
Pa-231	4.35E-04	7.86E-06	
Pa-233	2.78E-02	5.02E-04	
Pa-234	4.12E-05	7.45E-07	
Pa-234m	1.25E-02	2.25E-04	
Pb-209	2.46E-03	4.44E-05	
Pb-210	3.48E-05	6.28E-07	
Pb-211	4.35E-04	7.86E-06	
Pb-212	8.95E-04	1.62E-05	
Pb-214	3.96E-05	7.15E-07	
Pd-107	1.52E-03	2.75E-05	
Pm-147	9.32E-45	1.68E-46	
Po-210	3.47E-05	6.26E-07	
Po-211	1.22E-06	2.20E-08	

Nuclide	Y 2415 µCi/g	Fraction of Activity	Reportable
Po-212	5.73E-04	1.04E-05	
Po-213	2.41E-03	4.35E-05	
Po-214	3.96E-05	7.15E-07	
Po-215	4.35E-04	7.86E-06	
Po-216	8.95E-04	1.62E-05	
Po-218	3.96E-05	7.15E-07	
Pu-238	8.34E+00	1.51E-01	Yes
Pu-239	7.71E+00	1.39E-01	Yes
Pu-240	2.88E+00	5.21E-02	Yes
Pu-241	1.08E-02	1.96E-04	Yes
Pu-242	7.34E-03	1.33E-04	Yes
Pu-243	8.76E-07	1.58E-08	
Pu-244	2.80E-11	5.06E-13	
Ra-223	4.35E-04	7.86E-06	
Ra-224	8.95E-04	1.62E-05	
Ra-225	2.46E-03	4.44E-05	
Ra-226	3.96E-05	7.15E-07	
Ra-228	8.95E-04	1.62E-05	
Rn-219	4.35E-04	7.86E-06	
Rn-220	8.95E-04	1.62E-05	
Rn-222	3.96E-05	7.15E-07	
Sb-125	2.64E-45	4.76E-47	
Sb-126	3.94E-02	7.11E-04	
Sb-126m	2.81E-01	5.08E-03	
Se-79	1.04E-02	1.87E-04	Yes
Sm-147	3.09E-09	5.59E-11	
Sm-151	7.37E+00	1.33E-01	Yes
Sn-121	1.81E-03	3.27E-05	
Sn-121m	2.33E-03	4.22E-05	
Sn-126	2.81E-01	5.08E-03	Yes
Sr-90	6.88E-01	1.24E-02	Yes
Tc-99	3.43E-01	6.19E-03	Yes
Te-125m	6.37E-46	1.15E-47	
Th-227	4.29E-04	7.75E-06	
Th-228	8.95E-04	1.62E-05	
Th-229	2.46E-03	4.45E-05	
Th-230	4.11E-04	7.43E-06	
Th-231	5.44E-04	9.83E-06	
Th-232	8.95E-04	1.62E-05	
Th-234	1.25E-02	2.26E-04	
Tl-207	4.34E-04	7.84E-06	
Tl-208	3.22E-04	5.81E-06	
Tl-209	5.31E-05	9.60E-07	
U-233	5.99E-02	1.08E-03	Yes
U-234	1.12E-01	2.03E-03	Yes
U-235	5.44E-04	9.83E-06	
U-236	1.04E-03	1.89E-05	
U-237	2.65E-07	4.80E-09	
U-238	1.25E-02	2.26E-04	Yes
U-240	2.80E-11	5.05E-13	
Y-90	6.89E-01	1.24E-02	
Zr-93	7.02E-01	1.27E-02	Yes
TOTAL	**5.53E+01**	1.00E+00	

APPENDIX F. ACTIVITIES OF DRIED SLUDGE IN YEAR 2515 (μCi/g)

Nuclide	Y 2515 µCi/g	Fraction of Activity	Reportable
Ac-225	3.00E-03	7.41E-05	
Ac-227	4.35E-04	1.08E-05	
Ac-228	8.95E-04	2.21E-05	
Am-241	1.29E+01	3.19E-01	Yes
Am-242	1.43E-02	3.54E-04	
Am-242m	1.44E-02	3.56E-04	Yes
Am-243	1.79E+00	4.43E-02	Yes
At-217	3.00E-03	7.41E-05	
At-218	1.15E-08	2.84E-10	
Ba-133	5.68E-16	1.40E-17	
Ba-137m	7.40E-03	1.83E-04	
Bi-210	5.15E-05	1.27E-06	
Bi-211	4.35E-04	1.08E-05	
Bi-212	8.95E-04	2.21E-05	
Bi-213	3.00E-03	7.41E-05	
Bi-214	5.75E-05	1.42E-06	
Bk-247	1.20E-03	2.98E-05	
Cd-113m	1.82E-11	4.50E-13	
Cf-249	6.26E-03	1.55E-04	Yes
Cf-250	1.82E-16	4.51E-18	
Cf-251	3.25E-02	8.04E-04	Yes
Cf-252	4.32E-59	1.07E-60	
Cl-36	1.32E-04	3.26E-06	
Cm-242	1.19E-02	2.94E-04	
Cm-243	3.65E-07	9.03E-09	
Cm-244	3.08E-07	7.62E-09	
Cm-245	1.08E-02	2.67E-04	Yes
Cm-246	2.88E-02	7.12E-04	Yes
Cm-247	1.03E-06	2.54E-08	
Cm-248	9.05E-06	2.24E-07	
Co-60	2.68E-29	6.62E-31	
Cs-135	4.55E-03	1.12E-04	Yes
Cs-137	7.82E-03	1.93E-04	Yes
Eu-152	1.32E-12	3.27E-14	
Eu-154	7.47E-17	1.85E-18	
Eu-155	5.43E-31	1.34E-32	
Fr-221	3.00E-03	7.41E-05	
Fr-223	6.00E-06	1.48E-07	
Gd-152	9.89E-15	2.44E-16	
I-129	2.04E-03	5.04E-05	
Nb-93m	7.02E-01	1.73E-02	Yes
Ni-59	7.50E-01	1.85E-02	Yes
Ni-63	2.49E+00	6.15E-02	Yes
Np-237	2.82E-02	6.97E-04	Yes
Np-238	6.85E-05	1.69E-06	
Np-239	1.79E+00	4.43E-02	
Np-240m	3.49E-11	8.63E-13	
Pa-231	4.35E-04	1.08E-05	
Pa-233	2.82E-02	6.97E-04	
Pa-234	4.12E-05	1.02E-06	
Pa-234m	1.25E-02	3.08E-04	
Pb-209	3.00E-03	7.41E-05	
Pb-210	5.15E-05	1.27E-06	
Pb-211	4.35E-04	1.08E-05	
Pb-212	8.95E-04	2.21E-05	
Pb-214	5.75E-05	1.42E-06	
Pd-107	1.52E-03	3.76E-05	
Pm-147	3.12E-56	7.72E-58	
Po-210	5.14E-05	1.27E-06	
Po-211	1.22E-06	3.01E-08	

Nuclide	Y 2515 µCi/g	Fraction of Activity	Reportable
Po-212	5.73E-04	1.42E-05	
Po-213	2.94E-03	7.25E-05	
Po-214	5.75E-05	1.42E-06	
Po-215	4.35E-04	1.08E-05	
Po-216	8.95E-04	2.21E-05	
Po-218	5.75E-05	1.42E-06	
Pu-238	3.79E+00	9.38E-02	Yes
Pu-239	7.69E+00	1.90E-01	Yes
Pu-240	2.85E+00	7.05E-02	Yes
Pu-241	1.08E-02	2.67E-04	Yes
Pu-242	7.34E-03	1.81E-04	Yes
Pu-243	1.03E-06	2.54E-08	
Pu-244	3.50E-11	8.64E-13	
Ra-223	4.35E-04	1.08E-05	
Ra-224	8.95E-04	2.21E-05	
Ra-225	3.00E-03	7.41E-05	
Ra-226	5.75E-05	1.42E-06	
Ra-228	8.95E-04	2.21E-05	
Rn-219	4.35E-04	1.08E-05	
Rn-220	8.95E-04	2.21E-05	
Rn-222	5.75E-05	1.42E-06	
Sb-125	3.58E-56	8.84E-58	
Sb-126	3.93E-02	9.72E-04	
Sb-126m	2.81E-01	6.95E-03	
Se-79	1.03E-02	2.56E-04	Yes
Sm-147	3.09E-09	7.65E-11	
Sm-151	3.41E+00	8.44E-02	Yes
Sn-121	5.14E-04	1.27E-05	
Sn-121m	6.62E-04	1.64E-05	
Sn-126	2.81E-01	6.95E-03	Yes
Sr-90	6.37E-02	1.57E-03	Yes
Tc-99	3.42E-01	8.46E-03	Yes
Te-125m	8.65E-57	2.14E-58	
Th-227	4.29E-04	1.06E-05	
Th-228	8.95E-04	2.21E-05	
Th-229	3.00E-03	7.42E-05	
Th-230	5.13E-04	1.27E-05	
Th-231	5.45E-04	1.35E-05	
Th-232	8.95E-04	2.21E-05	
Th-234	1.25E-02	3.09E-04	
Tl-207	4.34E-04	1.07E-05	
Tl-208	3.22E-04	7.95E-06	
Tl-209	6.48E-05	1.60E-06	
U-233	5.99E-02	1.48E-03	Yes
U-234	1.14E-01	2.81E-03	Yes
U-235	5.45E-04	1.35E-05	
U-236	1.05E-03	2.60E-05	
U-237	2.65E-07	6.54E-09	
U-238	1.25E-02	3.09E-04	Yes
U-240	3.49E-11	8.63E-13	
Y-90	6.37E-02	1.57E-03	
Zr-93	7.02E-01	1.73E-02	Yes
TOTAL	**4.05E+01**	1.00E+00	

APPENDIX G. ACTIVITIES OF DRIED SLUDGE IN YEAR 2615 (μCi/g)

Nuclide	Y 2615 µCi/g	Fraction of Activity	Reportable
Ac-225	3.53E-03	1.07E-04	
Ac-227	4.35E-04	1.31E-05	
Ac-228	8.95E-04	2.70E-05	
Am-241	1.10E+01	3.32E-01	Yes
Am-242	9.08E-03	2.74E-04	
Am-242m	9.12E-03	2.75E-04	Yes
Am-243	1.78E+00	5.36E-02	Yes
At-217	3.53E-03	1.07E-04	
At-218	1.58E-08	4.77E-10	
Ba-133	8.94E-19	2.70E-20	
Ba-137m	7.34E-04	2.22E-05	
Bi-210	7.18E-05	2.17E-06	
Bi-211	4.35E-04	1.31E-05	
Bi-212	8.95E-04	2.70E-05	
Bi-213	3.53E-03	1.07E-04	
Bi-214	7.90E-05	2.38E-06	
Bk-247	1.15E-03	3.46E-05	
Cd-113m	1.11E-13	3.36E-15	
Cf-249	5.14E-03	1.55E-04	Yes
Cf-250	9.12E-19	2.75E-20	
Cf-251	3.01E-02	9.08E-04	Yes
Cf-252	1.68E-70	5.06E-72	
Cl-36	1.32E-04	3.98E-06	
Cm-242	7.53E-03	2.27E-04	
Cm-243	3.21E-08	9.69E-10	
Cm-244	6.71E-09	2.02E-10	
Cm-245	1.08E-02	3.24E-04	Yes
Cm-246	2.84E-02	8.56E-04	Yes
Cm-247	1.16E-06	3.51E-08	
Cm-248	9.04E-06	2.73E-07	
Co-60	5.21E-35	1.57E-36	
Cs-135	4.55E-03	1.37E-04	Yes
Cs-137	7.76E-04	2.34E-05	
Eu-152	7.30E-15	2.20E-16	
Eu-154	2.84E-20	8.56E-22	
Eu-155	4.63E-37	1.40E-38	
Fr-221	3.53E-03	1.07E-04	
Fr-223	6.01E-06	1.81E-07	
Gd-152	9.89E-15	2.98E-16	
I-129	2.04E-03	6.16E-05	
Nb-93m	7.02E-01	2.12E-02	Yes
Ni-59	7.49E-01	2.26E-02	Yes
Ni-63	1.21E+00	3.65E-02	Yes
Np-237	2.86E-02	8.63E-04	Yes
Np-238	4.34E-05	1.31E-06	
Np-239	1.78E+00	5.36E-02	
Np-240m	4.19E-11	1.26E-12	
Pa-231	4.35E-04	1.31E-05	
Pa-233	2.86E-02	8.63E-04	
Pa-234	4.12E-05	1.24E-06	
Pa-234m	1.25E-02	3.76E-04	
Pb-209	3.53E-03	1.07E-04	
Pb-210	7.19E-05	2.17E-06	
Pb-211	4.35E-04	1.31E-05	
Pb-212	8.95E-04	2.70E-05	
Pb-214	7.90E-05	2.38E-06	
Pd-107	1.52E-03	4.59E-05	
Pm-147	1.05E-67	3.16E-69	
Po-210	7.17E-05	2.16E-06	
Po-211	1.22E-06	3.68E-08	

Nuclide	Y 2615 µCi/g	Fraction of Activity	Reportable
Po-212	5.73E-04	1.73E-05	
Po-213	3.46E-03	1.04E-04	
Po-214	7.90E-05	2.38E-06	
Po-215	4.35E-04	1.31E-05	
Po-216	8.95E-04	2.70E-05	
Po-218	7.90E-05	2.38E-06	
Pu-238	1.73E+00	5.21E-02	Yes
Pu-239	7.68E+00	2.32E-01	Yes
Pu-240	2.82E+00	8.52E-02	Yes
Pu-241	1.08E-02	3.25E-04	Yes
Pu-242	7.34E-03	2.22E-04	Yes
Pu-243	1.16E-06	3.51E-08	
Pu-244	4.19E-11	1.27E-12	
Ra-223	4.35E-04	1.31E-05	
Ra-224	8.95E-04	2.70E-05	
Ra-225	3.54E-03	1.07E-04	
Ra-226	7.90E-05	2.38E-06	
Ra-228	8.95E-04	2.70E-05	
Rn-219	4.35E-04	1.31E-05	
Rn-220	8.95E-04	2.70E-05	
Rn-222	7.90E-05	2.38E-06	
Sb-125	4.86E-67	1.47E-68	
Sb-126	3.93E-02	1.19E-03	
Sb-126m	2.81E-01	8.47E-03	
Se-79	1.03E-02	3.12E-04	Yes
Sm-147	3.09E-09	9.33E-11	
Sm-151	1.58E+00	4.77E-02	Yes
Sn-121	1.46E-04	4.39E-06	
Sn-121m	1.88E-04	5.66E-06	
Sn-126	2.81E-01	8.47E-03	Yes
Sr-90	5.89E-03	1.78E-04	Yes
Tc-99	3.42E-01	1.03E-02	Yes
Te-125m	1.17E-67	3.55E-69	
Th-227	4.29E-04	1.30E-05	
Th-228	8.95E-04	2.70E-05	
Th-229	3.54E-03	1.07E-04	Yes
Th-230	6.15E-04	1.86E-05	
Th-231	5.46E-04	1.65E-05	
Th-232	8.95E-04	2.70E-05	
Th-234	1.25E-02	3.77E-04	
Tl-207	4.34E-04	1.31E-05	
Tl-208	3.22E-04	9.70E-06	
Tl-209	7.64E-05	2.30E-06	
U-233	5.99E-02	1.81E-03	Yes
U-234	1.15E-01	3.46E-03	Yes
U-235	5.46E-04	1.65E-05	
U-236	1.06E-03	3.20E-05	
U-237	2.64E-07	7.96E-09	
U-238	1.25E-02	3.77E-04	Yes
U-240	4.19E-11	1.26E-12	
Y-90	5.90E-03	1.78E-04	
Zr-93	7.02E-01	2.12E-02	Yes
TOTAL	**3.31E+01**	1.00E+00	

APPENDIX H. ACTIVITIES OF DRIED SLUDGE IN YEAR 2715 (μCi/g)

Nuclide	Y 2715 µCi/g	Fraction of Activity	Reportable
Ac-225	4.06E-03	1.40E-04	
Ac-227	4.36E-04	1.50E-05	
Ac-228	8.95E-04	3.09E-05	
Am-241	9.38E+00	3.23E-01	Yes
Am-242	5.75E-03	1.98E-04	
Am-242m	5.78E-03	1.99E-04	Yes
Am-243	1.76E+00	6.07E-02	Yes
At-217	4.06E-03	1.40E-04	
At-218	2.08E-08	7.17E-10	
Ba-133	1.41E-21	4.85E-23	
Ba-137m	7.28E-05	2.51E-06	
Bi-210	9.57E-05	3.30E-06	
Bi-211	4.36E-04	1.50E-05	
Bi-212	8.95E-04	3.09E-05	
Bi-213	4.06E-03	1.40E-04	
Bi-214	1.04E-04	3.58E-06	
Bk-247	1.09E-03	3.76E-05	
Cd-113m	6.81E-16	2.35E-17	
Cf-249	4.22E-03	1.45E-04	Yes
Cf-250	4.55E-21	1.57E-22	
Cf-251	2.79E-02	9.61E-04	Yes
Cf-252	6.51E-82	2.25E-83	
Cl-36	1.32E-04	4.54E-06	
Cm-242	4.77E-03	1.65E-04	
Cm-243	2.82E-09	9.73E-11	
Cm-244	1.46E-10	5.04E-12	
Cm-245	1.07E-02	3.69E-04	Yes
Cm-246	2.80E-02	9.65E-04	Yes
Cm-247	1.29E-06	4.46E-08	
Cm-248	9.04E-06	3.12E-07	
Co-60	1.01E-40	3.50E-42	
Cs-135	4.55E-03	1.57E-04	Yes
Cs-137	7.70E-05	2.66E-06	
Eu-152	4.03E-17	1.39E-18	
Eu-154	1.08E-23	3.71E-25	
Eu-155	3.95E-43	1.36E-44	
Fr-221	4.06E-03	1.40E-04	
Fr-223	6.01E-06	2.07E-07	
Gd-152	9.89E-15	3.41E-16	
I-129	2.04E-03	7.03E-05	
Nb-93m	7.02E-01	2.42E-02	Yes
Ni-59	7.48E-01	2.58E-02	Yes
Ni-63	5.88E-01	2.03E-02	Yes
Np-237	2.89E-02	9.98E-04	Yes
Np-238	2.75E-05	9.49E-07	
Np-239	1.76E+00	6.07E-02	
Np-240m	4.88E-11	1.68E-12	
Pa-231	4.36E-04	1.50E-05	
Pa-233	2.89E-02	9.97E-04	
Pa-234	4.12E-05	1.42E-06	
Pa-234m	1.25E-02	4.30E-04	
Pb-209	4.06E-03	1.40E-04	
Pb-210	9.57E-05	3.30E-06	
Pb-211	4.36E-04	1.50E-05	
Pb-212	8.95E-04	3.09E-05	
Pb-214	1.04E-04	3.58E-06	
Pd-107	1.52E-03	5.24E-05	
Pm-147	3.51E-79	1.21E-80	
Po-210	9.55E-05	3.29E-06	
Po-211	1.22E-06	4.21E-08	

Nuclide	Y 2715 µCi/g	Fraction of Activity	Reportable
Po-212	5.73E-04	1.98E-05	
Po-213	3.98E-03	1.37E-04	
Po-214	1.04E-04	3.58E-06	
Po-215	4.36E-04	1.50E-05	
Po-216	8.95E-04	3.09E-05	
Po-218	1.04E-04	3.58E-06	
Pu-238	7.87E-01	2.71E-02	Yes
Pu-239	7.66E+00	2.64E-01	Yes
Pu-240	2.79E+00	9.63E-02	Yes
Pu-241	1.07E-02	3.69E-04	Yes
Pu-242	7.35E-03	2.53E-04	Yes
Pu-243	1.29E-06	4.46E-08	
Pu-244	4.89E-11	1.69E-12	
Ra-223	4.36E-04	1.50E-05	
Ra-224	8.95E-04	3.09E-05	
Ra-225	4.06E-03	1.40E-04	
Ra-226	1.04E-04	3.58E-06	
Ra-228	8.95E-04	3.09E-05	
Rn-219	4.36E-04	1.50E-05	
Rn-220	8.95E-04	3.09E-05	
Rn-222	1.04E-04	3.58E-06	
Sb-125	6.60E-78	2.27E-79	
Sb-126	3.93E-02	1.35E-03	
Sb-126m	2.81E-01	9.68E-03	
Se-79	1.03E-02	3.56E-04	Yes
Sm-147	3.09E-09	1.07E-10	
Sm-151	7.32E-01	2.52E-02	Yes
Sn-121	4.13E-05	1.42E-06	
Sn-121m	5.32E-05	1.84E-06	
Sn-126	2.81E-01	9.68E-03	Yes
Sr-90	5.45E-04	1.88E-05	
Tc-99	3.42E-01	1.18E-02	Yes
Te-125m	1.60E-78	5.50E-80	
Th-227	4.30E-04	1.48E-05	
Th-228	8.95E-04	3.09E-05	
Th-229	4.07E-03	1.40E-04	Yes
Th-230	7.18E-04	2.48E-05	
Th-231	5.46E-04	1.88E-05	
Th-232	8.95E-04	3.09E-05	
Th-234	1.25E-02	4.31E-04	
Tl-207	4.34E-04	1.50E-05	
Tl-208	3.22E-04	1.11E-05	
Tl-209	8.78E-05	3.03E-06	
U-233	5.99E-02	2.07E-03	Yes
U-234	1.15E-01	3.96E-03	Yes
U-235	5.46E-04	1.88E-05	
U-236	1.07E-03	3.69E-05	
U-237	2.63E-07	9.05E-09	
U-238	1.25E-02	4.31E-04	Yes
U-240	4.88E-11	1.68E-12	
Y-90	5.45E-04	1.88E-05	
Zr-93	7.02E-01	2.42E-02	Yes
TOTAL	**2.90E+01**	1.00E+00	

APPENDIX I. ACTIVITIES OF DRIED SLUDGE IN YEAR 2815 (μCi/g)

Nuclide	Y 2815 µCi/g	Fraction of Activity	Reportable
Ac-225	4.59E-03	1.74E-04	
Ac-227	4.36E-04	1.65E-05	
Ac-228	8.95E-04	3.39E-05	
Am-241	7.99E+00	3.03E-01	Yes
Am-242	3.65E-03	1.38E-04	
Am-242m	3.66E-03	1.39E-04	Yes
Am-243	1.74E+00	6.60E-02	Yes
At-217	4.59E-03	1.74E-04	
At-218	2.64E-08	1.00E-09	
Ba-133	2.22E-24	8.39E-26	
Ba-137m	7.23E-06	2.74E-07	
Bi-210	1.23E-04	4.65E-06	
Bi-211	4.36E-04	1.65E-05	
Bi-212	8.95E-04	3.39E-05	
Bi-213	4.59E-03	1.74E-04	
Bi-214	1.32E-04	5.00E-06	
Bk-247	1.04E-03	3.92E-05	
Cd-113m	4.16E-18	1.58E-19	
Cf-249	3.46E-03	1.31E-04	Yes
Cf-250	2.28E-23	8.62E-25	
Cf-251	2.58E-02	9.77E-04	Yes
Cf-252	2.53E-93	9.57E-95	
Cl-36	1.32E-04	4.99E-06	
Cm-242	3.02E-03	1.15E-04	
Cm-243	2.48E-10	9.39E-12	
Cm-244	3.18E-12	1.20E-13	
Cm-245	1.06E-02	4.03E-04	Yes
Cm-246	2.76E-02	1.04E-03	Yes
Cm-247	1.41E-06	5.35E-08	
Cm-248	9.04E-06	3.42E-07	
Co-60	1.97E-46	7.47E-48	
Cs-135	4.55E-03	1.72E-04	Yes
Cs-137	7.64E-06	2.89E-07	
Eu-152	2.22E-19	8.42E-21	
Eu-154	4.08E-27	1.55E-28	
Eu-155	3.37E-49	1.28E-50	
Fr-221	4.59E-03	1.74E-04	
Fr-223	6.01E-06	2.28E-07	
Gd-152	9.89E-15	3.75E-16	
I-129	2.04E-03	7.73E-05	
Nb-93m	7.02E-01	2.66E-02	Yes
Ni-59	7.47E-01	2.83E-02	Yes
Ni-63	2.85E-01	1.08E-02	Yes
Np-237	2.92E-02	1.11E-03	Yes
Np-238	1.74E-05	6.61E-07	
Np-239	1.74E+00	6.60E-02	
Np-240m	5.58E-11	2.11E-12	
Pa-231	4.36E-04	1.65E-05	
Pa-233	2.92E-02	1.11E-03	
Pa-234	4.12E-05	1.56E-06	
Pa-234m	1.25E-02	4.72E-04	
Pb-209	4.59E-03	1.74E-04	
Pb-210	1.23E-04	4.65E-06	
Pb-211	4.36E-04	1.65E-05	
Pb-212	8.95E-04	3.39E-05	
Pb-214	1.32E-04	5.00E-06	
Pd-107	1.52E-03	5.76E-05	
Pm-147	1.18E-90	4.46E-92	
Po-210	1.23E-04	4.65E-06	
Po-211	1.22E-06	4.62E-08	

Nuclide	Y 2815 µCi/g	Fraction of Activity	Reportable
Po-212	5.73E-04	2.17E-05	
Po-213	4.49E-03	1.70E-04	
Po-214	1.32E-04	5.00E-06	
Po-215	4.36E-04	1.65E-05	
Po-216	8.95E-04	3.39E-05	
Po-218	1.32E-04	5.00E-06	
Pu-238	3.59E-01	1.36E-02	Yes
Pu-239	7.64E+00	2.90E-01	Yes
Pu-240	2.76E+00	1.05E-01	Yes
Pu-241	1.07E-02	4.04E-04	Yes
Pu-242	7.35E-03	2.78E-04	Yes
Pu-243	1.41E-06	5.35E-08	
Pu-244	5.58E-11	2.12E-12	
Ra-223	4.36E-04	1.65E-05	
Ra-224	8.95E-04	3.39E-05	
Ra-225	4.59E-03	1.74E-04	
Ra-226	1.32E-04	5.01E-06	
Ra-228	8.95E-04	3.39E-05	
Rn-219	4.36E-04	1.65E-05	
Rn-220	8.95E-04	3.39E-05	
Rn-222	1.32E-04	5.00E-06	
Sb-125	8.95E-89	3.39E-90	
Sb-126	3.93E-02	1.49E-03	
Sb-126m	2.80E-01	1.06E-02	
Se-79	1.03E-02	3.91E-04	Yes
Sm-147	3.09E-09	1.17E-10	
Sm-151	3.39E-01	1.28E-02	Yes
Sn-121	1.17E-05	4.44E-07	
Sn-121m	1.51E-05	5.72E-07	
Sn-126	2.80E-01	1.06E-02	Yes
Sr-90	5.05E-05	1.91E-06	
Tc-99	3.42E-01	1.30E-02	Yes
Te-125m	2.16E-89	8.20E-91	
Th-227	4.30E-04	1.63E-05	
Th-228	8.95E-04	3.39E-05	
Th-229	4.59E-03	1.74E-04	Yes
Th-230	8.21E-04	3.11E-05	
Th-231	5.47E-04	2.07E-05	
Th-232	8.95E-04	3.39E-05	
Th-234	1.25E-02	4.73E-04	
Tl-207	4.35E-04	1.65E-05	
Tl-208	3.22E-04	1.22E-05	
Tl-209	9.91E-05	3.75E-06	
U-233	5.99E-02	2.27E-03	Yes
U-234	1.15E-01	4.36E-03	Yes
U-235	5.47E-04	2.07E-05	
U-236	1.08E-03	4.08E-05	
U-237	2.61E-07	9.89E-09	
U-238	1.25E-02	4.73E-04	Yes
U-240	5.58E-11	2.11E-12	
Y-90	5.05E-05	1.91E-06	
Zr-93	7.02E-01	2.66E-02	Yes
TOTAL	**2.64E+01**	1.00E+00	

APPENDIX J. ACTIVITIES OF DRIED SLUDGE IN YEAR 2915 (μCi/g)

Nuclide	Y 2915 µCi/g	Fraction of Activity	Reportable
Ac-225	5.11E-03	2.08E-04	
Ac-227	4.36E-04	1.77E-05	
Ac-228	8.95E-04	3.64E-05	
Am-241	6.81E+00	2.77E-01	Yes
Am-242	2.31E-03	9.39E-05	
Am-242m	2.32E-03	9.44E-05	
Am-243	1.73E+00	7.02E-02	Yes
At-217	5.11E-03	2.08E-04	
At-218	3.27E-08	1.33E-09	
Ba-133	3.49E-27	1.42E-28	
Ba-137m	7.17E-07	2.91E-08	
Bi-210	1.53E-04	6.22E-06	
Bi-211	4.36E-04	1.77E-05	
Bi-212	8.95E-04	3.64E-05	
Bi-213	5.11E-03	2.08E-04	
Bi-214	1.64E-04	6.64E-06	
Bk-247	9.85E-04	4.00E-05	
Cd-113m	2.55E-20	1.04E-21	
Cf-249	2.84E-03	1.15E-04	Yes
Cf-250	1.14E-25	4.62E-27	
Cf-251	2.39E-02	9.70E-04	Yes
Cf-252	9.81E-105	3.98E-106	
Cl-36	1.32E-04	5.35E-06	
Cm-242	1.92E-03	7.79E-05	
Cm-243	2.18E-11	8.85E-13	
Cm-244	6.92E-14	2.81E-15	
Cm-245	1.06E-02	4.30E-04	Yes
Cm-246	2.72E-02	1.10E-03	Yes
Cm-247	1.52E-06	6.19E-08	
Cm-248	9.04E-06	3.67E-07	
Co-60	3.84E-52	1.56E-53	
Cs-135	4.55E-03	1.85E-04	Yes
Cs-137	7.58E-07	3.08E-08	
Eu-152	1.23E-21	4.98E-23	
Eu-154	1.55E-30	6.30E-32	
Eu-155	2.88E-55	1.17E-56	
Fr-221	5.11E-03	2.08E-04	
Fr-223	6.02E-06	2.44E-07	
Gd-152	9.89E-15	4.02E-16	
I-129	2.04E-03	8.29E-05	
Nb-93m	7.02E-01	2.85E-02	Yes
Ni-59	7.47E-01	3.03E-02	Yes
Ni-63	1.39E-01	5.63E-03	Yes
Np-237	2.94E-02	1.20E-03	Yes
Np-238	1.11E-05	4.49E-07	
Np-239	1.73E+00	7.02E-02	
Np-240m	6.27E-11	2.55E-12	
Pa-231	4.36E-04	1.77E-05	
Pa-233	2.94E-02	1.20E-03	
Pa-234	4.12E-05	1.67E-06	
Pa-234m	1.25E-02	5.07E-04	
Pb-209	5.11E-03	2.08E-04	
Pb-210	1.53E-04	6.23E-06	
Pb-211	4.36E-04	1.77E-05	
Pb-212	8.95E-04	3.64E-05	
Pb-214	1.64E-04	6.64E-06	
Pd-107	1.52E-03	6.17E-05	
Pm-147	3.95E-102	1.60E-103	
Po-210	1.53E-04	6.22E-06	
Po-211	1.22E-06	4.96E-08	

Nuclide	Y 2915 µCi/g	Fraction of Activity	Reportable
Po-212	5.73E-04	2.33E-05	
Po-213	5.00E-03	2.03E-04	
Po-214	1.64E-04	6.64E-06	
Po-215	4.36E-04	1.77E-05	
Po-216	8.95E-04	3.64E-05	
Po-218	1.64E-04	6.64E-06	
Pu-238	1.64E-01	6.68E-03	Yes
Pu-239	7.63E+00	3.10E-01	Yes
Pu-240	2.73E+00	1.11E-01	Yes
Pu-241	1.06E-02	4.31E-04	Yes
Pu-242	7.36E-03	2.99E-04	Yes
Pu-243	1.52E-06	6.19E-08	
Pu-244	6.28E-11	2.55E-12	
Ra-223	4.36E-04	1.77E-05	
Ra-224	8.95E-04	3.64E-05	
Ra-225	5.11E-03	2.08E-04	
Ra-226	1.64E-04	6.64E-06	
Ra-228	8.95E-04	3.64E-05	
Rn-219	4.36E-04	1.77E-05	
Rn-220	8.95E-04	3.64E-05	
Rn-222	1.64E-04	6.64E-06	
Sb-125	1.21E-99	4.94E-101	
Sb-126	3.92E-02	1.59E-03	
Sb-126m	2.80E-01	1.14E-02	
Se-79	1.03E-02	4.18E-04	Yes
Sm-147	3.09E-09	1.26E-10	
Sm-151	1.57E-01	6.37E-03	Yes
Sn-121	3.32E-06	1.35E-07	
Sn-121m	4.28E-06	1.74E-07	
Sn-126	2.80E-01	1.14E-02	Yes
Sr-90	4.67E-06	1.90E-07	
Tc-99	3.42E-01	1.39E-02	Yes
Te-125m	2.94E-100	1.19E-101	
Th-227	4.30E-04	1.75E-05	
Th-228	8.95E-04	3.64E-05	
Th-229	5.11E-03	2.08E-04	Yes
Th-230	9.24E-04	3.75E-05	
Th-231	5.48E-04	2.23E-05	
Th-232	8.95E-04	3.64E-05	
Th-234	1.25E-02	5.08E-04	
Tl-207	4.35E-04	1.77E-05	
Tl-208	3.22E-04	1.31E-05	
Tl-209	1.10E-04	4.48E-06	
U-233	5.99E-02	2.43E-03	Yes
U-234	1.15E-01	4.68E-03	Yes
U-235	5.48E-04	2.23E-05	
U-236	1.09E-03	4.41E-05	
U-237	2.60E-07	1.06E-08	
U-238	1.25E-02	5.08E-04	Yes
U-240	6.27E-11	2.55E-12	
Y-90	4.67E-06	1.90E-07	
Zr-93	7.02E-01	2.85E-02	Yes
TOTAL	**2.46E+01**	1.00E+00	

APPENDIX K. ACTIVITIES OF DRIED SLUDGE IN YEAR 3015 (μCi/g)

Nuclide	Y 3015 µCi/g	Fraction of Activity	Reportable
Ac-225	5.62E-03	2.42E-04	
Ac-227	4.36E-04	1.87E-05	
Ac-228	8.95E-04	3.84E-05	
Am-241	5.80E+00	2.49E-01	Yes
Am-242	1.46E-03	6.29E-05	
Am-242m	1.47E-03	6.32E-05	
Am-243	1.71E+00	7.35E-02	Yes
At-217	5.62E-03	2.42E-04	
At-218	3.96E-08	1.70E-09	
Ba-133	5.49E-30	2.36E-31	
Ba-137m	7.11E-08	3.06E-09	
Bi-210	1.87E-04	8.02E-06	
Bi-211	4.36E-04	1.87E-05	
Bi-212	8.95E-04	3.84E-05	
Bi-213	5.62E-03	2.42E-04	
Bi-214	1.98E-04	8.50E-06	
Bk-247	9.37E-04	4.02E-05	
Cd-113m	1.56E-22	6.69E-24	
Cf-249	2.33E-03	1.00E-04	Yes
Cf-250	5.68E-28	2.44E-29	
Cf-251	2.21E-02	9.49E-04	Yes
Cf-252	3.81E-116	1.63E-117	
Cl-36	1.32E-04	5.66E-06	
Cm-242	1.21E-03	5.22E-05	
Cm-243	1.91E-12	8.22E-14	
Cm-244	1.51E-15	6.47E-17	
Cm-245	1.05E-02	4.52E-04	Yes
Cm-246	2.68E-02	1.15E-03	Yes
Cm-247	1.62E-06	6.98E-08	
Cm-248	9.04E-06	3.88E-07	
Co-60	7.47E-58	3.21E-59	
Cs-135	4.55E-03	1.95E-04	Yes
Cs-137	7.52E-08	3.23E-09	
Eu-152	6.77E-24	2.91E-25	
Eu-154	5.89E-34	2.53E-35	
Eu-155	2.45E-61	1.05E-62	
Fr-221	5.62E-03	2.42E-04	
Fr-223	6.02E-06	2.59E-07	
Gd-152	9.89E-15	4.25E-16	
I-129	2.04E-03	8.76E-05	
Nb-93m	7.02E-01	3.01E-02	Yes
Ni-59	7.46E-01	3.20E-02	Yes
Ni-63	6.74E-02	2.89E-03	Yes
Np-237	2.96E-02	1.27E-03	Yes
Np-238	7.01E-06	3.01E-07	
Np-239	1.71E+00	7.35E-02	
Np-240m	6.97E-11	2.99E-12	
Pa-231	4.36E-04	1.87E-05	
Pa-233	2.96E-02	1.27E-03	
Pa-234	4.12E-05	1.77E-06	
Pa-234m	1.25E-02	5.36E-04	
Pb-209	5.62E-03	2.42E-04	
Pb-210	1.87E-04	8.02E-06	
Pb-211	4.36E-04	1.87E-05	
Pb-212	8.95E-04	3.84E-05	
Pb-214	1.98E-04	8.50E-06	
Pd-107	1.52E-03	6.53E-05	
Pm-147	1.32E-113	5.69E-115	
Po-210	1.86E-04	8.01E-06	
Po-211	1.22E-06	5.25E-08	

Nuclide	Y 3015 µCi/g	Fraction of Activity	Reportable
Po-212	5.73E-04	2.46E-05	
Po-213	5.50E-03	2.36E-04	
Po-214	1.98E-04	8.50E-06	
Po-215	4.36E-04	1.87E-05	
Po-216	8.95E-04	3.84E-05	
Po-218	1.98E-04	8.50E-06	
Pu-238	7.54E-02	3.24E-03	Yes
Pu-239	7.61E+00	3.27E-01	Yes
Pu-240	2.71E+00	1.16E-01	Yes
Pu-241	1.05E-02	4.53E-04	Yes
Pu-242	7.36E-03	3.16E-04	Yes
Pu-243	1.62E-06	6.98E-08	
Pu-244	6.98E-11	3.00E-12	
Ra-223	4.36E-04	1.87E-05	
Ra-224	8.95E-04	3.84E-05	
Ra-225	5.62E-03	2.42E-04	
Ra-226	1.98E-04	8.50E-06	
Ra-228	8.95E-04	3.84E-05	
Rn-219	4.36E-04	1.87E-05	
Rn-220	8.95E-04	3.84E-05	
Rn-222	1.98E-04	8.50E-06	
Sb-125	1.65E-110	7.08E-112	
Sb-126	3.92E-02	1.68E-03	
Sb-126m	2.80E-01	1.20E-02	
Se-79	1.03E-02	4.42E-04	Yes
Sm-147	3.09E-09	1.33E-10	
Sm-151	7.26E-02	3.12E-03	Yes
Sn-121	9.42E-07	4.05E-08	
Sn-121m	1.21E-06	5.21E-08	
Sn-126	2.80E-01	1.20E-02	Yes
Sr-90	4.32E-07	1.86E-08	
Tc-99	3.42E-01	1.47E-02	Yes
Te-125m	3.99E-111	1.71E-112	
Th-227	4.30E-04	1.85E-05	
Th-228	8.95E-04	3.84E-05	
Th-229	5.62E-03	2.42E-04	Yes
Th-230	1.03E-03	4.41E-05	
Th-231	5.49E-04	2.36E-05	
Th-232	8.95E-04	3.84E-05	
Th-234	1.25E-02	5.37E-04	
Tl-207	4.35E-04	1.87E-05	
Tl-208	3.22E-04	1.38E-05	
Tl-209	1.21E-04	5.22E-06	
U-233	5.99E-02	2.57E-03	Yes
U-234	1.15E-01	4.94E-03	Yes
U-235	5.49E-04	2.36E-05	
U-236	1.09E-03	4.70E-05	
U-237	2.58E-07	1.11E-08	
U-238	1.25E-02	5.37E-04	Yes
U-240	6.97E-11	2.99E-12	
Y-90	4.32E-07	1.86E-08	
Zr-93	7.02E-01	3.01E-02	Yes
TOTAL	**2.33E+01**	1.00E+00	

APPENDIX L. ACTIVITIES OF DRIED SLUDGE IN YEAR 3115 (μCi/g)

Nuclide	Y 3115 µCi/g	Fraction of Activity	Reportable
Ac-225	6.13E-03	2.76E-04	
Ac-227	4.36E-04	1.96E-05	
Ac-228	8.95E-04	4.03E-05	
Am-241	4.94E+00	2.22E-01	Yes
Am-242	9.28E-04	4.18E-05	
Am-242m	9.33E-04	4.20E-05	
Am-243	1.70E+00	7.63E-02	Yes
At-217	6.13E-03	2.76E-04	
At-218	4.71E-08	2.12E-09	
Ba-133	8.65E-33	3.89E-34	
Ba-137m	7.06E-09	3.18E-10	
Bi-210	2.23E-04	1.00E-05	
Bi-211	4.36E-04	1.96E-05	
Bi-212	8.95E-04	4.03E-05	
Bi-213	6.13E-03	2.76E-04	
Bi-214	2.35E-04	1.06E-05	
Bk-247	8.91E-04	4.01E-05	
Cd-113m	9.54E-25	4.29E-26	
Cf-249	1.91E-03	8.60E-05	
Cf-250	2.84E-30	1.28E-31	
Cf-251	2.05E-02	9.20E-04	Yes
Cf-252	1.48E-127	6.65E-129	
Cl-36	1.32E-04	5.92E-06	
Cm-242	7.70E-04	3.46E-05	
Cm-243	1.68E-13	7.56E-15	
Cm-244	3.28E-17	1.48E-18	
Cm-245	1.05E-02	4.70E-04	Yes
Cm-246	2.64E-02	1.19E-03	Yes
Cm-247	1.72E-06	7.73E-08	
Cm-248	9.04E-06	4.06E-07	
Co-60	1.45E-63	6.54E-65	
Cs-135	4.55E-03	2.05E-04	Yes
Cs-137	7.46E-09	3.36E-10	
Eu-152	3.73E-26	1.68E-27	
Eu-154	2.23E-37	1.00E-38	
Eu-155	2.09E-67	9.42E-69	
Fr-221	6.13E-03	2.76E-04	
Fr-223	6.02E-06	2.71E-07	
Gd-152	9.89E-15	4.45E-16	
I-129	2.04E-03	9.18E-05	
Nb-93m	7.02E-01	3.16E-02	Yes
Ni-59	7.45E-01	3.35E-02	Yes
Ni-63	3.27E-02	1.47E-03	Yes
Np-237	2.98E-02	1.34E-03	Yes
Np-238	4.44E-06	2.00E-07	
Np-239	1.70E+00	7.63E-02	
Np-240m	7.66E-11	3.45E-12	
Pa-231	4.37E-04	1.96E-05	
Pa-233	2.98E-02	1.34E-03	
Pa-234	4.12E-05	1.85E-06	
Pa-234m	1.25E-02	5.61E-04	
Pb-209	6.13E-03	2.76E-04	
Pb-210	2.23E-04	1.00E-05	
Pb-211	4.36E-04	1.96E-05	
Pb-212	8.95E-04	4.03E-05	
Pb-214	2.35E-04	1.06E-05	
Pd-107	1.52E-03	6.84E-05	
Pm-147	4.44E-125	2.00E-126	
Po-210	2.23E-04	1.00E-05	
Po-211	1.22E-06	5.50E-08	

Nuclide	Y 3115 µCi/g	Fraction of Activity	Reportable
Po-212	5.73E-04	2.58E-05	
Po-213	6.00E-03	2.70E-04	
Po-214	2.35E-04	1.06E-05	
Po-215	4.36E-04	1.96E-05	
Po-216	8.95E-04	4.03E-05	
Po-218	2.35E-04	1.06E-05	
Pu-238	3.48E-02	1.56E-03	Yes
Pu-239	7.59E+00	3.42E-01	Yes
Pu-240	2.68E+00	1.20E-01	Yes
Pu-241	1.05E-02	4.71E-04	Yes
Pu-242	7.36E-03	3.31E-04	Yes
Pu-243	1.72E-06	7.73E-08	
Pu-244	7.67E-11	3.45E-12	
Ra-223	4.36E-04	1.96E-05	
Ra-224	8.95E-04	4.03E-05	
Ra-225	6.13E-03	2.76E-04	
Ra-226	2.35E-04	1.06E-05	
Ra-228	8.95E-04	4.03E-05	
Rn-219	4.36E-04	1.96E-05	
Rn-220	8.95E-04	4.03E-05	
Rn-222	2.35E-04	1.06E-05	
Sb-125	2.24E-121	1.01E-122	
Sb-126	3.92E-02	1.76E-03	
Sb-126m	2.80E-01	1.26E-02	
Se-79	1.03E-02	4.62E-04	Yes
Sm-147	3.09E-09	1.39E-10	
Sm-151	3.36E-02	1.51E-03	Yes
Sn-121	2.67E-07	1.20E-08	
Sn-121m	3.44E-07	1.55E-08	
Sn-126	2.80E-01	1.26E-02	Yes
Sr-90	4.00E-08	1.80E-09	
Tc-99	3.42E-01	1.54E-02	Yes
Te-125m	5.42E-122	2.44E-123	
Th-227	4.30E-04	1.94E-05	
Th-228	8.95E-04	4.03E-05	
Th-229	6.13E-03	2.76E-04	Yes
Th-230	1.13E-03	5.08E-05	
Th-231	5.49E-04	2.47E-05	
Th-232	8.95E-04	4.03E-05	
Th-234	1.25E-02	5.62E-04	
Tl-207	4.35E-04	1.96E-05	
Tl-208	3.22E-04	1.45E-05	
Tl-209	1.32E-04	5.96E-06	
U-233	5.98E-02	2.69E-03	Yes
U-234	1.15E-01	5.18E-03	Yes
U-235	5.49E-04	2.47E-05	
U-236	1.10E-03	4.96E-05	
U-237	2.56E-07	1.15E-08	
U-238	1.25E-02	5.62E-04	Yes
U-240	7.66E-11	3.45E-12	
Y-90	4.00E-08	1.80E-09	
Zr-93	7.02E-01	3.16E-02	Yes
TOTAL	**2.22E+01**	1.00E+00	

Distribution:

S. L. Marra, 773-A
D. H. McGuire, 999-W
T. B. Brown, 773-A
S. D. Fink, 773-A
C. C. Herman, 773-A
E. N. Hoffman, 999-W
F. M. Pennebaker, 773-42A
W. R. Wilmarth, 773-A
Records Administration (EDWS)

M. J. Barnes, 773-A
R. H. Young, 773-A
C. C. Diprete, 773-A
D. P. Diprete, 773-41A
W. A. Drown, Jr., 773-41A

C. J. Bannochie, 773-42A
J. M. Pareizs, 773-A
S. H. Reboul, 773-A
D. K. Peeler, 999-W
M. E. Stone, 999-W
D. P. Lambert, 999-W
J. D. Newell, 999-W
T. B. Edwards, 999-W
F. C. Johnson, 999-W
J. R. Zamecnik, 999-W
C. M. Jantzen, 773-A
D. J. Adamson, 999-W

J. M. Bricker, 704-27S
J. S. Contardi, 704-56H
T. L. Fellinger, 766-H
E. J. Freed, 704-S
A. Samadi-Dezfouli, 704-27S
J. M. Gillam, 766-H
B. A. Hamm, 766-H
E. W. Holtzscheiter, 766-H
J. F. Iaukea, 704-27S
M. T. Keefer, 766-H
J. W. Ray, 704-27S
H. B. Shah, 766-H
D. C. Sherburne, 704-S
P. J. Ryan, 704-S

P. R. Jackson, DOE-SR, 703-46A