CBU-PIT-2005-00120
REVISION 0
June 16, 2005

KEYWORDS:
Tank Closure,
Ancillary Equipment

RETENTION: PERMANENT
CLASSIFICATION: U
Does not contain UCNI

Ancillary Equipment Residual Radioactivity Estimate To Support Tank Closure Activities For F-Tank Farm

T. B. Caldwell

Westinghouse Savannah River Company
Closure Business Unit
Planning Integration & Technology Department
Aiken, SC 29808

PREPARED FOR THE U. S. DEPARTMENT OF ENERGY UNDER CONTRACT NO. DE-AC09-96S

APPROVAL PAGE

Technical Contributions by:

G. J. Hutchens: Complimentary Error Function for Isotopic Diffusivity Integration

R. F. O'Bryant: Radiological Survey to Curie Distribution Derivation

Prepared by:

June 16, 2005

T.B. Caldwell, Technical Planning — Date

Source Term Verification by:

6/16/05

H. Q. Tran, Data Acquisition, Evaluation, and Management — Date

Reviewed by:

6/16/05

E. T. Ketusky, Technical Integration and Process Development — Date

Approved by:

Jeff Newman for Tom C. Robinson per telecon — 6/16/05

T. C. Robinson, Jr., Manager, Tank Closure Planning — Date

SUMMARY OF REVISIONS

Revision Number	Date of Issue	Description of Changes
0	June 16, 2005	Initial Issue

TABLE OF CONTENTS

Summary of Tables

Ancillary Equipment Residual Radioactivity Estimate to Support Tank Closure Activities for F-Tank Farm

1.0 Purpose

The amount of radioactivity left behind in ancillary equipment must be accounted before facility closure. Previously, a conservative estimate of 20% of what is left in waste tanks was assumed as the source term contributor for ancillary equipment, which includes equipment such as buried pipes (transfer lines), pump tanks and evaporators [Tank Closure Modules for Tanks 17 and 20, 1997]. Upon further consideration, this globally applied factor is unnecessarily conservative. This paper documents the method and results in which a reasonable source term is applied for performance assessment modeling or for curies at closure reporting.

2.0 Methodology

Ancillary equipment is buried pipe (transfer lines), pump tanks, and evaporators. Over the operating life of the facility, radioactive waste comes in physical contact with these components, contaminating them and hence, leaving a small amount of contamination on the components. The degree of contamination depends on many factors, which include, but are not limited to, the service life of the component, the material of construction, and the type of waste in contact with the component.

For the purpose of this effort ancillary equipment was further divided into two categories. They are 1) buried pipe, and 2) pump tanks and evaporators.

2.1 *Establishing a Representative Source Term*

The contaminating medium is waste defined by Georgeton and Hester (1995). Though F-Tank Farm predominately received waste from F-Canyon, streams from both canyons are considered in the source term with the exception of Th-232 and its daughter Ra-228, which is negligible in F-Tank Farm. The references for additional radionuclides are found in Appendix I. The following table is a summary of the source term used in this report (taken from Appendix I).

Table 1 – Isotopic Concentration of Waste (Curies per gallon) (

Isotope	Isotopic Concentration	Isotope	Isotopic Concentration	Isotope	Isotopic Concentration
H−3	7.28E-03	Cs−137	1.07E+01	U−238	5.35E-07
C−14	7.80E-08	Ba−137m	1.01E+01	Np−237	2.39E-06
Al-26	1.13E-05	Ce−144	1.60E-04	Pu−238	3.33E-01
Co−60	4.42E-02	Pr−144	1.60E-04	Pu−239	2.97E-03
Ni−59	8.56E-05	Pm−147	7.46E-01	Pu−240	2.08E-03
Ni−63	8.55E-03	Sm−151	2.22E-01	Pu−241	2.42E-01
Se−79	6.13E-05	Eu−152	1.73E-03	Pu−242	3.01E-06
Sr−90	8.52E+00	Eu−154	9.34E-02	Pu−244	1.39E-08
Y−90	8.52E+00	Eu−155	8.52E-02	Am−241	8.32E-03
Nb−94	4.60E-08	Ra−226	9.26E-08	Am−242m	1.13E-05
Tc−99	1.20E-03	Ra−228	0.00E+00	Am−243	2.93E-06
Rh−106	1.13E-03	Ac−227	2.79E-09	Cm−242	9.24E-06
Ru−106	1.13E-03	Th−229	7.98E-03	Cm−243	1.98E-06
Te−125	1.06E-02	Th−230	1.18E-07	Cm−244	4.44E-05

Table 1 – Isotopic Concentration of Waste (Curies per gallon) (Continued)

Isotope	Isotopic Concentration	Isotope	Isotopic Concentration	Isotope	Isotopic Concentration
Sb−125	4.35E-02	Th−232	0.00E+00	Cm−245	2.83E-09
Sb−126	1.60E-05	Pa−231	2.80E-09	Cm−247	3.32E-16
Sb−126m	1.14E-04	U−232	7.87E-07	Cm−248	3.46E-16
Sn−126	1.14E-04	U−233	1.28E-02	Bk−249	2.39E-18
I−129	1.14E-06	U−234	1.33E-06	Cf−249	1.98E-15
Cs−134	3.13E-02	U−235	1.47E-08		
Cs−135	7.09E-07	U−236	3.38E-07		

2.2 *Methodology for Evaluating Transfer Piping Systems*

The amount of residue in the piping systems was determined analytically. The results were compared to results from standard characterization techniques using field surveys. Waste in contact with piping systems adheres to the pipe in three ways: 1) diffusion into the metal; 2) diffusion into the oxide film; 3) residue left behind after a transfer and flush. Diffusion calculations assume a 100-year contact time and a 100°C exposure temperature. Appendix II describes the methodology in which diffusion estimates are made.

2.3 *Methodology for Evaluating Pump Tanks and Evaporators*

Pump tanks and evaporators differ from piping systems with respect to such features as geometry and usage. Only residue left behind after rinsing and flushing is considered for these components. Field characterization data for the F-Tank Farm evaporators (including the 242-3F Concentrate Transfer System pump tank) will be used to estimate the residual radioactivity for each evaporator.

3.0 Estimation of Residue in Transfer Piping Systems

A list of transfer piping in the tank farm is in Appendix III. The list identifies the pipe diameter, material of construction, and the core pipe dimensions.

3.1 *Residue by Diffusion into Metal*

Diffusion is the technique for carburizing and nitriding of metals; and therefore is a known industrial transport phenomenon. Appendix II provides the derivation of the diffusion correlations. The following table provides a summary of the results.

Table 2 – Surface Concentration by Diffusion into Metal

	Diffusion Coefficient (cm^2/sec)		*Surface Concentration (Ci per ft^2)*	
Isotope	**Carbon Steel**	**Stainless**	**Carbon Steel**	**Stainless**
H-3	9.70E-08	1.48E-09	3.67E-03	4.54E-04
C-14	1.50E-17	1.80E-21	4.89E-13	5.36E-15
Al-26	5.48E-23	7.08E-35	1.36E-13	1.54E-19
Co-60	2.59E-36	2.42E-43	1.15E-16	3.52E-20
Ni-59	2.01E-33	4.27E-40	6.21E-18	2.86E-21
Ni-63	2.01E-33	4.27E-40	6.20E-16	2.86E-19
Se-79	2.00E-32	2.79E-43	1.40E-17	5.24E-23
Sr-90	1.64E-33	3.77E-44	5.58E-13	2.68E-18

Table 2 – Surface Concentration by Diffusion into Metal (continued)

Isotope	*Diffusion Coefficient (cm^2/sec)* Carbon Steel	*Diffusion Coefficient (cm^2/sec)* Stainless	*Surface Concentration (Ci per ft^2)* Carbon Steel	*Surface Concentration (Ci per ft^2)* Stainless
Y-90	9.13E-34	2.39E-44	4.17E-13	2.13E-18
Nb-94	2.97E-34	1.00E-44	1.28E-21	7.44E-27
Tc-99	1.70E-31	4.44E-45	8.00E-16	1.29E-22
Rh-106	8.10E-32	3.01E-45	5.23E-16	1.01E-22
Ru-106	3.91E-32	2.07E-45	3.63E-16	8.35E-23
Te-125	3.19E-34	2.02E-46	3.07E-16	2.44E-22
Sb-125	1.05E-36	2.73E-46	7.20E-17	1.16E-21
Sb-126	1.05E-36	2.73E-46	2.64E-20	4.27E-25
Sb-126m	6.17E-34	2.73E-46	4.58E-18	3.05E-24
Sn-126	1.20E-33	3.74E-46	6.40E-18	3.57E-24
I-129	1.67E-34	1.50E-46	2.38E-20	2.26E-26
Cs-134	4.65E-35	8.54E-47	3.46E-16	4.68E-22
Cs-135	4.65E-35	8.54E-47	7.83E-21	1.06E-26
Cs-137	4.65E-35	8.54E-47	1.18E-13	1.59E-19
Ba-137m	2.49E-35	6.51E-47	8.14E-14	1.32E-19
Ce-144	7.26E-36	3.87E-47	6.97E-19	1.61E-24
Pr-144	3.97E-36	3.02E-47	5.15E-19	1.42E-24
Pm-147	1.21E-36	1.87E-47	1.33E-15	5.23E-21
Sm-151	6.71E-37	1.49E-47	2.94E-16	1.39E-21
Eu-152	3.76E-37	1.19E-47	1.72E-18	9.67E-24
Eu-154	3.76E-37	1.19E-47	9.27E-17	5.22E-22
Eu-155	3.76E-37	1.19E-47	8.45E-17	4.76E-22
Ra-226	8.55E-43	2.09E-49	1.39E-25	6.85E-29
Ra-228	8.55E-43	2.09E-49	0.00E+00	0.00E+00
Ac-227	5.33E-43	1.86E-49	3.30E-27	1.95E-30
Th-229	3.34E-43	1.67E-49	7.46E-21	5.28E-24
Th-230	3.34E-43	1.67E-49	1.11E-25	7.83E-29
Th-232	3.34E-43	1.67E-49	0.00E+00	0.00E+00
Pa-231	2.09E-43	1.50E-49	2.07E-27	1.75E-30
U-232	1.32E-43	1.35E-49	4.62E-25	4.68E-28
U-233	1.32E-43	1.35E-49	7.50E-21	7.60E-24
U-234	1.32E-43	1.35E-49	7.81E-25	7.91E-28
U-235	1.32E-43	1.35E-49	8.63E-27	8.74E-30
U-236	1.32E-43	1.35E-49	1.98E-25	2.01E-28
U-238	1.32E-43	1.35E-49	3.14E-25	3.18E-28
Np-237	8.30E-44	1.22E-49	1.11E-24	1.35E-27
Pu-238	5.25E-44	1.10E-49	1.24E-19	1.79E-22
Pu-239	5.25E-44	1.10E-49	1.10E-21	1.60E-24
Pu-240	5.25E-44	1.10E-49	7.70E-22	1.12E-24
Pu-241	5.25E-44	1.10E-49	8.97E-20	1.30E-22
Pu-242	5.25E-44	1.10E-49	1.12E-24	1.62E-27
Pu-244	5.25E-44	1.10E-49	5.16E-27	7.48E-30
Am-241	3.33E-44	1.00E-49	2.46E-21	4.26E-24
Am-242m	3.33E-44	1.00E-49	3.32E-24	5.77E-27
Am-243	3.33E-44	1.00E-49	8.64E-25	1.50E-27
Cm-242	2.11E-44	9.12E-50	2.17E-24	4.52E-27
Cm-243	2.11E-44	9.12E-50	4.65E-25	9.66E-28

Table 2 – Surface Concentration by Diffusion into Metal (continued)

Isotope	*Diffusion Coefficient (cm^2/sec)* Carbon Steel	Stainless	*Surface Concentration (Ci per ft^2)* Carbon Steel	Stainless
Cm-244	2.11E-44	9.12E-50	1.05E-23	2.17E-26
Cm-245	2.11E-44	9.12E-50	6.65E-28	1.38E-30
Cm-247	2.11E-44	9.12E-50	7.81E-35	1.62E-37
Cm-248	2.11E-44	9.12E-50	8.14E-35	1.69E-37
Bk-249	1.35E-44	8.33E-50	4.49E-37	1.12E-39
Cf-249	8.60E-45	7.62E-50	2.97E-34	8.83E-37

3.2 *Residue by Diffusion into Oxide Film*

Stainless and carbon steels form an oxide film, which provides corrosion protection. Diffusion data of the isotopes into the films is sparse; therefore, a conservative assumption equates the isotopic concentration of the layer equivalent to that of sludge. The oxide film thicknesses for the two metals are,

Stainless steel — 10 μm (the layer is usually much less than this [in the hundreds of nanometer realm], but for the sake of conservatism, the 10-micron value is used) [Odeka and Ueda, 1995]

Carbon steel — 0.018 inches (the thickness of rust from 100 years of accumulation on the pipe walls at a rate of approximately 0.9 mils per 5 years) [Wiersma, 2002]

Therefore, the specific volume of oxide for 304L stainless steel was found to be 2.454×10^{-4} gallons per square foot; the specific volume for carbon steel was found to be 1.122×10^{-2} gallons per square foot. The following table shows the results of multiplying the source term by these volumetric terms.

Table 3 – Surface Concentration by Diffusion into Oxide Layer (Curies per ft^2)

Isotope	Carbon Steel	Stainless Steel
H-3	8.17E-05	1.79E-06
C-14	8.76E-10	1.92E-11
Al-26	1.27E-07	2.78E-09
Co-60	4.96E-04	1.09E-05
Ni-59	9.60E-07	2.10E-08
Ni-63	9.60E-05	2.10E-06
Se-79	6.88E-07	1.50E-08
Sr-90	9.56E-02	2.09E-03
Y-90	9.56E-02	2.09E-03
Nb-94	5.16E-10	1.13E-11
Tc-99	1.35E-05	2.95E-07
Rh-106	1.27E-05	2.78E-07
Ru-106	1.27E-05	2.78E-07
Te-125	1.19E-04	2.61E-06
Sb-125	4.88E-04	1.07E-05
Sb-126	1.79E-07	3.92E-09
Sb-126m	1.28E-06	2.80E-08
Sn-126	1.28E-06	2.80E-08
I-129	1.28E-08	2.80E-10

Isotope	Carbon Steel	Stainless Steel
Ra-228	0.00E+00	0.00E+00
Ac-227	3.13E-11	6.85E-13
Th-229	8.96E-05	1.96E-06
Th-230	1.33E-09	2.91E-11
Th-232	0.00E+00	0.00E+00
Pa-231	3.14E-11	6.87E-13
U-232	8.83E-09	1.93E-10
U-233	1.43E-04	3.14E-06
U-234	1.49E-08	3.26E-10
U-235	1.65E-10	3.61E-12
U-236	3.79E-09	8.30E-11
U-238	6.00E-09	1.31E-10
Np-237	2.68E-08	5.87E-10
Pu-238	3.74E-03	8.18E-05
Pu-239	3.33E-05	7.29E-07
Pu-240	2.33E-05	5.10E-07
Pu-241	2.71E-03	5.93E-05
Pu-242	3.38E-08	7.39E-10
Pu-244	1.56E-10	3.41E-12

Table 3 – Surface Concentration by Diffusion into Oxide Layer (Curies per ft^2) (Continued)

Isotope	Carbon Steel	Stainless Steel
Cs-134	3.51E-04	7.69E-06
Cs-135	7.96E-09	1.74E-10
Cs-137	1.20E-01	2.62E-03
Ba-137m	1.13E-01	2.48E-03
Ce-144	1.79E-06	3.92E-08
Pr-144	1.79E-06	3.92E-08
Pm-147	8.37E-03	1.83E-04
Sm-151	2.49E-03	5.45E-05
Eu-152	1.94E-05	4.25E-07
Eu-154	1.05E-03	2.29E-05
Eu-155	9.56E-04	2.09E-05
Ra-226	1.04E-09	2.27E-11

Isotope	Carbon Steel	Stainless Steel
Am-241	9.34E-05	2.04E-06
Am-242m	1.26E-07	2.76E-09
Am-243	3.28E-08	7.18E-10
Cm-242	1.04E-07	2.27E-09
Cm-243	2.22E-08	4.85E-10
Cm-244	4.98E-07	1.09E-08
Cm-245	3.17E-11	6.94E-13
Cm-247	3.73E-18	8.15E-20
Cm-248	3.88E-18	8.49E-20
Bk-249	2.68E-20	5.87E-22
Cf-249	2.22E-17	4.85E-19

3.3 *Residue of Particles Left Behind After a Flush*

Water is used to flush transfer piping. The waste concentrations follow an exponential decay curve with respect to time [Caldwell, 1999],

$$C(t) = C_o e^{-Qt/V} \quad (1)$$

Let F equal the number of flush volumes, and since $Q = V / t$, the previous equation becomes,

$$C = C_o e^{-F} \quad (2)$$

Where C_o is the initial concentration and F is the number of flush volumes. In this case, $F = 3$ for the number of volumes.

On a per area basis, the following equation applies:

$$C_{per\ unit\ area} = 0.156\ C\ d \quad (3)$$

Where C is concentration in Ci/gallon and d is pipe diameter in inches

Table 4 – Surface Concentration by Residue after Flushing (Curies per ft^2)

Isotope	*Core Pipe Size* 2-inch	3-inch	4-inch
H-3	1.17E-04	1.73E-04	2.27E-04
C-14	1.25E-09	1.86E-09	2.44E-09
Al-26	1.81E-07	2.69E-07	3.53E-07
Co-60	7.09E-04	1.05E-03	1.38E-03
Ni-59	1.37E-06	2.04E-06	2.67E-06
Ni-63	1.37E-04	2.04E-04	2.67E-04
Se-79	9.83E-07	1.46E-06	1.91E-06
Sr-90	1.37E-01	2.03E-01	2.66E-01
Y-90	1.37E-01	2.03E-01	2.66E-01
Nb-94	7.37E-10	1.09E-09	1.44E-09
Tc-99	1.92E-05	2.86E-05	3.75E-05

Isotope	**Core Pipe Size** 2-inch	3-inch	3-inch
Ra-228	0.00E+00	0.00E+00	0.00E+00
Ac-227	4.48E-11	6.65E-11	8.72E-11
Th-229	1.28E-04	1.90E-04	2.49E-04
Th-230	1.90E-09	2.82E-09	3.70E-09
Th-232	0.00E+00	0.00E+00	0.00E+00
Pa-231	4.49E-11	6.67E-11	8.75E-11
U-232	1.26E-08	1.87E-08	2.46E-08
U-233	2.05E-04	3.04E-04	3.99E-04
U-234	2.13E-08	3.17E-08	4.15E-08
U-235	2.36E-10	3.50E-10	4.59E-10
U-236	5.42E-09	8.05E-09	1.06E-08

Table 4 – Surface Concentration by Residue after Flushing (Curies per ft^2) (Continued)

	Core Pipe Size		
Isotope	**2-inch**	**3-inch**	**4-inch**
Rh-106	1.82E-05	2.70E-05	3.54E-05
Ru-106	1.82E-05	2.70E-05	3.54E-05
Te-125	1.70E-04	2.53E-04	3.32E-04
Sb-125	6.98E-04	1.04E-03	1.36E-03
Sb-126	2.56E-07	3.80E-07	4.99E-07
Sb-126m	1.83E-06	2.71E-06	3.56E-06
Sn-126	1.83E-06	2.71E-06	3.56E-06
I-129	1.83E-08	2.71E-08	3.56E-08
Cs-134	5.02E-04	7.46E-04	9.78E-04
Cs-135	1.14E-08	1.69E-08	2.22E-08
Cs-137	1.71E-01	2.54E-01	3.33E-01
Ba-137m	1.62E-01	2.40E-01	3.15E-01
Ce-144	2.56E-06	3.80E-06	4.99E-06
Pr-144	2.56E-06	3.80E-06	4.99E-06
Pm-147	1.20E-02	1.78E-02	2.33E-02
Sm-151	3.56E-03	5.29E-03	6.94E-03
Eu-152	2.78E-05	4.12E-05	5.41E-05
Eu-154	1.50E-03	2.22E-03	2.92E-03
Eu-155	1.37E-03	2.03E-03	2.66E-03
Ra-226	1.49E-09	2.20E-09	2.89E-09

	Core Pipe Size		
Isotope	**2-inch**	**3-inch**	**3-inch**
U-238	8.58E-09	1.27E-08	1.67E-08
Np-237	3.83E-08	5.69E-08	7.47E-08
Pu-238	5.35E-03	7.94E-03	1.04E-02
Pu-239	4.76E-05	7.07E-05	9.27E-05
Pu-240	3.33E-05	4.94E-05	6.49E-05
Pu-241	3.88E-03	5.76E-03	7.55E-03
Pu-242	4.83E-08	7.17E-08	9.40E-08
Pu-244	2.23E-10	3.31E-10	4.35E-10
Am-241	1.33E-04	1.98E-04	2.60E-04
Am-242m	1.81E-07	2.68E-07	3.52E-07
Am-243	4.69E-08	6.96E-08	9.14E-08
Cm-242	1.48E-07	2.20E-07	2.89E-07
Cm-243	3.17E-08	4.70E-08	6.17E-08
Cm-244	7.12E-07	1.06E-06	1.39E-06
Cm-245	4.53E-11	6.73E-11	8.83E-11
Cm-247	5.32E-18	7.90E-18	1.04E-17
Cm-248	5.55E-18	8.24E-18	1.08E-17
Bk-249	3.83E-20	5.69E-20	7.47E-20
Cf-249	3.17E-17	4.70E-17	6.17E-17

The total affected surface according to Appendix III is 34,089 ft^2. Therefore, using data derived from Tables 2, 3, and 4, the results for the following isotopes for buried pipe using analytical methods are shown in the following table.

Table 5 – Analytical Estimate of Residual Radioactivity in Buried Pipe for F-Tank Farm

Isotope	Remaining Curies	Isotope	Remaining Curies	Isotope	Remaining Curies
H-3	2.25E+01	Cs-137	8.43E+03	U-238	4.23E-04
C-14	6.17E-05	Ba-137m	7.98E+03	Np-237	1.89E-03
Al-26	8.94E-03	Ce-144	1.26E-01	Pu-238	2.64E+02
Co-60	3.50E+01	Pr-144	1.26E-01	Pu-239	2.35E+00
Ni-59	6.77E-02	Pm-147	5.90E+02	Pu-240	1.64E+00
Ni-63	6.76E+00	Sm-151	1.76E+02	Pu-241	1.91E+02
Se-79	4.85E-02	Eu-152	1.37E+00	Pu-242	2.38E-03
Sr-90	6.74E+03	Eu-154	7.39E+01	Pu-244	1.10E-05
Y-90	6.74E+03	Eu-155	6.74E+01	Am-241	6.58E+00
Nb-94	3.64E-05	Ra-226	7.32E-05	Am-242m	8.91E-03
Tc-99	9.49E-01	Ra-228	0.00E+00	Am-243	2.31E-03
Rh-106	8.97E-01	Ac-227	2.21E-06	Cm-242	7.30E-03
Ru-106	8.97E-01	Th-229	6.31E+00	Cm-243	1.56E-03
Te-125	8.40E+00	Th-230	9.37E-05	Cm-244	3.51E-02
Sb-125	3.44E+01	Th-232	0.00E+00	Cm-245	2.24E-06
Sb-126	1.26E-02	Pa-231	2.21E-06	Cm-247	2.63E-13
Sb-126m	9.02E-02	U-232	6.22E-04	Cm-248	2.74E-13
Sn-126	9.02E-02	U-233	1.01E+01	Bk-249	1.89E-15

Table 5 – Analytical Estimate of Residual Radioactivity in Buried Pipe for F-Tank Farm (Cont)

Isotope	Remaining Curies	Isotope	Remaining Curies	Isotope	Remaining Curies
I-129	9.02E-04	U-234	1.05E-03	Cf-249	1.56E-12
Cs-134	2.48E+01	U-235	1.16E-05		
Cs-135	5.61E-04	U-236	2.67E-04		

3.4 *Comparison to Field Characterization Data*

Appendix IV demonstrates another method in which to estimate residual pipe activity. Using field surveys, known isotopic distributions, and estimated dose-to-curie factors, an estimate of source term for some of the isotopes are established. The following isotopes in Table 6 were found to have a greater radionuclide inventory than the values predicted using the analytical methods. For conservatism, these values supersede those predicted in Table 5.

Table 6. Isotopes with Higher Inventory Based on the Field Survey Method

Isotope	Analytical Method (Curies)	Field Characterization Method (Curies)
C-14	6.17E-05	1.79E-03
U-234	1.05E-03	1.64E-03
U-235	1.16E-05	2.69E-05
U-238	4.23E-04	1.24E-03
Pu-242	2.38E-03	1.22E-02
Am-241	6.58E+00	1.06E+01
Am-241m	8.91E-03	1.40E-02
Am-243	2.31E-03	3.45E-02
Cm-244	3.51E-02	3.09E-01
Cm-245	2.24E-06	1.42E-04
Cm-247	2.63E-13	2.30E-09

4.0 Estimation of Residue in Pump Tanks and Evaporators

4.1 *Pump Tanks*

There are three pump tanks in F-Tank Farm: FPT-1, FPT-2, and FPT-3. They have a nominal capacity of 8,000 gallons each. Rather than a typical three volume flush as prescribed for piping systems, pump tanks are physically accessible for more rigorous waste removal. It is anticipated that these facilities will undergo extensive cleaning, and surpass the cleanliness level achieved with simple flushing. For the purpose of this evaluation a four-volume water flush is used. The following table shows the inventory in the pump tanks assuming all three tanks were completely filled with waste and then a four volume rinse is performed.

Table 7 – Analytical Estimate of Residual Radioactivity in F-Tank Farm Pump Tanks

Isotope	Remaining Curies	Isotope	Remaining Curies	Isotope	Remaining Curies
H-3	3.20E+00	Cs-137	4.69E+03	U-238	2.35E-04
C-14	3.43E-05	Ba-137m	4.43E+03	Np-237	1.05E-03
Al-26	4.97E-03	Ce-144	7.02E-02	Pu-238	1.47E+02
Co-60	1.94E+01	Pr-144	7.02E-02	Pu-239	1.30E+00
Ni-59	3.76E-02	Pm-147	3.28E+02	Pu-240	9.13E-01
Ni-63	3.76E+00	Sm-151	9.76E+01	Pu-241	1.06E+02
Se-79	2.69E-02	Eu-152	7.61E-01	Pu-242	1.32E-03
Sr-90	3.75E+03	Eu-154	4.11E+01	Pu-244	6.11E-06
Y-90	3.75E+03	Eu-155	3.74E+01	Am-241	3.66E+00
Nb-94	2.02E-05	Ra-226	4.07E-05	Am-242m	4.95E-03
Tc-99	5.27E-01	Ra-228	0.00E+00	Am-243	1.29E-03
Rh-106	4.99E-01	Ac-227	1.23E-06	Cm-242	4.06E-03
Ru-106	4.99E-01	Th-229	3.51E+00	Cm-243	8.68E-04
Te-125	4.67E+00	Th-230	5.21E-05	Cm-244	1.95E-02
Sb-125	1.91E+01	Th-232	0.00E+00	Cm-245	1.24E-06
Sb-126	7.01E-03	Pa-231	1.23E-06	Cm-247	1.46E-13
Sb-126m	5.01E-02	U-232	3.46E-04	Cm-248	1.52E-13
Sn-126	5.01E-02	U-233	5.62E+00	Bk-249	1.05E-15
I-129	5.01E-04	U-234	5.85E-04	Cf-249	8.68E-13
Cs-134	1.38E+01	U-235	6.46E-06		
Cs-135	3.12E-04	U-236	1.49E-04		

4.2 *Evaporators (including Overheads Tanks)*

The 242-F Evaporator and the 242-16F Evaporator were included as ancillary equipment. Each evaporator is similar in service use, design, size, capacity, and materials of construction. The 242-F Evaporator has been characterized by Nguyen (2005). Doubling the inventory reported in Nguyen (2005) for the 242-F Evaporator vessel (including the accompanying Overheads Tanks) reveals the residual inventory for the two F-Tank Farm evaporators as shown in the following table,

Table 8 – Estimate of Residual Radioactivity in F-Tank Farm Evaporators

Isotope	Remaining Curies	Isotope	Remaining Curies	Isotope	Remaining Curies
H-3	2.91E-01	Cs-137	1.97E+02	U-238	1.52E-03
C-14	4.74E-02	Ba-137m	1.86E+02	Np-237	2.22E-03
Al-26	6.44E-04	Ce-144	3.03E-09	Pu-238	1.12E+00
Co-60	2.51E-01	Pr-144	1.51E-06	Pu-239	2.95E+00
Ni-59	2.79E+00	Pm-147	7.48E-02	Pu-240	1.10E+00
Ni-63	2.53E+02	Sm-151	3.75E-01	Pu-241	8.96E+00
Se-79	2.67E-04	Eu-152	1.62E-03	Pu-242	8.97E-03
Sr-90	1.15E+01	Eu-154	4.12E-02	Pu-244	3.37E-09
Y-90	1.15E+01	Eu-155	2.19E-02	Am-241	8.36E-01
Nb-94	1.22E-07	Ra-226	3.29E-08	Am-242m	4.05E-02
Tc-99	2.60E-01	Ra-228	0.00E+00	Am-243	5.04E-08
Rh-106	1.20E-04	Ac-227	4.78E-09	Cm-242	2.62E-22
Ru-106	1.20E-04	Th-229	6.43E-05	Cm-243	7.80E-07
Te-125	6.16E-02	Th-230	4.03E-06	Cm-244	2.81E-06
Sb-125	2.52E-01	Th-232	0.00E+00	Cm-245	1.98E-12

Table 8 – Estimate of Residual Radioactivity in F-Tank Farm Evaporators (Cont'd)

Isotope	Remaining Curies	Isotope	Remaining Curies	Isotope	Remaining Curies
Sb-126	3.16E-03	Pa-231	1.33E-08	Cm-247	1.78E-20
Sb-126m	2.26E-02	U-232	1.54E-03	Cm-248	4.11E-21
Sn-126	2.26E-02	U-233	2.26E-02	Bk-249	1.55E-30
I-129	1.90E-02	U-234	1.46E-02	Cf-249	1.14E-22
Cs-134	2.16E-01	U-235	2.09E-05		
Cs-135	2.67E-03	U-236	1.63E-04		

4.3 *242-3F Concentrate Transfer System*

The 242-3F Concentrate Transfer System (CTS) pump tank is characterized in Nguyen (2005). The results are summarized in the following table.

Table 9 – Estimate of Residual Radioactivity in 242-3F CTS Tank

Isotope	Remaining Curies	Isotope	Remaining Curies	Isotope	Remaining Curies
H-3	1.08E-01	Cs-137	4.55E+02	U-238	2.62E-04
C-14	1.48E-01	Ba-137m	4.30E+02	Np-237	3.16E-04
Al-26	2.01E-03	Ce-144	9.46E-09	Pu-238	6.95E-01
Co-60	5.58E-02	Pr-144	4.73E-06	Pu-239	9.80E-01
Ni-59	8.72E+00	Pm-147	2.34E-01	Pu-240	2.57E-01
Ni-63	7.91E+02	Sm-151	1.17E+00	Pu-241	3.56E+00
Se-79	1.18E-06	Eu-152	5.07E-03	Pu-242	8.72E-04
Sr-90	3.58E+01	Eu-154	1.29E-01	Pu-244	1.05E-08
Y-90	3.58E+01	Eu-155	6.83E-02	Am-241	6.95E-01
Nb-94	3.83E-07	Ra-226	3.13E-09	Am-242m	1.27E-01
Tc-99	7.30E-02	Ra-228	0.00E+00	Am-243	1.58E-07
Rh-106	3.77E-04	Ac-227	7.96E-10	Cm-242	8.18E-22
Ru-106	3.77E-04	Th-229	6.10E-06	Cm-243	2.44E-06
Te-125	1.93E-01	Th-230	3.83E-07	Cm-244	8.78E-06
Sb-125	7.89E-01	Th-232	0.00E+00	Cm-245	6.18E-12
Sb-126	9.88E-03	Pa-231	2.21E-09	Cm-247	5.56E-20
Sb-126m	7.06E-02	U-232	4.81E-03	Cm-248	1.28E-20
Sn-126	7.06E-02	U-233	2.14E-03	Bk-249	4.83E-30
I-129	5.94E-02	U-234	1.39E-03	Cf-249	3.57E-22
Cs-134	6.76E-01	U-235	3.49E-06		
Cs-135	8.36E-03	U-236	1.44E-05		

5.0 Summary of Results

5.1 Estimate of Residual Mass

The amount of actual residue left behind, which includes inert material, is estimated by performing a mass balance on the ancillary volumes. The following assumptions are made for this estimation,

Average Specific Gravity of Sludge Particles,	SG_{slurry}	=	3.0
Average Specific Gravity of Carrier Liquid,	SG_{liquid}	=	1.2
Mass Fraction of Solids in the Slurry,	x_{solids}	=	0.12 [Poirier, 1993]

The specific gravity of a slurry is determined from the following equation [Caldwell, 2005],

$$\frac{1}{SG_{slurry}} = \frac{1}{SG_{liquid}} + x_{solids}\left(\frac{1}{SG_{solids}} - \frac{1}{SG_{liquid}}\right) \tag{4}$$

From Equation (4) and using the given assumptions, the average sludge slurry specific gravity is approximately 1.29. A summary of the volumes is listed below:

Total Pipe Volume	=	15,402 gallons (derived from Appendix III)
Total Pump Tank Volume	=	24,000 gallons (from Section 4.1)

After flushing (three volumes for pipes and four volumes for pump tanks), the wet residual volume is approximately 1,206 gallons. Using the above specific gravity, this correlates to 13,012 pounds of wet slurry or approximately 1,561 pounds of dry solids.

According to Nguyen (2005), the residual volume in the concentrate transfer system tank is 60 gallons. The volume for the 242-F Evaporator (including overheads tanks) is 142.3 gallons. Hence, the estimated evaporator residual for the 242-F and 242-16F Evaporators is approximately 284.3 gallons. This adds to a total residual volume for the evaporator systems and CTS of 344.6 gallons. These volumes are considered *settled*, and an 80% weight fraction is assumed. Therefore, the settled specific gravity of the solids is estimated at 2.31. This correlates to roughly 6,633 pounds of wet material or approximately 5,307 pound of dry solids.

Therefore, the total estimated mass of dry solids remaining in the ancillary equipment is 6,868 pounds or 3.12×10^6 grams.

5.2 Summary of Isotopes

Table 10 is developed by combining the results for each isotope from Tables 7, 8, and 9 with the maximum value from Tables 5 and 6. This summarizes the predicted estimated residual radioactive material for F-Tank Farm after closure activities are completed.

Table 10. Estimate of Residual Radioactivity in F-Tank Farm Ancillary Equipment

Isotope	Total Curies	Specific[1] Activity of Isotope (Ci/g)	Mass of Pure Isotope (grams)	Curies per Total Mass (Ci/g)	Mass of Pure Isotope per Total Mass (g/g)
H-3	2.61E+01	9.69E+03	2.69E-03	8.38E-06	8.65E-10
C-14	1.97E-01	4.45E+00	4.44E-02	6.34E-08	1.42E-08
Al-26	1.66E-02	1.92E-02	8.63E-01	5.32E-09	2.77E-07
Co-60	5.47E+01	1.13E+03	4.84E-02	1.76E-05	1.55E-08
Ni-59	1.16E+01	8.00E-02	1.45E+02	3.73E-06	4.66E-05
Ni-63	1.05E+03	5.67E+01	1.86E+01	3.38E-04	5.97E-06
Se-79	7.57E-02	4.10E-03	1.85E+01	2.43E-08	5.93E-06
Sr-90	1.05E+04	1.38E+02	7.63E+01	3.38E-03	2.45E-05
Y-90	1.05E+04	5.45E+05	1.93E-02	3.38E-03	6.20E-09
Nb-94	5.71E-05	1.87E-01	3.05E-04	1.83E-11	9.80E-11
Tc-99	1.81E+00	1.71E-02	1.06E+02	5.81E-07	3.40E-05
Rh-106	1.40E+00	3.57E+09	3.91E-10	4.48E-07	1.26E-16
Ru-106	1.40E+00	3.30E+03	4.23E-04	4.48E-07	1.36E-10
Te-125m	1.33E+01	1.82E+04	7.32E-04	4.28E-06	2.35E-10
Sb-125	5.46E+01	1.04E+03	5.25E-02	1.75E-05	1.68E-08
Sb-126	3.27E-02	8.29E+04	3.94E-07	1.05E-08	1.27E-13
Sb-126m	2.33E-01	7.79E+07	3.00E-09	7.49E-08	9.62E-16
Sn-126	2.33E-01	3.00E-02	7.78E+00	7.49E-08	2.50E-06
I-129	7.98E-02	1.77E-04	4.51E+02	2.56E-08	1.45E-04
Cs-134	3.94E+01	1.29E+03	3.06E-02	1.27E-05	9.81E-09
Cs-135	1.19E-02	1.10E-03	1.08E+01	3.82E-09	3.47E-06
Cs-137	1.38E+04	8.67E+01	1.59E+02	4.42E-03	5.10E-05
Ba-137m	1.30E+04	5.38E+08	2.42E-05	4.18E-03	7.77E-12
Ce-144	1.97E-01	3.18E+03	6.18E-05	6.31E-08	1.98E-11
Pr-144	1.97E-01	7.53E+07	2.61E-09	6.31E-08	8.38E-16
Pm-147	9.19E+02	9.28E+02	9.90E-01	2.95E-04	3.18E-07
Sm-151	2.75E+02	2.00E+01	1.37E+01	8.82E-05	4.41E-06
Eu-152	2.14E+00	1.74E+02	1.23E-02	6.86E-07	3.94E-09
Eu-154	1.15E+02	2.70E+02	4.26E-01	3.70E-05	1.37E-07
Eu-155	1.05E+02	4.85E+02	2.16E-01	3.37E-05	6.94E-08
Ra-226	1.14E-04	9.80E-01	1.16E-04	3.66E-11	3.73E-11
Ra-228	0.00E+00	2.73E+02	0.00E+00	0.00E+00	0.00E+00
Ac-227	3.44E-06	7.22E+01	4.77E-08	1.10E-12	1.53E-14
Th-229	9.82E+00	2.12E-01	4.63E+01	3.15E-06	1.49E-05
Th-230	1.50E-04	2.06E-02	7.29E-03	4.82E-11	2.34E-09
Th-232	0.00E+00	1.09E-07	0.00E+00	0.00E+00	0.00E+00
Pa-231	3.46E-06	4.70E-02	7.36E-05	1.11E-12	2.36E-11
U-232	7.32E-03	2.24E+01	3.27E-04	2.35E-09	1.05E-10
U-233	1.58E+01	9.65E-03	1.63E+03	5.06E-06	5.24E-04
U-234	1.82E-02	6.21E-03	2.93E+00	5.85E-09	9.41E-07
U-235	5.78E-05	2.16E-06	2.68E+01	1.86E-11	8.59E-06
U-236	5.94E-04	6.48E-05	9.16E+00	1.91E-10	2.94E-06
U-238	3.26E-03	3.36E-07	9.70E+03	1.05E-09	3.11E-03
Np-237	5.47E-03	7.05E-04	7.76E+00	1.76E-09	2.49E-06
Pu-238	4.12E+02	1.71E+01	2.41E+01	1.32E-04	7.73E-06
Pu-239	7.59E+00	6.20E-02	1.22E+02	2.44E-06	3.93E-05

Table 10. Estimate of Residual Radioactivity in F-Tank Farm Ancillary Equipment

Isotope	Total Curies	Specific[1] Activity of Isotope (Ci/g)	Mass of Pure Isotope (grams)	Curies per Total Mass (Ci/g)	Mass of Pure Isotope per Total Mass (g/g)
Pu-240	3.92E+00	2.27E-01	1.72E+01	1.26E-06	5.54E-06
Pu-241	3.10E+02	1.04E+02	2.98E+00	9.95E-05	9.57E-07
Pu-242	2.33E-02	3.96E-03	5.89E+00	7.48E-09	1.89E-06
Pu-244	1.71E-05	1.83E-05	9.36E-01	5.50E-12	3.00E-07
Am-241	1.58E+01	3.43E+00	4.61E+00	5.08E-06	1.48E-06
Am-242m	1.86E-01	1.05E+01	1.77E-02	5.97E-08	5.69E-09
Am-243	3.57E-02	2.00E-01	1.79E-01	1.15E-08	5.74E-08
Cm-242	1.14E-02	3.31E+03	3.43E-06	3.65E-09	1.10E-12
Cm-243	2.43E-03	5.06E+01	4.81E-05	7.81E-10	1.54E-11
Cm-244	3.28E-01	8.09E+01	4.06E-03	1.05E-07	1.30E-09
Cm-245	1.43E-04	1.70E-01	8.43E-04	4.60E-11	2.71E-10
Cm-247	2.30E-09	9.28E-05	2.48E-05	7.39E-16	7.97E-12
Cm-248	4.26E-13	4.14E-03	1.03E-10	1.37E-19	3.30E-17
Bk-249	2.94E-15	1.60E+03	1.84E-18	9.44E-22	5.90E-25
Cf-249	2.43E-12	4.09E+00	5.94E-13	7.80E-19	1.91E-19

1. Tuli, 2005

REFERENCES

Abramowitz, Milton and Stegun, Irene, *Handbook of Mathematical Functions*, Dover Publications, Mineola, New York, 1974.

Caldwell, T. B., to Freed, E. J., *Tank 8F Waste Removal – Pump Tank Concentrations During Dilution Operations*, HLW-STE-99-0023, January 27, 1999.

Caldwell, T. B., to Robinson, T. C., Jr., *Derivation of Weight Percent Solids in a Slurry*, CBU-PIT-2005-00145, June 16, 2005.

Georgeton, G. K., and Hester, J. R., *Characterization of Radionuclides in HLW Sludge Based on Isotopic Distribution in Irradiated Assemblies (U)*, WSRC-TR-94-0562, Revision 1, January 27, 1995.

High Level Waste Emergency Response Data and Waste Tank Data, N-ESR-G-00001, Revision 319, May 23, 2005.

Hutchens, G. J., *Estimate of Pu-244 Abundance in SRS High Level Waste Sludge*, CBU-PIT-2005-00039, Revision 0, March 10, 2005 (a).

Hutchens, G. J., *Estimate of Actinide Concentration by Radioactive Decay*, CBU-PIT-2005-00040, Revision, 0, March 15, 2005 (b).

Hutchens, G. J., *Estimate of Al-26 Abundance in SRS High Level Waste*, CBU-PIT-2005-00041, Revision 0, March 30, 2005.

REFERENCES (Continued)

Industrial Wastewater Closure Module for the High-Level Waste Tank 17 System, Revision 2, Construction Permit Number 17,424-IW, United States Department of Energy, Savannah River Site, Aiken, South Carolina, 29808, August 26, 1997.

Industrial Wastewater Closure Module for the High-Level Waste Tank 20 System, Construction Permit Number 17,424-IW, United States Department of Energy, Savannah River Site, Aiken, South Carolina, 29808, January 8, 1997.

Ledbetter, L. A., *Waste Characterization of Ni-63 in High Level Waste Sludge*, CBU-PIT-2005-00017, Revision 0, January 31, 2005.

Nguyen, Q. L., *Inventory of Residual Radionuclides Remaining in the 242-F Evaporator System*, CBU-PIT-2005-00075, Revision 0, June 16, 2005.

O'Bryant, R. F. and Weiss, W. R., *HLW Supernate Radionuclide Characterization*, WSRC-TR-94-00290, Revision 4, March 12, 2003.

O'Bryant, R. F., to Robinson, T. C., *F-Tank Farm Transfer Characterization Documentation*, ESH-WPF-2005-00050, June 7, 2005(a).

O'Bryant, R. F., *Characterization of Radionuclides in PUREX Waste Sludge from F-Area High Level Waste Tanks*, Revision 2, June 16, 2005(b).

Odaka, K, and Ueda, S, *Dependence of out-gassing rate on surface oxide layer thickness in type 304 stainless steel before and after surface oxidation in air* Mechanical Engineering Research Laboratory, Ibaraki, Japan. 13th International Vacuum Congress and 9th International Conference on Solid Surfaces, Yokohama, Japan, 25-29, Sept. 1995.

Poirier, M. R., to Looper, M. G., *ESP Sludge Transfers from H-Area to S-Area*, WSRC-RP-93-576, April 15, 1993.

Tran, H. Q. *Total Iodine-129 Curie Inventory Report*, CBU-PIT-2005-00033, Revision 0, February 14, 2005 (a).

Tran, H. Q., *Waste Characterization of Nb-94 in High Level Waste Sludge*, CBU-PIT-2005-00044, Revision 0, February 23, 2005 (b).

Tran, H. Q., *Compilation of Additional Radionuclide Data for SRS HLW Sludge to be Included in Waste Characterization System (WCS II)*, CBU-PIT-2005-00034, Revision 0, March 1, 2005 (c).

Tuli, J. K., *Nuclear Wallet Cards*, 6th Edition, National Nuclear Data Center Brookhaven National Laboratory, January 2000.

Savannah River Site Liquid Waste Facilities – Waste Characterization System, Version 1.5, March 1, 2005.

Shewmon, Paul, *Diffusion in Solids,* The Minerals, Metals, and Materials Society, Warrendale, Pennsylvania, 1989.

Weist, R.C. (ed.), *CRC Handbook of Chemistry and Physics,* 59th ed., CRC Press, Inc., Boca Raton, Florida, 1979.

Wiersma, B. J., to Cook, J. R., *Calculation of the Amount of Corrosion Product in HLW Tank 19*, Interoffice Memorandum, SRT-MTS-2002-20004, Rev. 1, February 8, 2002.

The following table of parent and daughter isotopes is generated from various sources. In general, the maximum concentrations were chosen when given an option of the type of waste characterized. Isotopes in secular equilibrium with the parent are shown in *italics*. The reference source terms are given as "fresh" waste with a post-reactor aging period of 180 days. The last day of production for SRS is assumed to be August 31, 1988. Therefore, date of the Reference Source Term is February 27, 1989. The source term date is June 1, 2005. The elapsed time is 5.1304E+08 seconds.

Table I-1. Source Term Summary

Isotope	Reference Source Term (Ci/gallon)	Halflife	Halflife Units	Halflife (sec)	Source Term (Ci/gallon)	Reference	Table or Page
H-3	1.82E-02	1.23E+01	y	3.88E+08	7.28E-03	Georgeton and Hester (1995)	Table III
C-14	7.82E-08	5.73E+03	y	1.81E+11	7.80E-08	Georgeton and Hester (1995)	Table IV
Al-26	1.13E-05	7.17E+05	y	2.26E+13	1.13E-05	Hutchens (2005c)	Page 8
Co-60	3.72E-01	1.93E+03	d	1.67E+08	4.42E-02	Georgeton and Hester (1995)	Table IV
Ni-59	8.56E-05	7.60E+04	y	2.40E+12	8.56E-05	Georgeton and Hester (1995)	Table III
Ni-63	9.57E-03	1.00E+02	y	3.16E+09	8.55E-03	Ledbetter (2005)	Table 1
Se-79	6.13E-05	1.1E+06	y	3.50E+13	6.13E-05	Georgeton and Hester (1995)	Table III
Sr-90	1.26E+01	2.88E+01	y	9.09E+08	8.52E+00	Georgeton and Hester (1995)	Table III
Y-90	1.26E+01	6.40E+01	h	2.30E+05	8.52E+00	Georgeton and Hester (1995)	Secular Equilibrium with Sr-90
Nb-94	4.60E-08	2.03E+04	y	6.41E+11	4.60E-08	Tran (2005b)	Table 4
Tc-99	1.20E-03	2.11E+05	y	6.66E+12	1.20E-03	Georgeton and Hester (1995)	Table III
Rh-106	6.86E+01	2.98E+01	s	2.98E+01	1.13E-03	Georgeton and Hester (1995)	Table III
Ru-106	6.86E+01	3.74E+02	d	3.23E+07	1.13E-03	Georgeton and Hester (1995)	Table III
Te-125m	6.30E-01	5.74E+01	d	4.96E+06	1.06E-02	Tran (2005c)	Page 9
Sb-125	2.58E+00	2.76E+00	y	8.71E+07	4.35E-02	Tran (2005c)	Table 7
Sb-126	1.60E-05	1.25E+01	d	1.08E+06	1.60E-05	Tran (2005c)	Table 10
Sb-126m	1.14E-04	1.92E+01	m	1.15E+03	1.14E-04	Tran (2005c)	Page 9
Sn-126	1.14E-04	1.00E+05	y	3.00E+12	1.14E-04	Georgeton and Hester (1995)	Table III
I-129	1.14E-06	1.57E+07	y	4.95E+14	5.04E-06	Tran (2005a)	Page 3 (based on 301.7 pCi/ml)
Cs-134	7.32E+00	7.55E+02	d	6.52E+07	3.13E-02	Georgeton and Hester (1995)	Table IV
Cs-135	7.09E-07	2.30E+06	y	7.30E+13	7.09E-07	WCS Sludge 1.5 (Version 6.1.05)	Sheet "RadComp"
Cs-137	1.55E+01	3.01E+01	y	9.50E+08	1.07E+01	Georgeton and Hester (1995)	Table III
Ba-137m	1.47E+01	2.55E+00	m	1.53E+02	1.01E+01	Georgeton and Hester (1995)	Secular Equilibrium with Cs-137
Ce-144	3.03E+02	2.85E+02	d	2.46E+07	1.60E-04	Georgeton and Hester (1995)	Table III
Pr-144	3.03E+02	1.73E+01	m	1.04E+03	1.60E-04	WCS Sludge 1.5 (Version 6.1.05)	Sheet "RadComp"
Pm-147	5.50E+01	2.62E+00	y	8.27E+07	7.46E-01	Georgeton and Hester (1995)	Table III
Sm-151	2.50E-01	9.00E+01	y	3.00E+09	2.22E-01	Tran (2005c)	Table 5

Table I-1. Source Term Summary (Continued)

Isotope	Reference Source Term (Ci/gallon)	Halflife	Halflife Units	Halflife (sec)	Source Term (Ci/gallon)	Reference	Table or Page
Eu-152	3.99E-03	1.35E+01	y	4.26E+08	1.73E-03	Tran (2005c)	Table 5
Eu-154	3.47E-01	8.59E+00	y	2.71E+08	9.34E-02	Georgeton and Hester (1995)	Table IV
Eu-155	9.12E-01	4.76E+00	y	1.50E+08	8.52E-02	Tran (2005c)	Table 5
Ra-226	9.26E-08	1.60E+03	y	5.10E+10	9.26E-08	Hutchens (2005b)	Page 8
Ra-228	0.00E+00	5.75E+00	y	1.81E+08	0.00E+00	Hutchens (2005b)	Page 8
Ac-227	2.79E-09	2.18E+01	y	6.88E+08	2.79E-09	Hutchens (2005b)	Page 10
Th-229	1.12E-02	7.34E+03	y	2.32E+11	7.98E-03	Hutchens (2005b)	Page 9
Th-230	1.18E-07	7.54E+04	y	2.38E+12	1.18E-07	Hutchens (2005b)	Page 8
Th-232	0.00E+00	1.41E+10	y	4.45E+17	0.00E+00	Hutchens (2005b)	Page 8
Pa-231	2.80E-09	3.28E+04	y	1.04E+12	2.80E-09	Hutchens (2005b)	Page 10
U-232	9.27E-07	6.89E+01	y	2.17E+09	7.87E-07	Georgeton and Hester (1995)	Table IV
U-233	1.80E-02	1.59E+05	y	5.02E+12	1.28E-02	Georgeton and Hester (1995)	Table IX - Scale to Sr-90 "Adjusted"
U-234	1.33E-06	2.46E+05	y	7.76E+12	1.33E-06	Georgeton and Hester (1995)	Table IV
U-235	1.47E-08	7.04E+08	y	2.22E+16	1.47E-08	Georgeton and Hester (1995)	Table IV
U-236	3.38E-07	2.34E+07	y	7.38E+14	3.38E-07	Georgeton and Hester (1995)	Table IV
U-238	5.35E-07	4.47E+09	y	1.41E+17	5.35E-07	Georgeton and Hester (1995)	Table III
Np-237	2.39E-06	2.14E+06	y	6.75E+13	2.39E-06	Georgeton and Hester (1995)	Table IV
Pu-238	3.79E-01	8.77E+01	y	2.77E+09	3.33E-01	Georgeton and Hester (1995)	Table IV
Pu-239	2.97E-03	2.41E+04	y	7.61E+11	2.97E-03	Georgeton and Hester (1995)	Table IV
Pu-240	2.08E-03	6.56E+03	y	2.07E+11	2.08E-03	Georgeton and Hester (1995)	Table IV
Pu-241	5.32E-01	1.43E+01	y	4.51E+08	2.42E-01	Georgeton and Hester (1995)	Table IV
Pu-242	3.01E-06	3.73E+05	y	1.18E+13	3.01E-06	Georgeton and Hester (1995)	Table IV
Pu-244	1.39E-08	8.00E+07	y	2.52E+15	1.39E-08	Hutchens (2005a)	Page 3
Am-241	8.54E-03	4.32E+02	y	1.36E+10	8.32E-03	Georgeton and Hester (1995)	Table III
Am-242m	1.22E-05	1.41E+02	y	4.45E+09	1.13E-05	Georgeton and Hester (1995)	Table III
Am-243	2.93E-06	7.37E+03	y	2.33E+11	2.93E-06	Tran (2005c)	Table 5
Cm-242	1.00E-05	1.63E+02	d	1.41E+07	9.24E-06	Tran (2005c)	Table 5
Cm-243	2.91E-06	2.91E+01	y	9.18E+08	1.98E-06	Tran (2005c)	Page 12
Cm-244	8.28E-05	1.81E+01	y	5.71E+08	4.44E-05	Georgeton and Hester (1995)	Table IV
Cm-245	2.83E-09	8.50E+03	y	2.70E+11	2.83E-09	Georgeton and Hester (1995)	Table IV
Cm-247	3.32E-16	1.56E+07	y	4.92E+14	3.32E-16	Tran (2005c)	Table 5
Cm-248	3.46E-16	3.48E+05	y	1.10E+13	3.46E-16	Tran (2005c)	Table 5
Bk-249	5.06E-13	3.30E+02	d	2.90E+07	2.39E-18	Tran (2005c)	Table 5
Cf-249	2.04E-15	3.51E+02	y	1.11E+10	1.98E-15	Tran (2005c)	Table 5

APPENDIX II

ESTIMATION OF DIFFUSION OF ISOTOPES INTO CARBON AND STAINLESS STEELS

This appendix provides a standard methodology for estimating the migration of radionuclides into carbon and stainless steel. Shewmon (1989) shows that Fick's Second Law of Diffusion can be used to calculate diffusion in metal; therefore, the diffusion rate is estimated using published lattice jump mechanisms and follows Fick's Second Law of Diffusion [Shewmon, 1989]. Equation II.1 is the continuity equation where $\partial c/\partial t$ is the change in concentration with respect to time and $-\nabla \cdot \vec{J}$ is the flow per unit area in all directions,

$$\frac{\partial c}{\partial t} = -\nabla \cdot \vec{J} \,. \qquad \text{(II.1)}$$

Because the diffusion takes place on the surface for this application, diffusion occurs in one direction, and the diffusion coefficient is independent of position, Equation II.1 becomes,

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \,. \qquad \text{(II.2)}$$

Assuming an infinite slab (because the depth of infiltration is very small compared to the thickness of the pipe), the solution to Equation II.2 becomes,

$$C(x,t) = C_0 \left[1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}} \right) \right] \qquad \text{(II.3)}$$

Where:
C_0 = initial concentration
x = distance from wall (cm)
D = diffusion coefficient (cm^2/sec)
t = time (sec)
erf = the error function

The maximum curie diffusion into the pipe walls per unit area (or *surface concentration*) is estimated by integrating Equation II.3 (the complementary error function) from zero to infinity with respect to wall thickness,

$$\int_0^\infty C(x,t)dx = \int_0^\infty C_0 \left[1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}} \right) \right] dx \,.$$

The complementary error function is defined as, erfc (x) = 1 – erf (x). Repeated integrals of the complementary error function according to Abramowitz (1974),

$$\mathbf{i}^{n}\,\mathrm{erfc}(x) = \int_x^\infty \mathbf{i}^{n-1}\,\mathrm{erfc}\,(t)\,dt\,, \tag{II.4}$$

where $\mathbf{i}$ is the integral operator $\mathbf{i} = \int_x^\infty \cdot \; dt$. [Note that $\mathbf{i}$ is not the imaginary unit $\sqrt{-1}$].

Expressed as a single integral [Abramowitz, 1974],

$$\mathbf{i}^{n}\,\mathrm{erfc}\,(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty \frac{(t-x)^n}{n!} e^{-t^2}\,dt \tag{II.5}$$

Of interest is,

$$\int_x^\infty \mathrm{erfc}\,(x)\,dx = \lim_{x \to 0} \mathbf{i}^{n}\,\mathrm{erfc}\,(x) \;\; \text{where} \;\; n = 1 \tag{II.6}$$

$$= \lim_{x \to 0} \frac{2}{\sqrt{\pi}} \int_x^\infty (t-x)\,e^{-t^2}\,dt \tag{II.7}$$

$$= \lim_{x \to 0} \left[\frac{2}{\sqrt{\pi}} \int_x^\infty t\,e^{-t^2}\,dt \,-\, x \underbrace{\frac{2}{\sqrt{\pi}} \int_x^\infty e^{-t^2}\,dt}_{\mathrm{erfc}(x)} \right] \tag{II.8}$$

$$= \lim_{x \to 0} \left[\frac{2}{\sqrt{\pi}} \int_x^\infty t\,e^{-t^2}\,dt \,-\, x\,\mathrm{erfc}\,(x) \right] \tag{II.9}$$

Let $u = t^2$ and $du = 2t\,dt$, then $t\,dt$= ½ du, then,

$$\frac{2}{\sqrt{\pi}} \int_x^\infty t\,e^{-t^2}\,dt = \frac{1}{2} \int_{x^2}^\infty e^{-u}\,du = \frac{1}{2}(-1)\;e^{-u}\Big|_{x^2}^{\infty} = \frac{1}{2} e^{-x^2} \tag{II.10}$$

So that,

$$\int_0^\infty \mathrm{erfc}\,(x)\,dx = \lim_{x \to 0} \left[\frac{2}{\sqrt{\pi}} \frac{1}{2} e^{-x^2} - x\,\mathrm{erfc}\,(x) \right] \tag{II.11}$$

$$= \lim_{x \to 0} \left[\frac{e^{-x^2}}{\sqrt{\pi}} - x\,\mathrm{erfc}\,(x) \right] = \frac{1}{\sqrt{\pi}} \tag{II.12}$$

After an appropriate change of variables from Equation II.3, Equation II.12 yields,

$$\int_0^\infty C(x,t)dx = \int_0^\infty C_0\left[1 - \operatorname{erf}\left(\frac{x}{2\sqrt{D\,t}}\right)\right]dx = 2\,C_0\sqrt{\frac{D\,t}{\pi}} \tag{II.13}$$

A paucity of data for diffusion coefficients for the isotopes tracked herein encourages the use of published works on isotopic tracers. Diffusion behavior of the unknown isotopes is estimated by plotting the behavior of known tracer elements in magnetic iron and non-magnetic iron. The Arrhenius equation defines the diffusion coefficient (D)

$$D = D_0 e^{-Q/RT} \tag{II.14}$$

Where
R = 0.0019872 kcal/mole-K
D_0 = Frequency Factor (cm^2/sec)
Q = Activation Energy (kcal/mole)
T = Temperature (K)

Because diffusivity of a solute partially depends on atomic number (Z), plots of Z versus the frequency factor (D_0) and the activation energy (Q) show a relationship. Though other factors such as melting point of the solvent, elastic constants, and position in the periodic table also influence the frequency factor and activation energy, Figures 1 through 3 illustrate a rough order relationship at the expense of a more exhaustive analysis. For the sake of this study, these relationships are sufficient to gain an understanding of the diffusion contribution to the ancillary equipment source term.

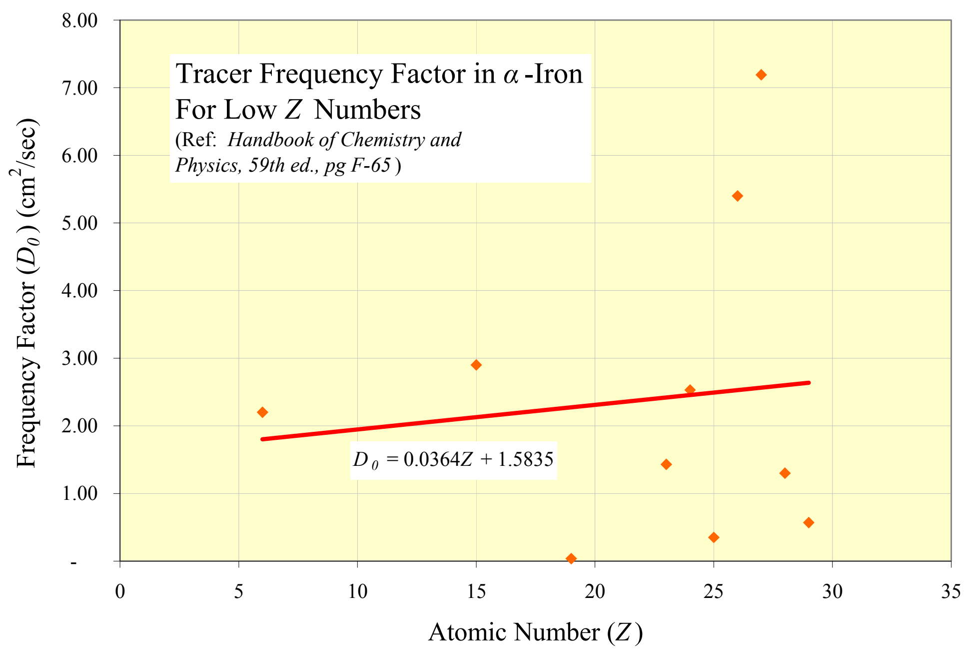

Figure II.1 – Frequency Factor D_0 vs. atomic number Z for low Z-number isotopic migration into α-iron.

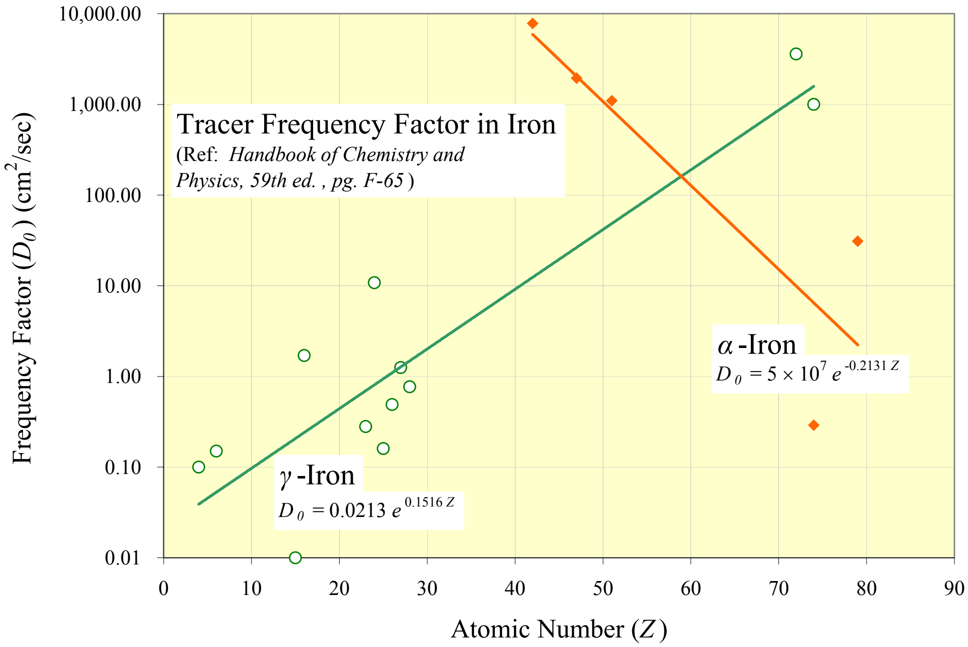

Figure II.2 – Frequency factor D_0 vs. atomic number Z for isotopic migration into α-iron and γ-iron.

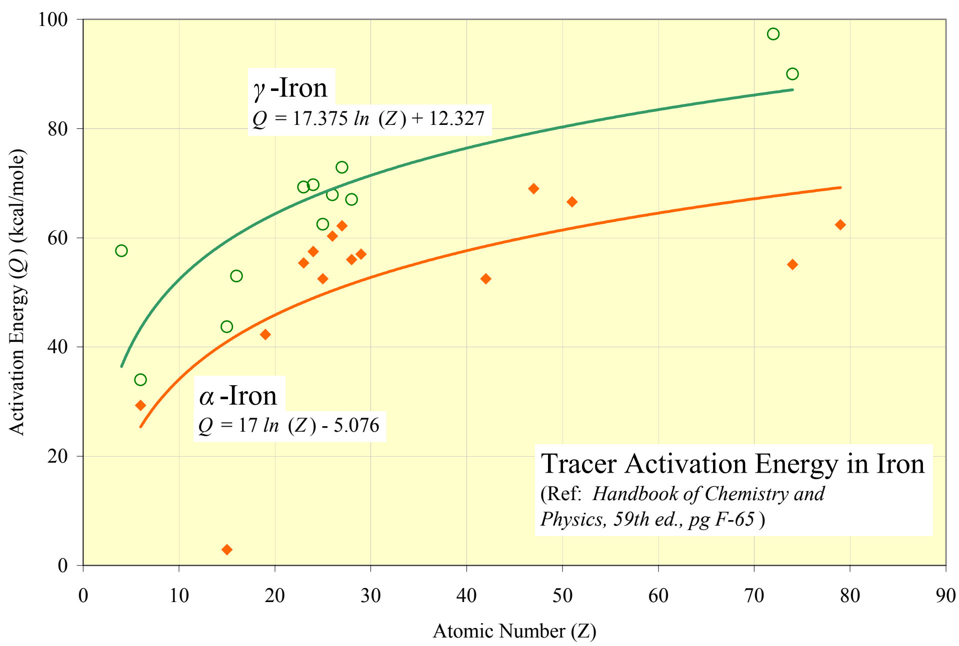

Figure II.3 – Activation energy Q vs. atomic number Z for isotopic migration into α-iron and γ-iron.

APPENDIX II

Carbon steel is predominantly an alloy of α-iron, whereas stainless steel is an austenitic alloy of iron and non-ferritic metals and possesses a crystalline structure similar to γ-iron. Therefore, Figures II.1 through II.3 provide the following correlations:

For stainless steel pipes:

$$D_0 = 0.0213\ e^{0.1516\ Z} \quad \text{(II.15)}$$

$$Q = 17.375\ ln\ (Z) + 12.327 \quad \text{(II.16)}$$

For carbon steel pipes:

$$D_0 = 0.0364\ Z + 1.5835 \quad \text{for Z < 42} \quad \text{(II.17)}$$

$$D_0 = 5 \times 10^7\ e^{-0.2131\ Z} \text{ for } Z \geq 42 \quad \text{(II.18)}$$

$$Q = 17\ ln\ (Z) - 5.076 \quad \text{(II.19)}$$

The isotopes in **bold** listed in Table II.1 use the diffusion data found in Weist (1979) rather than ascertained from the correlations above.

Table II.1 – Isotopic Diffusion Data Estimation

		Frequency Factor (D_0) cm^2/sec		*Activation Energy (Q) kcal/mole*	
Isotope	***Z***	**Carbon Steel**	**Stainless Steel**	**Carbon Steel**	**Stainless Steel**
H-3	1	1.6199E+00	2.4787E-02	1.2327E+01	1.2327E+01
C-14	6	**2.2000E+00**	**1.5000E-01**	**2.9300E+01**	**3.4000E+01**
Al-26	13	2.0567E+00	1.5286E-01	3.8528E+01	5.6893E+01
Co-60	27	**7.1900E+00**	**1.2500E+00**	**6.2200E+01**	**7.2900E+01**
Ni-59	28	**1.3000E+00**	**7.7000E-01**	**5.6000E+01**	**6.7000E+01**
Ni-63	28	**1.3000E+00**	**7.7000E-01**	**5.6000E+01**	**6.7000E+01**
Se-79	34	2.8211E+00	3.6890E+00	5.4872E+01	7.3598E+01
Sr-90	38	2.9667E+00	6.7649E+00	5.6763E+01	7.5530E+01
Y-90	39	3.0031E+00	7.8723E+00	5.7205E+01	7.5981E+01
Nb-94	41	3.0759E+00	1.0661E+01	5.8055E+01	7.6850E+01
Tc-99	43	5.2408E+03	1.4436E+01	5.8864E+01	7.7678E+01
Rh-106	44	4.2350E+03	1.6800E+01	5.9255E+01	7.8077E+01
Ru-106	45	3.4222E+03	1.9550E+01	5.9637E+01	7.8468E+01
Te-125	52	7.6996E+02	5.6495E+01	6.2095E+01	8.0980E+01
Sb-125	51	**1.1000E+03**	4.8548E+01	**6.6600E+01**	8.0642E+01
Sb-126	51	**1.1000E+03**	4.8548E+01	**6.6600E+01**	8.0642E+01
Sb-126m	51	9.5283E+02	4.8548E+01	6.1765E+01	8.0642E+01
Sn-126	50	1.1791E+03	4.1719E+01	6.1428E+01	8.0298E+01
I-129	53	6.2218E+02	6.5743E+01	6.2419E+01	8.1311E+01
Cs-134	55	4.0628E+02	8.9028E+01	6.3049E+01	8.1954E+01
Cs-135	55	4.0628E+02	8.9028E+01	6.3049E+01	8.1954E+01
Cs-137	55	4.0628E+02	8.9028E+01	6.3049E+01	8.1954E+01
Ba-137m	56	3.2830E+02	1.0360E+02	6.3355E+01	8.2267E+01
Ce-144	58	2.1438E+02	1.4030E+02	6.3952E+01	8.2877E+01
Pr-144	59	1.7323E+02	1.6326E+02	6.4242E+01	8.3174E+01
Pm-147	61	1.1312E+02	2.2109E+02	6.4809E+01	8.3753E+01
Sm-151	62	9.1408E+01	2.5728E+02	6.5085E+01	8.4036E+01
Eu-152	63	7.3865E+01	2.9939E+02	6.5357E+01	8.4314E+01

Table II.1 – Isotopic Diffusion Data Estimation

		Frequency Factor (D_0) cm^2/sec		*Activation Energy (Q) kcal/mole*	
Isotope	***Z***	**Carbon Steel**	**Stainless Steel**	**Carbon Steel**	**Stainless Steel**
Eu-154	63	7.3865E+01	2.9939E+02	6.5357E+01	8.4314E+01
Eu-155	63	7.3865E+01	2.9939E+02	6.5357E+01	8.4314E+01
Ra-226	88	3.5870E-01	1.3250E+04	7.1039E+01	9.0121E+01
Ra-228	88	3.5870E-01	1.3250E+04	7.1039E+01	9.0121E+01
Ac-227	89	2.8986E-01	1.5419E+04	7.1231E+01	9.0317E+01
Th-229	90	2.3423E-01	1.7943E+04	7.1421E+01	9.0511E+01
Th-230	90	2.3423E-01	1.7943E+04	7.1421E+01	9.0511E+01
Th-232	90	2.3423E-01	1.7943E+04	7.1421E+01	9.0511E+01
Pa-231	91	1.8927E-01	2.0880E+04	7.1609E+01	9.0703E+01
U-232	92	1.5295E-01	2.4298E+04	7.1794E+01	9.0893E+01
U-233	92	1.5295E-01	2.4298E+04	7.1794E+01	9.0893E+01
U-234	92	1.5295E-01	2.4298E+04	7.1794E+01	9.0893E+01
U-235	92	1.5295E-01	2.4298E+04	7.1794E+01	9.0893E+01
U-236	92	1.5295E-01	2.4298E+04	7.1794E+01	9.0893E+01
U-238	92	1.5295E-01	2.4298E+04	7.1794E+01	9.0893E+01
Np-237	93	1.2359E-01	2.8276E+04	7.1978E+01	9.1081E+01
Pu-238	94	9.9872E-02	3.2904E+04	7.2160E+01	9.1267E+01
Pu-239	94	9.9872E-02	3.2904E+04	7.2160E+01	9.1267E+01
Pu-240	94	9.9872E-02	3.2904E+04	7.2160E+01	9.1267E+01
Pu-241	94	9.9872E-02	3.2904E+04	7.2160E+01	9.1267E+01
Pu-242	94	9.9872E-02	3.2904E+04	7.2160E+01	9.1267E+01
Pu-244	94	9.9872E-02	3.2904E+04	7.2160E+01	9.1267E+01
Am-241	95	8.0704E-02	3.8290E+04	7.2340E+01	9.1451E+01
Am-242m	95	8.0704E-02	3.8290E+04	7.2340E+01	9.1451E+01
Am-243	95	8.0704E-02	3.8290E+04	7.2340E+01	9.1451E+01
Cm-242	96	6.5215E-02	4.4558E+04	7.2518E+01	9.1633E+01
Cm-243	96	6.5215E-02	4.4558E+04	7.2518E+01	9.1633E+01
Cm-244	96	6.5215E-02	4.4558E+04	7.2518E+01	9.1633E+01
Cm-245	96	6.5215E-02	4.4558E+04	7.2518E+01	9.1633E+01
Cm-247	96	6.5215E-02	4.4558E+04	7.2518E+01	9.1633E+01
Cm-248	96	6.5215E-02	4.4558E+04	7.2518E+01	9.1633E+01
Bk-249	97	5.2699E-02	5.1852E+04	7.2694E+01	9.1813E+01
Cf-249	98	4.2584E-02	6.0340E+04	7.2868E+01	9.1991E+01

Applying D_0 and Q to the Arrhenius equation (Equation II.14) gives an estimate of the diffusion coefficient and subsequently the surface concentration of each isotope (Equation II.13).

Table II.2 shows the diffusion coefficient via the application of Equations II.15 through II.19.

Table II.2 Diffusion Coefficient Estimation

Isotope	Diffusion Coefficient (D) cm^2/sec Carbon Steel	Diffusion Coefficient (D) cm^2/sec Stainless Steel
H-3	9.70E-08	1.48E-09
C-14	1.50E-17	1.80E-21
Al-26	5.48E-23	7.08E-35
Co-60	2.59E-36	2.42E-43
Ni-59	2.01E-33	4.27E-40
Ni-63	2.01E-33	4.27E-40
Se-79	2.00E-32	2.79E-43
Sr-90	1.64E-33	3.77E-44
Y-90	9.13E-34	2.39E-44
Nb-94	2.97E-34	1.00E-44
Tc-99	1.70E-31	4.44E-45
Rh-106	8.10E-32	3.01E-45
Ru-106	3.91E-32	2.07E-45
Te-125	3.19E-34	2.02E-46
Sb-125	1.05E-36	2.73E-46
Sb-126	1.05E-36	2.73E-46
Sb-126m	6.17E-34	2.73E-46
Sn-126	1.20E-33	3.74E-46
I-129	1.67E-34	1.50E-46
Cs-134	4.65E-35	8.54E-47
Cs-135	4.65E-35	8.54E-47
Cs-137	4.65E-35	8.54E-47
Ba-137m	2.49E-35	6.51E-47
Ce-144	7.26E-36	3.87E-47
Pr-144	3.97E-36	3.02E-47
Pm-147	1.21E-36	1.87E-47
Sm-151	6.71E-37	1.49E-47
Eu-152	3.76E-37	1.19E-47
Eu-154	3.76E-37	1.19E-47
Eu-155	3.76E-37	1.19E-47
Ra-226	8.55E-43	2.09E-49
Ra-228	8.55E-43	2.09E-49
Ac-227	5.33E-43	1.86E-49
Th-229	3.34E-43	1.67E-49
Th-230	3.34E-43	1.67E-49
Th-232	3.34E-43	1.67E-49
Pa-231	2.09E-43	1.50E-49
U-232	1.32E-43	1.35E-49
U-233	1.32E-43	1.35E-49
U-234	1.32E-43	1.35E-49
U-235	1.32E-43	1.35E-49
U-236	1.32E-43	1.35E-49
U-238	1.32E-43	1.35E-49
Np-237	8.30E-44	1.22E-49
Pu-238	5.25E-44	1.10E-49
Pu-239	5.25E-44	1.10E-49
Pu-240	5.25E-44	1.10E-49
Pu-241	5.25E-44	1.10E-49
Pu-242	5.25E-44	1.10E-49
Pu-244	5.25E-44	1.10E-49
Am-241	3.33E-44	1.00E-49
Am-242m	3.33E-44	1.00E-49
Am-243	3.33E-44	1.00E-49
Cm-242	2.11E-44	9.12E-50
Cm-243	2.11E-44	9.12E-50
Cm-244	2.11E-44	9.12E-50
Cm-245	2.11E-44	9.12E-50
Cm-247	2.11E-44	9.12E-50
Cm-248	2.11E-44	9.12E-50
Bk-249	1.35E-44	8.33E-50
Cf-249	8.60E-45	7.62E-50

APPENDIX III – Line Segments

Table III-1. Line Segment Listing for F-Tank Farm

Line No.	From	To	Core Material	Core Diameter (inches)	Jacket Diameter (inches)	Line Length (ft)	Reference Drawings	Affected Surface Area (ft^2)
1	1F Evap	1F CTS	SS	3	4	50	S5-2-5943, S5-2-5970	40
2	Tk33(C2) VN	Tk34(C2) VN	SS	2	3	190	W239840, W238338, W259468, M-M6-F-3355	103
2 (old)	1F Evap	Tk18	SS	3	6	80	S5-2-5970, S5-2-1388, W164177	64
3	FDB-1(28)	Tk18	SS	3	6	430	W163901, W164193	345
4	FDB-1(29)	Tk17	SS	3	6	480	W163901	386
7	Tk17	Tk19	SS	4	6	55	W717008	58
8	Tk20	Tk18	SS	4	6	55	W717613	58
9	#9000	Tk19 (NW)	CS	3	4	35	W709575, W717164, W716823, M-M6-F-3363	97
11	1F Evap	1F CTS	SS	3	4	50	S5-2-5943, S5-2-5970	40
73	Tk44 (C1) TJ	Tk26 (C1)	SS	3	10	447	W706328, W703325, W701873, M-M6-F-3107, M-M6-F-3111	359
74	Tk45 (C1) TJ	Tk26 (C1)	SS	3	10	289	W706328, W703325, W703416, M-M6-F-3107, M-M6-F-3112	232
75	Tk46 (C1)	Tk26 (C1)	SS	3	10	404	W706330, W703325, W703418, M-M6-F-3107, M-M6-F-3113	324
76	Tk47(C1)TJ	Tk26 (C1)	SS	3	10	547	W706330, W703325, W703418, M-M6-F-3107, M-M6-F-3114	439
100 (221F)	221-F	#1475	SS	3	10	1661	W713074, W713075, W712364, W700782, M-M6-F-3119	1334
100 (IAL)	FDB-2(26)	HiPt flush pit (6)	SS	3	4	4288	W235672, W714300, W234806, M-M6-F-3310, M-M6-F-3349, M-M6-F-3309	3444

Table III-1. Line Segment Listing for F-Tank Farm (continued)

Line No.	From	To	Core Material	Core Diameter (inches)	Jacket Diameter (inches)	Line Length (ft)	Reference Drawings	Affected Surface Area (ft^2)
101 (DB4)	FDB-4(5)	FPP-2(6) pump in.	SS	3	0	34	W701347, M-M6-F-3121, M-M6-F-3116,	27
101 (IAL)	HiPt flush pit (4)	FDB-2(25)	SS	3	4	4288	W234806, M-M6-F-3310, M-M6-F-3349, M-M6-F-3309, W712694, W714758	3444
101(221F)	221-F	#1478	SS	3	10	1661	W713074, W713075, W712364, W700782, M-M6-F-3116	1334
102 (221F)	221-F	#1488	SS	3	10	1661	W713074, W713075, W712364, W700782, M-M6-F-3116	1334
102 (DB2)	FPP-1(5)	FDB-2(35)	SS	3	4	46	W236643, W235672, W2017868, M-M6-F-3350, M-M6-F-3349, M-M6-F-3309	37
102 (DB4)	FDB-4(2)	FPP-3(6) pump in.	SS	3	0	50	W2017868, W701347, M-M6-F-3121, M-M6-F-3119	40
103 (DB2)	FDB-2(36)	FPP-1 (4)	SS	3	4	40	W236643, M-M6-F-3350, M-M6-F-3349, M-M6-F-3309	32
103 (DB4)	FDB-4(7)	FPP-1(1)	SS	3	4	153	W718059, W236643, W701123, M-M6-F-3350, M-M6-F-3121	123
103(221F)	221-F	#1476	SS	3	10	1661	W713074, W713075, W712364, W700782, M-M6-F-3119	1334
104 (DB2)	FDB-2(27)	FDB-1(8)	SS	3	4	1000	W235672, W236672, W2017868, M-M6-F-3349, M-M6-F-3359	803
104 (DB4)	FDB-4(9)	FDB-3(9)	SS	3	10	150	W701347, W701121, W712694, M-M6-F-3121, M-M6-F-3353	120
105	Tk27(S) VN	FDB-4(11)	SS	3	10	108	W700932, W701016, W701227, M-M6-F-3121, M-M6-F-3108	87
106 (DB2)	FPP-1(2)	FDB-2(28)	SS	3	4	22	W236643, W235672, M-M6-F-3349, M-M6-F-3350, W712694	18
106 (DB4)	Tk28(S) valve box	FDB-4(10)	SS	3	10	538	W700932, W701016, W701227, M-M6-F-3121, M-M6-F-3110	432
107 (DB2)	FDB-2(33)	Tk18	SS	3	4	643	W236672, M-M6-F-3349, M-M6-F-3364	516
107 (DB4)	Tk26(C1) TJ	FDB-4(13)	SS	3	10	118	W700928, W701014, W700782, M-M6-F-3107, M-M6-F-3121	95

Table III-1. Line Segment Listing for F-Tank Farm (continued)

Line No.	From	To	Core Material	Core Diameter (inches)	Jacket Diameter (inches)	Line Length (ft)	Reference Drawings	Affected Surface Area (ft^2)
108 (DB2)	FDB-2(32)	FDB-3(15)	SS	3	4	80	W238338, W238427, M-M6-F-3349, M-M6-F-3353	64
108 (DB4)	Tk25(C1) TJ	FDB-4(16)	SS	3	8	323	W700782, W701013, W713153, M-M6-F-3106, M-M6-F-3121	259
108 (Tk18)	FDB-2(32)	Tk18	SS	3	4	450	W235672	361
109 (DB2)	FDB-2(37)	#3754 & #3755	SS	3	8	60	W718172, M-M6-F-3289, M-M6-F-3349	48
109 (DB4)	FDB-4(12)	Tk26(C1) VN	SS	3	10	118	W700928, W701014, W700782, M-M6-F-3107, M-M6-F-3121	95
110	#17015	FDB-2(31)	SS	3	6	285	W236672, W236643, M-M6-F-3288, M-M6-F-3349, W714298	229
110 (cut)	Tk7(2)	cut & capped	SS	3	4	23	W814578, M-M6-F-3288	18
111	FDB-2(30)	FDB-3(16)	SS	3	8	57	W238273, W706053, W238155, M-M6-F-3353, M-M6-F-3349	46
112	FDB-2(29)	FDB-3(17)	SS	3	8	67	W2017868, W713210, W238318, M-M6-F-3349, M-M6-F-3353	54
114	FDB-1(30)	FPP-1(1A)	SS	3	8	640	W718377, W702321, W238318, M-M6-F-3350, M-M6-F-3359, W702327	514
115	FDB-1(31)	cut & capped	SS	3	8	10	M-M6-F-3359	8
116	FDB-1(32)	cut & capped	SS	3	8	10	M-M6-F-3359	8
117	FDB-1(33)	cut & capped	SS	3	8	10	M-M6-F-3359	8
118	#5016	#213	SS	3	10	296	S5-2-5090, W235672, W709589, M-M6-F-4032	238
118 (DB1)	FDB-1(7)	cut & capped	SS	3	10	519	M-M6-F-3359	417
151 (DB3)	Tk33(NW)VN	FDB-3(4)	SS	3	8	190	W238318, W238338, W238155, M-M6-F-3353	153
151 (DB4)	FPP-2(5) pump out	FDB-4(6)	SS	3	0	46	W701347, W700566, W2017868, M-M6-F-3121, M-M6-F-3116	37
152 (DB3)	FDB-3(3)	Tk33(NW)VN	SS	3	8	190	W238318, W238338, W238155, M-M6-F-3353	153

Table III-1. Line Segment Listing for F-Tank Farm (continued)

Line No.	From	To	Core Material	Core Diameter (inches)	Jacket Diameter (inches)	Line Length (ft)	Reference Drawings	Affected Surface Area (ft^2)
152 (DB4)	FPP-2(7) TJ	FDB-4(4)	SS	3	0	36	W701347, W713770, W700566, M-M6-F-3121, M-M6-F-3116	29
156	Tk34 (C1) VN	FDB-3(2)	SS	3	8	295	W238318, W238338, M-M6-F-3353	237
157	FDB-3(1)	Tk34 (C1) VN	SS	3	8	295	W238318, W238338, M-M6-F-3353	237
161	FDB-3 sump	FDB-2 sump	SS	1.5	4	84	M-M6-F-3349, M-M6-F-3353	35
176 (old)	1F Evap	Tk18 (SW)	SS	3	6	20	S5-2-5942, W231025	16
176A	1F CTS	Tk7	SS	3	4	500	S5-2-5931, S5-2-5932, S5-2-5942	402
176B	Tk7	1F Evap	SS	3	4	40	W701934, S5-2-5932	32
177 (old)	1F Evap	Tk18 (SW)	SS	3	6	20	S5-2-5942, W231025	16
177A	1F CTS	Tk7	SS	3	4	500	S5-2-5931, S5-2-5932, S5-2-5942	402
177B	1F Evap	Tk18 (SW)	SS	3	6	20	S5-2-5942, W231025	16
201	FPP-3(5) pump out	FDB-4(3)	SS	3	0	56	W2017868, W701347, M-M6-F-3121, M-M6-F-3119	45
202	FPP-3(7) TJ	FDB-4(1)	SS	3	0	47	W2017868, W701347, M-M6-F-3121, M-M6-F-3119	38
210	Tk4(6)TJ	#3752	SS	3	10	227	W728976,W716927,W716595,W713153, M-M6-F-3583, M-M6-F-3289	182
211	Tk3(5) TJ	Tk7(6) VN	SS	3	10	272	W710315, W713153, M-M6-F-3287, M-M6-F-3288	218
212	Tk2(3)TJ	Tk7(6) VN	SS	3	10	420	W710315, W713153, M-M6-F-3583, M-M6-F-3288	337
213	#118	Tk7(6) VN	SS	3	10	376	W710315, W713153, M-M6-F-3288, M-M6-F-4032	302
213 (Tk1)	Tk1(3)TJ	cut & capped	SS	3	10	34	M-M6-F-3287	27

Table III-1. Line Segment Listing for F-Tank Farm (continued)

Line No.	From	To	Core Material	Core Diameter (inches)	Jacket Diameter (inches)	Line Length (ft)	Reference Drawings	Affected Surface Area (ft^2)
213 (DB2)	#109 (DB2)	cut & capped	SS	3	4	9	M-M6-F-3349	7
301	1F CTS	Tk1-4 loop line	SS	2	6	1942	W239840, W236128	1051
302	Tk18	1F CTS	SS	1.5	4	70	W236195	30
302 (old)	1F Evap	Tk18 (SE)	SS	1.5	4	20	S5-2-5942	8
303	1F Evap	1F CTS	SS	1.5	4	70	W236195	30
304	Tk18	1F CTS	SS	3	4	70	W236195	56
397	Tk25(C1) TJ	Tk26(S)	SS	3	8	312	W700764, W701011, W700766, M-M6-F-3107, M-M6-F-3106	251
497	Tk27(C1) TJ	Tk26(S)	SS	3	10	283	W700765, W701018, W700767,M-M6-F-3107, M-M6-F-3108	227
515	16030	#3754	SS	3	6	60	W716598, M-M6-F-3289, M-M6-F-3644	48
520	Tk5(6)	#3751	SS	3	6	128	W713153, W716596, M-M6-F-3289, M-M6-F-3287	103
521	Tk6(6)	#3753	SS	3	6	133	W719199, W812719, W716927, M-M6-F-3289, M-M6-F-3626	107
547	Tk28(C1) valve box	Tk26(S)	SS	3	10	392	W700765, W701018, W700767, M-M6-F-3107, M-M6-F-3110	315
960	Tk25(C2) VN	Tk26(C2)VN	SS	2	6	205	W702257,W702033,W702258,M-M6-F-3106,M-M6-F-3107,M-M6-F-3124	111
1012	Tk26(R2) VN	242-16F evaporator	SS	1	3	133	W701836, W703415, W701837, M-M6-F-3024, M-M6-F-3030	37
1013	Tk26(C2) VN	Tk27(C2) VN	SS	2	6	170	W702259, W702260, W702034, M-M6-F-3107, M-M6-F-3124, M-M6-F-3108	92
1040	Tk26(R1) VN	FDB-6(4)	SS	3	6	491	W701848, W702028, W702341, M-M6-F-3357, W700975	394

Table III-1. Line Segment Listing for F-Tank Farm (continued)

Line No.	From	To	Core Materia l	Core Diamete r (inches)	Jacket Diamete r (inches)	Line Length (ft)	Reference Drawings	Affected Surface Area (ft^2)
1054	Tk27(C2) VN	Tk28(C2) VN	SS	2	6	172	W702262, W702126, M-M6-F-3108, M-M6-F-3124, M-M6-F-3110	93
1104	Tk28(C2) VN	FDB-5(9)	SS	2	10	357	W702293, W702294, W702035, M-M6-F-3123, M-M6-F-3124, M-M6-F-3110	193
1209	3-valve box W328-15-3	Tk28 TTJ	SS	3	6	23	M-M6F-3110, W2021381, W818659, W818679	18
1377	242-16F evaporator (24)	Tk26(C3) VN	SS	2	6	75	W701134, W701135, W701403, M-M6-F-3024, M-M6-F-3030	41
1378	242-16F evaporator (23)	Tk25(C3) VN	SS	2	6	110	W701132, W701133, W701402, M-M6-F-3024, M-M6-F-3031	60
1379	242-16F evaporator (10)	Tk27(C3) VN	SS	2	6	77	W701387, W701388, W701407, M-M6-F-3024, M-M6-F-3027	42
1380	242-16F evaporator (11)	Tk28(C3) VN	SS	2	6	176	W702644, W702645, W701408, M-M6-F-3024, M-M6-F-3031	95
1383	242-16F evaporator (22)	Tk44(C3) VN	SS	2	6	190	W706010, W706011, W705722, M-M6-F-3024, M-M6-F-3032	103
1384	242-16F evaporator (21)	Tk45(C3) VN	SS	2	6	97	W706012, W706013, W705723, M-M6-F-3024, M-M6-F-3032	52
1385	242-16F evaporator (13)	Tk46(C3) VN	SS	2	6	97	W706014, W706015, W705724, M-M6-F-3024, M-M6-F-3033	52
1386	242-16F evaporator (12)	Tk47(C3) VN	SS	2	6	181	W706016, W706017, W705725, M-M6-F-3024, M-M6-F-3033	98
1408	242-16F Evap.	Tk27(M) CRC	SS	1.5	6	115	W703008, W703009, W703051, M-M6-F-3026, M-M6-F-3027, M-M6-F-3028	48
1414	Tk27(M) CRC	242-16F Evap.	SS	1.5	6	115	W703008, W703009, W703051, M-M6-F-3026, M-M6-F-3027, M-M6-F-3028	48
1461	Tk44(C1) TJ	FDB-4(20)	SS	3	10	483	W705250, W702129, W702302, M-M6-F-3121, M-M6-F-3111	388
1462	Tk45(C1) TJ	FDB-4(19)	SS	3	10	340	W705250, W702130, W702302, M-M6-F-3121, M-M6-F-3112	273
1467	Tk46(C1) VN	FDB-4(18)	SS	3	10	685	W705253, W702130, W701347, M-M6-F-3113, M-M6-F-3121	550

Table III-1. Line Segment Listing for F-Tank Farm (continued)

Line No.	From	To	Core Material	Core Diameter (inches)	Jacket Diameter (inches)	Line Length (ft)	Reference Drawings	Affected Surface Area (ft^2)
1468	Tk47 (C1)	FDB-4(17)	SS	3	10	826	W705253, W702130, W701347, M-M6-F-3114, M-M6-F-3121	663
1472	FDB-3(10)	FDB-4(8)	SS	3	10	150	W701347, W701121, W712694, M-M6-F-3121, M-M6-F-3353	120
1475	#100 (221F)	FPP-3(1)	SS	3	6	434	W701552, W701937, W704855,W700782, M-M6-F-3119	349
1476	#103 (221F)	FPP-3(2)	SS	3	10	650	W703322, W703333, W704857, W700782, M-M6-F-3119	522
1478	#101 (221F)	FPP-2(1)	SS	3	10	650	W703322, W703333, W704857, W700782, M-M6-F-3116	522
1488	#102 (221F)	FPP-2(2)	SS	3	6	161	W702671, W702672, W701122, W700782, M-M6-F-3116	129
3260	FDB-6 sump	FPP-3(3A)	SS	3	6	248	M-M6-F-3357, M-M6-F-3119,W702358, W702359, W701791,W700975	199
3261	Tk33(C2) VN	FDB-5 (3)	SS	2	6	141	W239840, W702026, W702734,M-M6-F-3123, M-M6-F-3355	76
3265	FDB-5(1)	F-CTS 242-3F	SS	2	8	1910	W702026, W702027, W702734, M-M6-F-3123, M-M6-F-3356	1034
3265-B	1F CTS	Tk33-34	SS	2	8	22	W702026	12
3266	242-F Evap.	FDB-6(5)	SS	3	6	324	W700975, W701934, W702732, M-M6-F-3357, W701196	260
3267	Tk7 (1) VN	FDB-6(1)	SS	3	6	192	W700975, W701934, W702732, M-M6-F-3357	154
3273	Tk25(C2) VN	FDB-5(10)	SS	2	6	393	W702295, W702127, W702032, M-M6-F-3124, M-M6-F-3123, M-M6-F-3106	213
3274	FDB-5 Waste drain	FPP-2(3)	SS	3	6	124	M-M6-F-3116, M-M6-F-3123,W700975,W702543,W701793	100
3275	F-CTS 242-3F	FDB-5(2)	SS	2	8	1910	W702026, W702027, W702734, M-M6-F-3123, M-M6-F-3356	1034
3275-B	1F CTS	Tk33-34	SS	2	8	22	W702026	12
3276	Tk34 (C2) VN	FDB-5(4)	SS	2	6	141	W239840, W702026, W702734,M-M6-F-3123, M-M6-F-3355	76

Table III-1. Line Segment Listing for F-Tank Farm (continued)

Line No.	From	To	Core Material	Core Diameter (inches)	Jacket Diameter (inches)	Line Length (ft)	Reference Drawings	Affected Surface Area (ft^2)
3277	FDB-6(6)	242-F Evap.	SS	3	6	324	W700975, W701934, W702732, M-M6-F-3357, W701196	260
3278	FDB-6(2)	Tk7(1) VN	SS	3	6	192	W700975, W701934, W702732, M-M6-F-3357	154
3751	#520	#3754	SS	3	6	2	M-M6-F-3289, W719199	2
3752	#210	#3754	SS	3	6	2	M-M6-F-3289, W719199	2
3753	#521	#3754	SS	3	6	2	M-M6-F-3289, W719199	2
3754	#515	#109 & #3755	SS	3	6	55	M-M6-F-3289, W719199	44
3755	#109 & #3754	#103	SS	3	6	3	M-M6-F-3289, W719199, M-M6-F-3350	2
4878	Tk17 (R) TTP	Tk18(W)	SS	3	4	112	M-M6-F-3363, W717008, S5-2-3524, M-M6-F-4032	90
5016	Tk18 (NE) TTP	#118	SS	3	4	54	M-M6-F-4032, W719182, W719183, S5-2-5090	43
9000	#9001	#9	CS	2	0	2	P-R1-F-0005, P-R1-F-0014, P-R1-F-0013, M-M6-F-3363	2
9001	Tank 18 (W)	#9000	CS	3	4	108	W717164, M-M6-F-3363, M-M6-F-4032	300
9852	Tk20(NW) Valve box	Tk18	SS	4	6	8	M-M6-F-3364, W717613, W164193, W719905	8
16030	Tank 8 (6)	#515	SS	3	4	20	M-M6-F-3644, P-P1-F-2346, P-R1-F-0004	16
16075	Tank 8 (6)	LDB-17	SS	3	4	8	M-M6-F-3644, P-P1-F-2346, P-R1-F-0004	6
16076	LDB-17	#515	SS	3	4	12	M-M6-F-3644, P-P1-F-2346, P-R1-F-0004	10
17015	Tk7(4) TTP	#110	SS	3	6	96	W2017868, W814578, W814579, M-M6-F-3288, M-M6-F-3614	77

Table III-1. Line Segment Listing for F-Tank Farm (continued)

Line No.	From	To	Core Material	Core Diameter (inches)	Jacket Diameter (inches)	Line Length (ft)	Reference Drawings	Affected Surface Area (ft^2)
GDL	1F Evap	Tk17-20	SS	3	12	36	W231025	29
Misc-1	Tk19	Tk18	SS	3	4	144	S5-2-3524	116
Misc-2	Tk17	Tk18	SS	3	4	106	S5-2-3524	85
							Total	**34,089**

The F Tank Farm (FTF) waste is characterized as sludge and supernate. The supernate waste for the both F and H Tank Farms is characterized under waste stream FHW00001 [O'Bryant and Weiss, 2003]. F-Tank Farm Sludge is characterized under FTK00002-1 [O'Bryant, 2005b]

Table IV-1. Isotopic Distribution for Characterization

	Mean Distribution		*Bounding Distribution*	
Isotopes	**FHW00001**	**FTK00002-1**	**Maximum**	**Normalized**
H-3	1.59E-03	0.00E+00	1.59E-03	1.57E-03
C-14	9.44E-07	1.07E-08	9.44E-07	9.34E-07
Co-60	1.01E-02	1.42E-03	1.01E-02	9.96E-03
Ni-59	9.98E-06	1.30E-05	1.30E-05	1.29E-05
Ni-63	3.33E-08	0.00E+00	3.33E-08	3.29E-08
Se-79	0.00E+00	9.04E-06	9.04E-06	8.94E-06
Sr-90	2.29E-02	4.47E-01	4.47E-01	4.43E-01
Y-90	2.29E-02	4.47E-01	4.47E-01	4.43E-01
Tc-99	9.60E-05	1.56E-04	1.56E-04	1.55E-04
Ru-106	0.00E+00	4.13E-05	4.13E-05	4.09E-05
Rh-106	0.00E+00	4.13E-05	4.13E-05	4.09E-05
Sb-125	0.00E+00	1.62E-03	1.62E-03	1.61E-03
Sn-126	0.00E+00	1.68E-05	1.68E-05	1.66E-05
I-129	9.93E-08	7.45E-10	9.93E-08	9.83E-08
Cs-134	0.00E+00	1.18E-05	1.18E-05	1.17E-05
Cs-135	0.00E+00	1.05E-07	1.05E-07	1.04E-07
Cs-137	4.83E-01	3.28E-02	3.28E-02	3.25E-02
Ba-137m	4.57E-01	3.11E-02	3.11E-02	3.07E-02
Ce-144	0.00E+00	1.30E-05	1.30E-05	1.29E-05
Pr-144	0.00E+00	1.30E-05	1.30E-05	1.29E-05
Pm-147	1.04E-03	2.91E-02	2.91E-02	2.88E-02
Eu-154	2.41E-04	2.06E-03	2.06E-03	2.04E-03
U-232	0.00E+00	7.85E-09	7.85E-09	7.77E-09
U-233	4.97E-08	3.88E-07	3.88E-07	3.84E-07
U-234	4.71E-08	8.63E-07	8.63E-07	8.54E-07
U-235	1.42E-08	1.12E-08	1.42E-08	1.40E-08
U-236	0.00E+00	6.01E-09	6.01E-09	5.94E-09
U-238	2.04E-08	6.55E-07	6.55E-07	6.48E-07
Np-237	2.31E-08	5.10E-07	5.10E-07	5.04E-07
Np-239	1.82E-05	0.00E+00	1.82E-05	1.80E-05
Pu-238	6.23E-04	4.13E-04	6.23E-04	6.17E-04
Pu-239	1.30E-05	1.55E-04	1.55E-04	1.54E-04
Pu-240	2.70E-04	3.31E-05	2.70E-04	2.67E-04
Pu-241	3.46E-04	6.01E-04	6.01E-04	5.95E-04
Pu-242	6.41E-06	5.60E-08	6.41E-06	6.34E-06
Am-241	2.39E-04	5.60E-03	5.60E-03	5.54E-03
Am-242m	7.39E-06	2.02E-06	7.39E-06	7.31E-06
Am-243	1.82E-05	0.00E+00	1.82E-05	1.80E-05
Cm-244	1.63E-04	1.40E-04	1.63E-04	1.61E-04
Cm-245	7.49E-08	3.55E-09	7.49E-08	7.41E-08
Cm-246	2.48E-07	0.00E+00	2.48E-07	2.46E-07
Cm-247	1.21E-12	0.00E+00	1.21E-12	1.20E-12

Line Tie-in Surveys

Historical radiological surveys [O'Bryant, 2005a] were collected to evaluate the typical dose rates associated with F Tank Farm transfer lines. The majority of F Tank Farm line work occurred between 2001 and 2002. The focus of this work was Tanks 7 and 18. Review of the surveys showed a range of values between "not detected" and 60 mrem/hr at 30 cm for whole body dose rates, with most of the readings falling below 15 mrem/hr. The results are summarized in the following table [O'Bryant, 2005a].

Table IV-2. Transfer Line Survey Data

Date	Survey No.	Tank Affiliation	Maximum Whole Body Dose Rate (mrem/hour @ 30 cm)
1/16/2001	359	7	8
3/22/2001	2238	34	0
1/28/2002	755	7	60
1/30/2002	789	7	15
2/4/2002	907	18 to 7	0
2/5/2002	930	7	5
2/11/2002	1061	7	8
2/12/2002	1093	7	8
2/13/2002	1115	18 to 7	1
2/14/2002	1158	18 to 7	2
2/18/2002	1211	18 to 7	2
2/19/2002	1262	7	5
2/25/2002	1393	18 to 7	0
2/25/2002	1395	7	5
2/26/2002	1424	7	5
2/26/2002	1425	18 to 7	0
2/27/2002	1455	7	5
2/27/2002	1458	7	0
2/27/2002	1467	18 to 7	2
3/5/2002	1613	7	5
3/6/2002	1651	7	10
3/6/2002	1657	18 to 7	0
3/7/2002	1680	7	8
3/7/2002	1692	18 to 7	0

The maximum dose rate of 60 mrem at 30 cm for the Tank 7 transfer line tie-in on January 28, 2002, (from Survey No. 755 of O'Bryant, 2005a) will be used as worst case.

Tank Concentrations

Worst case F Tank Farm transfer line residual has been determined to be sludge. The F Tank Farm Tank Concentrations for sludge are taken from the High Level Waste Emergency Response Data and Waste Tank Data (2005) and are summarized in the table below. In addition, the individual tank concentrations are ascertained by taking a ratio to the Tank 7 concentration as shown.

Table IV-3. Tank Ratios

Tank	Sludge/Salt Slurry Gamma Dose Concentrations (Ci Cs-137 equivalent per gallon)	Tank Ratio to Tank 7
1	1.22E+01	6.22E+00
2	4.52E+00	2.31E+00
3	4.58E+00	2.34E+00
4	8.32E+00	4.24E+00
5	7.32E+00	3.73E+00
6	7.75E+00	3.95E+00
7	1.96E+00	1.00E+00
8	1.05E+00	5.36E-01
18	1.43E+00	7.30E-01
19	1.66E-02	8.47E-03
25	2.31E+00	1.18E+00
26	6.36E+00	3.24E+00
27	4.90E+00	2.50E+00
28	2.73E+00	1.39E+00
33	3.86E+00	1.97E+00
34	5.41E+00	2.76E+00
44	3.24E+00	1.65E+00
45	3.06E+00	1.56E+00
46	4.59E+00	2.34E+00
47	9.33E-01	4.76E-01

Tank Transfer Line Dose Rates

Using the worst case dose rate for Tank 7 transfer lines and the tank ratios, dose rates are estimated for each tank's transfer lines as shown in Table IV-4.

Table IV-4. Tank Line Dose Rates

Tank	Tank Ratio to Tank 7	Tank 7 Dose Rate (mrem/hr @ 30 cm)	Dose Rate (mrem/hr @ 30 cm)
1	6.22E+00	60	3.73E+02
2	2.31E+00	60	1.38E+02
3	2.34E+00	60	1.40E+02
4	4.24E+00	60	2.55E+02
5	3.73E+00	60	2.24E+02
6	3.95E+00	60	2.37E+02
7	1.00E+00	60	6.00E+01
8	5.36E-01	60	3.21E+01
18	7.30E-01	60	4.38E+01
19	8.47E-03	60	5.08E-01
25	1.18E+00	60	7.07E+01
26	3.24E+00	60	1.95E+02

Table IV-4. Tank Line Dose Rates (Continued)

Tank	Tank Ratio to Tank 7	Tank 7 Dose Rate (mrem/hr @ 30 cm)	Dose Rate (mrem/hr @ 30 cm)
27	2.50E+00	60	1.50E+02
28	1.39E+00	60	8.36E+01
33	1.97E+00	60	1.18E+02
34	2.76E+00	60	1.66E+02
44	1.65E+00	60	9.92E+01
45	1.56E+00	60	9.37E+01
46	2.34E+00	60	1.41E+02
47	4.76E-01	60	2.86E+01

The dose rates for each tank will be used in determining, the curies of Cs-137 for each line.

Transfer Line Dose-to-Curie (DTC)

The F Tank Farm Transfer lines consist of carbon steel and stainless steel lines of various sizes. Site software SRS-DTC-3.10 by WMG, Inc (1998) was used to estimate the dose to curie conversion (DTC) factor. Each line was modeled as a hollow cylinder, using the core radius as the inner radius and the jacket radius as the outer radius. The length of the pipe was modeled as two feet because of the standard detector distance of 30 cm. For conservatism, the source between the core and jacket was assumed to be iron. The source inner (sludge) was assumed to have a specific gravity of 1.2. A summary of the resulting DTC conversion factors are given in the following table.

Table IV-5. Dose to Curie Conversion Factors

Core (in)	Jacket (in)	DTC (mrem/hr-Ci of Cs -137
1	3	9.89E+02
2	3	1.23E+03
2	4	8.50E+02
2	6	4.91E+02
2	8	3.32E+02
2	10	2.45E+02
3	4	1.11E+03
3	6	5.63E+02
3	8	3.60E+02
3	10	2.59E+02
4	6	6.88E+02

Using the DTC conversion factor for a given pipe size with the corresponding Tank Dose Rate will result in curies of Cs-137 for each line.

The following table shows the results of applying the tank dose rates to the lines listed in Appendix III. Note that 1½-inch core diameter lines are depicted in the following table as two-inch lines.

Table IV-6. Estimated Cs-137 Content in Each Line Using the Dose-to-Curie Factors (continued)

Line No.	From	To	Assumed Core Diameter	Assumed Jacket Diameter	Tank Affiliation	Assigned Dose Rate	Dose to Curie Factor	Cs-137 (Curies)
1	1F Evap	1F CTS	3	4	34	1.66E+02	1.11E+03	1.50E-01
2	Tk33(C2) VN	Tk34(C2) VN	2	3	34	1.66E+02	1.23E+03	1.35E-01
2 (old)	1F Evap	Tk18	3	6	18	4.38E+01	5.63E+02	7.78E-02
3	FDB-1(28)	Tk18	3	6	18	4.38E+01	5.63E+02	7.78E-02
4	FDB-1(29)	Tk17	3	6	19	5.08E-01	5.63E+02	9.03E-04
7	Tk17	Tk19	4	6	19	5.08E-01	6.88E+02	7.38E-04
8	Tk20	Tk18	4	6	18	4.38E+01	6.88E+02	6.36E-02
9	#9000	Tk19 (NW)	3	4	19	5.08E-01	1.11E+03	4.60E-04
11	1F Evap	1F CTS	3	4	34	1.66E+02	1.11E+03	1.50E-01
73	Tk44 (C1) TJ	Tk26 (C1)	3	10	44	9.92E+01	2.59E+02	3.83E-01
74	Tk45 (C1) TJ	Tk26 (C1)	3	10	45	9.37E+01	2.59E+02	3.62E-01
75	Tk46 (C1)	Tk26 (C1)	3	10	26	1.95E+02	2.59E+02	7.52E-01
76	Tk47(C1)TJ	Tk26 (C1)	3	10	26	1.95E+02	2.59E+02	7.52E-01
100 (221F)	221-F	#1475	3	10	1	3.73E+02	2.59E+02	1.44E+00
100 (IAL)	FDB-2(26)	HiPt flush pit	3	4	1	3.73E+02	1.11E+03	3.38E-01
101 (DB4)	FDB-4(5)	FPP-2(6) pump	3	4	1	3.73E+02	1.11E+03	3.38E-01
101 (IAL)	HiPt flush pit (4)	FDB-2(25)	3	4	1	3.73E+02	1.11E+03	3.38E-01
101(221F)	221-F	#1478	3	10	1	3.73E+02	2.59E+02	1.44E+00
102 (221F)	221-F	#1488	3	10	1	3.73E+02	2.59E+02	1.44E+00
102 (DB2)	FPP-1(5)	FDB-2(35)	3	4	1	3.73E+02	1.11E+03	3.38E-01
102 (DB4)	FDB-4(2)	FPP-3(6) pump	3	4	1	3.73E+02	1.11E+03	3.38E-01
103 (DB2)	FDB-2(36)	FPP-1 (4)	3	4	1	3.73E+02	1.11E+03	3.38E-01
103 (DB4)	FDB-4(7)	FPP-1(1)	3	4	1	3.73E+02	1.11E+03	3.38E-01
103(221F)	221-F	#1476	3	10	1	3.73E+02	2.59E+02	1.44E+00
104 (DB2)	FDB-2(27)	FDB-1(8)	3	4	1	3.73E+02	1.11E+03	3.38E-01
104 (DB4)	FDB-4(9)	FDB-3(9)	3	10	1	3.73E+02	2.59E+02	1.44E+00
105	Tk27(S) VN	FDB-4(11)	3	10	27	1.50E+02	2.59E+02	5.79E-01
106 (DB2)	FPP-1(2)	FDB-2(28)	3	4	1	3.73E+02	1.11E+03	3.38E-01
106 (DB4)	Tk28(S) valve box	FDB-4(10)	3	10	28	8.36E+01	2.59E+02	3.23E-01
107 (DB2)	FDB-2(33)	Tk18	3	4	18	4.38E+01	1.11E+03	3.96E-02
107 (DB4)	Tk26(C1) TJ	FDB-4(13)	3	10	26	1.95E+02	2.59E+02	7.52E-01
108 (DB2)	FDB-2(32)	FDB-3(15)	3	4	1	3.73E+02	1.11E+03	3.38E-01
108 (DB4)	Tk25(C1) TJ	FDB-4(16)	3	8	25	7.07E+01	3.60E+02	1.96E-01
108 (Tk18)	FDB-2(32)	Tk18	3	4	18	4.38E+01	1.11E+03	3.96E-02
109 (DB2)	FDB-2(37)	#3754 & #3755	3	8	1	3.73E+02	3.60E+02	1.04E+00
109 (DB4)	FDB-4(12)	Tk26(C1) VN	3	10	26	1.95E+02	2.59E+02	7.52E-01
110	#17015	FDB-2(31)	3	6	1	3.73E+02	5.63E+02	6.64E-01
110 (cut)	Tk7(2)	cut & capped	3	4	7	6.00E+01	1.11E+03	5.43E-02
111	FDB-2(30)	FDB-3(16)	3	8	1	3.73E+02	3.60E+02	1.04E+00
112	FDB-2(29)	FDB-3(17)	3	8	1	3.73E+02	3.60E+02	1.04E+00
114	FDB-1(30)	FPP-1(1A)	3	8	1	3.73E+02	3.60E+02	1.04E+00
115	FDB-1(31)	cut & capped	3	8	1	3.73E+02	3.60E+02	1.04E+00
116	FDB-1(32)	cut & capped	3	8	1	3.73E+02	3.60E+02	1.04E+00
117	FDB-1(33)	cut & capped	3	8	1	3.73E+02	3.60E+02	1.04E+00
118	#5016	#213	3	10	1	3.73E+02	2.59E+02	1.44E+00
118 (DB1)	FDB-1(7)	cut & capped	3	10	1	3.73E+02	2.59E+02	1.44E+00

Table IV-6. Estimated Cs-137 Content in Each Line Using the Dose-to-Curie Factors (continued)

Line No.	From	To	Assumed Core Diameter	Assumed Jacket Diameter	Tank Affiliation	Assigned Dose Rate	Dose to Curie Factor	Cs-137 (Curies)
151 (DB3)	Tk33(NW)VN	FDB-3(4)	3	8	33	1.18E+02	3.60E+02	3.28E-01
151 (DB4)	FPP-2(5) pump out	FDB-4(6)	3	4	1	3.73E+02	1.11E+03	3.38E-01
152 (DB3)	FDB-3(3)	Tk33(NW)VN	3	8	33	1.18E+02	3.60E+02	3.28E-01
152 (DB4)	FPP-2(7) TJ	FDB-4(4)	3	4	1	3.73E+02	1.11E+03	3.38E-01
156	Tk34 (C1) VN	FDB-3(2)	3	8	34	1.66E+02	3.60E+02	4.60E-01
157	FDB-3(1)	Tk34 (C1) VN	3	8	34	1.66E+02	3.60E+02	4.60E-01
161	FDB-3 sump	FDB-2 sump	2	4	1	3.73E+02	8.50E+02	4.40E-01
176 (old)	1F Evap	Tk18 (SW)	3	6	18	4.38E+01	5.63E+02	7.78E-02
176A	1F CTS	Tk7	3	4	7	6.00E+01	1.11E+03	5.43E-02
176B	Tk7	1F Evap	3	4	7	6.00E+01	1.11E+03	5.43E-02
177 (old)	1F Evap	Tk18 (SW)	3	6	18	4.38E+01	5.63E+02	7.78E-02
177A	1F CTS	Tk7	3	4	7	6.00E+01	1.11E+03	5.43E-02
177B	1F Evap	Tk18 (SW)	3	6	18	4.38E+01	5.63E+02	7.78E-02
201	FPP-3(5) pump out	FDB-4(3)	3	4	1	3.73E+02	1.11E+03	3.38E-01
202	FPP-3(7) TJ	FDB-4(1)	3	4	1	3.73E+02	1.11E+03	3.38E-01
210	Tk4(6)TJ	#3752	3	10	4	2.55E+02	2.59E+02	9.83E-01
211	Tk3(5) TJ	Tk7(6) VN	3	10	3	1.40E+02	2.59E+02	5.41E-01
212	Tk2(3)TJ	Tk7(6) VN	3	10	2	1.38E+02	2.59E+02	5.34E-01
213	#118	Tk7(6) VN	3	10	7	6.00E+01	2.59E+02	2.32E-01
213 (Tk1)	Tk1(3)TJ	cut & capped	3	10	1	3.73E+02	2.59E+02	1.44E+00
213 (DB2)	#109 (DB2)	cut & capped	3	4	1	3.73E+02	1.11E+03	3.38E-01
301	1F CTS	Tk1-4 loop line	2	6	1	3.73E+02	4.91E+02	7.61E-01
302	Tk18	1F CTS	2	4	18	4.38E+01	8.50E+02	5.15E-02
302 (old)	1F Evap	Tk18 (SE)	2	4	18	4.38E+01	8.50E+02	5.15E-02
303	1F Evap	1F CTS	2	4	18	4.38E+01	8.50E+02	5.15E-02
304	Tk18	1F CTS	3	4	18	4.38E+01	1.11E+03	3.96E-02
397	Tk25(C1) TJ	Tk26(S)	3	8	26	1.95E+02	3.60E+02	5.40E-01
497	Tk27(C1) TJ	Tk26(S)	3	10	26	1.95E+02	2.59E+02	7.52E-01
515	16030	#3754	3	6	1	3.73E+02	5.63E+02	6.64E-01
520	Tk5(6)	#3751	3	6	5	2.24E+02	5.63E+02	3.98E-01
521	Tk6(6)	#3753	3	6	6	2.37E+02	5.63E+02	4.22E-01
547	Tk28(C1) valve box	Tk26(S)	3	10	26	1.95E+02	2.59E+02	7.52E-01
960	Tk25(C2) VN	Tk26(C2)VN	2	6	26	1.95E+02	4.91E+02	3.97E-01
1012	Tk26(R2) VN	242-16F Evap.	1	3	26	1.95E+02	9.89E+02	1.97E-01
1013	Tk26(C2) VN	Tk27(C2) VN	2	6	26	1.95E+02	4.91E+02	3.97E-01
1040	Tk26(R1) VN	FDB-6(4)	3	6	26	1.95E+02	5.63E+02	3.46E-01
1054	Tk27(C2) VN	Tk28(C2) VN	2	6	27	1.50E+02	4.91E+02	3.06E-01
1104	Tk28(C2) VN	FDB-5(9)	2	10	28	8.36E+01	2.45E+02	3.41E-01
1209	3-valve box W328-15-3	Tk28 TTJ	3	6	28	8.36E+01	5.63E+02	1.48E-01
1377	242-16F evaporator (24)	Tk26(C3) VN	2	6	26	1.95E+02	4.91E+02	3.97E-01
1378	242-16F evaporator (23)	Tk25(C3) VN	2	6	25	7.07E+01	4.91E+02	1.44E-01
1379	242-16F evaporator (10)	Tk27(C3) VN	2	6	27	1.50E+02	4.91E+02	3.06E-01
1380	242-16F evaporator (11)	Tk28(C3) VN	2	6	28	8.36E+01	4.91E+02	1.70E-01
1383	242-16F evaporator (22)	Tk44(C3) VN	2	6	44	9.92E+01	4.91E+02	2.02E-01
1384	242-16F evaporator (21)	Tk45(C3) VN	2	6	45	9.37E+01	4.91E+02	1.91E-01
1385	242-16F evaporator (13)	Tk46(C3) VN	2	6	46	1.41E+02	4.91E+02	2.86E-01

Table IV-6. Estimated Cs-137 Content in Each Line Using the Dose-to-Curie Factors (continued)

Line No.	From	To	Assumed Core Diameter	Assumed Jacket Diameter	Tank Affiliation	Assigned Dose Rate	Dose to Curie Factor	Cs-137 (Curies)
1386	242-16F evaporator (12)	Tk47(C3) VN	2	6	47	2.86E+01	4.91E+02	5.82E-02
1408	242-16F Evap.	Tk27(M) CRC	2	6	27	1.50E+02	4.91E+02	3.06E-01
1414	Tk27(M) CRC	242-16F Evap.	2	6	27	1.50E+02	4.91E+02	3.06E-01
1461	Tk44(C1) TJ	FDB-4(20)	3	10	44	9.92E+01	2.59E+02	3.83E-01
1462	Tk45(C1) TJ	FDB-4(19)	3	10	45	9.37E+01	2.59E+02	3.62E-01
1467	Tk46(C1) VN	FDB-4(18)	3	10	46	1.41E+02	2.59E+02	5.43E-01
1468	Tk47 (C1)	FDB-4(17)	3	10	47	2.86E+01	2.59E+02	1.10E-01
1472	FDB-3(10)	FDB-4(8)	3	10	1	3.73E+02	2.59E+02	1.44E+00
1475	#100 (221F)	FPP-3(1)	3	6	1	3.73E+02	5.63E+02	6.64E-01
1476	#103 (221F)	FPP-3(2)	3	10	1	3.73E+02	2.59E+02	1.44E+00
1478	#101 (221F)	FPP-2(1)	3	10	1	3.73E+02	2.59E+02	1.44E+00
1488	#102 (221F)	FPP-2(2)	3	6	1	3.73E+02	5.63E+02	6.64E-01
3260	FDB-6 sump	FPP-3(3A)	3	6	1	3.73E+02	5.63E+02	6.64E-01
3261	Tk33(C2) VN	FDB-5 (3)	2	6	33	1.18E+02	4.91E+02	2.41E-01
3265	FDB-5(1)	F-CTS 242-3F	2	8	1	3.73E+02	3.32E+02	1.13E+00
3265-B	1F CTS	Tk33-34	2	8	34	1.66E+02	3.32E+02	4.99E-01
3266	242-F Evap.	FDB-6(5)	3	6	1	3.73E+02	5.63E+02	6.64E-01
3267	Tk7 (1) VN	FDB-6(1)	3	6	7	6.00E+01	5.63E+02	1.07E-01
3273	Tk25(C2) VN	FDB-5(10)	2	6	25	7.07E+01	4.91E+02	1.44E-01
3274	FDB-5 Waste drain	FPP-2(3)	3	6	1	3.73E+02	5.63E+02	6.64E-01
3275	F-CTS 242-3F	FDB-5(2)	2	8	1	3.73E+02	3.32E+02	1.13E+00
3275-B	1F CTS	Tk33-34	2	8	34	1.66E+02	3.32E+02	4.99E-01
3276	Tk34 (C2) VN	FDB-5(4)	2	6	34	1.66E+02	4.91E+02	3.37E-01
3277	FDB-6(6)	242-F Evap.	3	6	1	3.73E+02	5.63E+02	6.64E-01
3278	FDB-6(2)	Tk7(1) VN	3	6	7	6.00E+01	5.63E+02	1.07E-01
3751	#520	#3754	3	6	1	3.73E+02	5.63E+02	6.64E-01
3752	#210	#3754	3	6	1	3.73E+02	5.63E+02	6.64E-01
3753	#521	#3754	3	6	1	3.73E+02	5.63E+02	6.64E-01
3754	#515	#109 & #3755	3	6	1	3.73E+02	5.63E+02	6.64E-01
3755	#109 & #3754	#103	3	6	1	3.73E+02	5.63E+02	6.64E-01
4878	Tk17 (R) TTP	Tk18(W)	3	4	18	4.38E+01	1.11E+03	3.96E-02
5016	Tk18 (NE) TTP	#118	3	4	18	4.38E+01	1.11E+03	3.96E-02
9000	#9001	#9	2	3	1	3.73E+02	1.23E+03	3.04E-01
9001	Tank 18 (W)	#9000	3	4	18	4.38E+01	1.11E+03	3.96E-02
9852	Tk20(NW) Valve box	Tk18	4	6	18	4.38E+01	6.88E+02	6.36E-02
16030	Tank 8 (6)	#515	3	4	8	3.21E+01	1.11E+03	2.91E-02
16075	Tank 8 (6)	LDB-17	3	4	8	3.21E+01	1.11E+03	2.91E-02
16076	LDB-17	#515	3	4	1	3.73E+02	1.11E+03	3.38E-01
17015	Tk7(4) TTP	#110	3	6	7	6.00E+01	5.63E+02	1.07E-01
GDL	1F Evap	Tk17-20	3	10	18	4.38E+01	2.59E+02	1.69E-01
Misc-1	Tk19	Tk18	3	4	18	4.38E+01	1.11E+03	3.96E-02
Misc-2	Tk17	Tk18	3	4	18	4.38E+01	1.11E+03	3.96E-02

A summary for each isotope is listed in the following table

Table IV-7. Isotopic Inventory F-Tank via Waste Characterization from Surveys

Isotope	Curies	Isotope	Curies	Isotope	Curies
H-3	3.24E+00	Cs-134	2.42E-02	Np-237	1.04E-03
C-14	1.93E-03	Cs-135	2.14E-04	Np-239	3.71E-02
Co-60	2.06E+01	Cs-137	6.71E+01	Pu-238	1.27E+00
Ni-59	2.66E-02	Ba-137m	6.35E+01	Pu-239	3.17E-01
Ni-63	6.80E-05	Ce-144	2.65E-02	Pu-240	5.51E-01
Se-79	1.85E-02	Pr-144	2.65E-02	Pu-241	1.23E+00
Sr-90	9.14E+02	Pm-147	5.94E+01	Pu-242	1.31E-02
Y-90	9.14E+02	Eu-154	4.21E+00	Am-241	1.14E+01
Tc-99	3.20E-01	U-232	1.60E-05	Am-242m	1.51E-02
Ru-106	8.45E-02	U-233	7.93E-04	Am-243	3.71E-02
Rh-106	8.45E-02	U-234	1.76E-03	Cm-244	3.33E-01
Sb-125	3.32E+00	U-235	2.90E-05	Cm-245	1.53E-04
Sn-126	3.43E-02	U-236	1.23E-05	Cm-246	5.08E-04
I-129	2.03E-04	U-238	1.34E-03	Cm-247	2.48E-09