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Waste Acceptance Radionuclides to be Reported in Tank 51 Sludge Only Glass (U)

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Technical Reviewer

Derivative Classifier

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Introduction

High level radioactive waste from the Savannah River Site will be immobilized in glass in the DWPF. The glass product will eventually be placed into a Federal repository. DOE's Waste Acceptance Product Specifications (WAPS) ensure that the glass product will be accepted at the repository. The WAPS require that the significant long-lived radioisotopes must be quantified for all waste packages. "Significant" in this case has been established as referring to those radioisotopes that constitute at least 0.05% of the total radioactivity (on the basis of Becquerels or Curies) during the first one thousand years of waste storage.[1] The DWPF Waste Form Compliance Plan has extended this specification to include all isotopes exceeding 0.01% under these conditions, in order to be sure of incorporating all isotopes that might in some cases exceed the WAPS limits.[2]

The first high level waste glass to be generated at SRS will incorporate sludge from Tank 51. This sludge has been characterized by Bibler et al.,[3] who measured and estimated the radioisotope composition of the glass that might be derived from this sludge. In this report this characterization is used to determine which isotopes must be quantified to meet the legal criteria for repository placement.

Calculation of Isotopes from Waste Sludge

A list was developed of those isotopes that might meet the criteria for reporting. The list was derived from Ref. 4, which lists fission products, heavy elements, and activation products that may be encountered in waste. The isotopes from this list and their half lives are shown in Table 1.

From this list a number of isotopes were deleted, as follows:

- Rb-87, In-115, Ce-142, Nd-144, Sm-147, Sm-148, and Sm-149 were deleted because their long half-lives make their activities negligible at all times. Additionally, Rb should be present in the sludge in only minor amounts because of its solubility.

- Nb-94 and Eu-152 are shielded isotopes: fission product decay chains stop in a stable isotope before reaching these. They are therefore produced only by secondary processes, and are present only in very small amounts. They have not been observed in the sludge.

- I-129 will remain mainly in the supernate. Its volatility makes it unlikely that it will be put into glass, wherever it may be. It is neglected.

- 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.)

- A preliminary calculation indicated that the accumulations of the actinide daughter products Ra-226, Pb-210, and Bi-210 never reach concentrations of concern. This concurs with the conclusions of Ref. 4.

- No data were available for Np-236, or Am-242m, but these are known to be made only in very small amounts in reactor irradiations. Np-236 is a minor product of fast neutron spallation; Am-242m can be produced from neutron capture in Am-241, but has a high cross-section for neutrons and is rapidly removed. Both were neglected.

- Cf-250 was initially produced in amounts of about 10^{-3} to 10^{-4} of Cm production. It was therefore neglected, as it has decayed and will continue to decay more rapidly than Cm-244.

The other isotopes potentially present in the sludge were then calculated on the following bases:

1. Glass composition data from Reference 3 were used as a basis for those isotopes covered in this report or derivable from it (using decay information).

2. Curium isotopes 245-248 were taken from a fax from John E. Bigelow, ORNL,[5] as representing relative isotopic ratios in March of 1979. These isotopic concentrations were measured by ORNL, and are representative of the Cm produced by reactors at SRS. These ratios were then decay corrected and ratioed to the measured value of Cm-244 in Ref. 2 to get the other isotopic concentrations as of September, 1995.

3. The decay chain Pu-238 - U-234 - Th-230 was calculated using the initial values for Pu-238 and U-234 given in WSRC-TR-94-0505.

4. Ingrowth of Th-229 was calculated on the basis of U-233 decay. It was assumed that no Th-229 was initially present. The U-233 present was last separated from its daughters several decades ago, so a small amount of Th-229 is presumably in the sludge. This should not significantly affect the calculations, as this isotope does not become significant until several hundred years have passed.

Additional factors affecting the calculations were as follows:

1. Nb-93m is a daughter of Zr-93, formed in ca. 95% of decays, and is present in secular equilibrium with it after a relatively short time. It is not shown in the attached tables, but has been incorporated into the calculations.

2. Formation of Pu-240 by decay of Cm-244 was neglected, because the relative amount of the parent is small. Similarly, Am-243 does not contribute significantly to the Pu-239 concentration, nor Am-241 to Np-237.

3. Calculation of daughter isotopes was made using explicit equations for their ingrowth, as published in standard texts.[6]

Calculational Results:

Tables 2 through 9 present the results of calculations of radioactivity over the period 0 to 1100 years for each of the isotopes of concern, both in terms of absolute amounts (Bq/kg glass) and of relative activity. Calculational details are given in Appendix B.

Figures 1(a-d) are based on Tables 2-9, and show the amounts of activity in a canister of waste glass as a function of time. A canister is assumed to contain 3700 pounds of glass.

Figures 2(a-d), also based on the tabulated data, show the relative amounts of activity as a function of time to a period of 1100 years after the measurements made in WSRC-TR-94-0505.

The following isotopes were found to exceed the WAPS limit of 0.05% of the total during this period:

Nickel 59 and 63
Selenium 79
Strontium 90
Zirconium 93 and its daughter Niobium 93m
Technetium 99
Tin 126
Cesium 137
Samarium 151
Uranium 233, 234, and 238
Neptunium 237
Plutonium 238, 239, 240, and 241
Americium 241 and 243
Curium 244 and 246

Additionally, the following isotopes exceeded the secondary limit of 0.01% of total activity, and will also need to be reported for glass containing Tank 51 sludge:

Thorium 229
Uranium 236
Plutonium 242
Curium 245

Heat Per Glass Canister

The calculations were continued to determine the maximum heat output per canister. This calculation is shown in Table 2. At zero time the decay heat per canister is calculated as 5.58 Watts. Of this, 3.60 W is from Sr-90, 1.05 W from Cs-137, and the remainder from other isotopes. This value is very far below the design basis value of 460 W/canister.

References:

1. USDOE OFfice of Environmental Management, *Waste Acceptance Product Specifications for Vitrified High-Level Waste Forms,* DOE-EM-0093, Rev. 1, May, 1995, Item 1.2.1.
2. *DWPF Waste Form Compliance Plan,,* WSRC-IM-91-116-0, Rev. 4, Part 3, "Waste Form Specifications",Item 400, Sect. 1.2.2 "Radionuclide Inventory During Production", December, 1994.
3. N. E. Bibler, W. F. Kinard, R. A. Dewberry, and C. J. Coleman, *A Method for the Determination of Waste Acceptance Radionuclides in DWPF Glass and Demonstration of that Method Using SRS Tank 51 Radioactive Sludge and Glass,* WSRC-TR-94-0505, October 20, 1994.
4. Basic Data Report, Defense Waste Processing Facility Sludge Plant, Savannah River Site 200-S Area (U), WSRC-RP-92-1186.
5. Memorandum, J. E. Bigelow, Oak Ridge National Laboratory, to N. E. Bibler, SRTC, "Isotopic Analyses of Curium Oxide Lot CMP-576", November 19, 1992. (Included as Appendix A)
6. G. Friedlander, J. W. Kennedy, and J. M. Miller, *Nuclear and Radiochemistry, Second Edition,* John Wiley & Sons, New York, 1964.

Appendices:

A. Reference 5
B. Methods of Calculation

Table 1: Isotopes With $t_{1/2}$ > 10 Years That Might Be in Waste

Isotope	Half-Life, yr	Type	Isotope	Half-Life, yr	Type
Ni-59	76,000	a	Th-229	7300	d
Ni-63	100	a	Th-230	75,000	d
Se-79	65,000	f	Th-232	14,000,000,000	n
Rb-87	4.9×10^{10}	f/n	Pa-231	33,000	d
Sr-90	29	f	U-232	70	a
Zr-93	1,500,000	f	U-233	160,000	a
Nb-93m	13.6	f	U-234	250,000	d
Nb-94	20,000	a	U-235	700,000,000	n
Tc-99	210,000	f	U-236	23,000,000	a
Pd-107	6,500,000	f	U-238	4,500,000,000	n
In-115	4.4×10^{14}	f/n	Np-236	120,000	a
Sn-121m	55	f	Np-237	2,100,000	a
Sn-126	100,000	f	Pu-238	87	a
I-129	16,000,000	f	Pu-239	24,000	a
Cs-135	3,000,000	f	Pu-240	6600	a
Cs-137	30.2	f	Pu-241	14.3	a
Ce-142	5.00×10^{16}	f/n	Pu-242	380,000	a
Nd-144	2.00×10^{15}	f/n	Am-241	432	a
Sm-147	1.00×10^{11}	f/n	Am-242m	141	a
Sm-148	7.00×10^{15}	n	Am-243	7400	a
Sm-149	1.00×10^{16}	f/n	Cm-243	28.5	a
Sm-151	90	f	Cm-244	18.1	a
Eu-152	13.4	a	Cm-245	8500	a
Pb-210	22.3	d	Cm-246	4800	a
Bi-210	3,000,000	d	Cm-247	1,600,000	a
Ra-226	1600	d	Cm-248	340,000	a
Ac-227	21.7	d	Cf-250	13.2	a

Type:
a = Activation Product
f = Fission Product
n = Naturally Occurring Isotope
d = Daughter of a Natural Isotope

Table 2

		Radionuclides in Waste Glass, Half Life > 10y (Initial Composition)					
Decayed	Decayed			Time,yr	0		
Activity, Bq/kg	Activity, %	Nuclide	Ci/Can	Beta E/Bq	Gam. E/Bq	Alpha E/Bq	Total E, W
7.17E+05	0.005	Ni-59	3.25E-02				0.000
1.24E+08	0.861	Ni-63	5.62E+00	0.017			0.001
1.75E+05	0.001	Se-79	7.94E-03				0.000
1.19E+10	82.475	Sr/Y-90	5.38E+02	1.131			3.602
7.30E+05	0.005	Zr-93	3.31E-02				0.000
0.00E+00	0.000	Nb-93m	0.00E+00				0.000
2.42E+06	0.017	Tc-99	1.10E-01				0.000
3.99E+03	0.000	Pd-107	1.81E-04				0.000
6.82E+04	0.000	Sn/Sb-126	3.09E-03				0.000
2.58E+03	0.000	Cs-135	1.17E-04				0.000
7.03E+08	4.891	Cs/Ba-137	3.19E+01	0.198	6.19E-01		0.154
3.30E+08	2.292	Sm-151	1.50E+01	0.019	3.67E-04		0.002
0.00E+00	0.000	Ac-227	0.00E+00				0.000
0.00E+00	0.000	Th-229	0.00E+00				0.000
3.98E+02	0.000	Th-230	1.80E-05				0.000
6.92E+02	0.000	Th-232	3.14E-05				0.000
0.00E+00	0.000	Pa-231	0.00E+00				0.000
4.29E+05	0.003	U-233	1.94E-02				0.000
3.69E+05	0.003	U-234	1.67E-02				0.000
6.08E+02	0.000	U-235	2.76E-05				0.000
1.46E+04	0.000	U-236	6.63E-04				0.000
1.21E+05	0.001	U-238	5.47E-03				0.000
1.10E+05	0.001	Np-237	4.97E-03				0.000
6.97E+08	4.847	Pu-238	3.16E+01			5.592	1.047
5.05E+07	0.351	Pu-239	2.29E+00			5.243	0.071
2.52E+07	0.176	Pu-240	1.14E+00			5.255	0.036
1.60E+08	1.113	Pu-241	7.26E+00	0.005			0.000
5.09E+04	0.000	Pu-242	2.31E-03				0.000
9.39E+07	0.653	Am-241	4.26E+00			5.64	0.142
1.63E+06	0.011	Am-243	7.37E-02				0.000
4.83E+04	0.000	Cm-243	2.19E-03				0.000
3.29E+08	2.291	Cm-244	1.49E+01			5.902	0.522
1.56E+04	0.000	Cm-245	7.06E-04				0.000
1.49E+05	0.001	Cm-246	6.75E-03				0.000
8.58E-01	0.000	Cm-247	3.89E-08				0.000
2.15E+01	0.000	Cm-248	9.75E-07				0.000
1.44E+10			6.52E+02				5.576

Table 3

		Radionuclides in Waste Glass, Half Life > 10y (After 10 Years)				
Decayed	Decayed			Time,yr	10	
Activity, Bq/kg	Activity, %	Nuclide	Ci/Can			
7.17E+05	0.006	Ni-59	3.25E-02			
1.16E+08	1.011	Ni-63	5.24E+00			
1.75E+05	0.002	Se-79	7.94E-03			
9.30E+09	81.393	Sr/Y-90	4.22E+02			
7.30E+05	0.006	Zr-93	3.31E-02			
2.77E+05	0.002	Nb-93m	1.26E-02			
2.42E+06	0.021	Tc-99	1.10E-01			
3.99E+03	0.000	Pd-107	1.81E-04			
6.82E+04	0.001	Sn/Sb-126	3.09E-03			
2.58E+03	0.000	Cs-135	1.17E-04			
5.59E+08	4.893	Cs/Ba-137	2.54E+01			
3.06E+08	2.678	Sm-151	1.39E+01			
1.28E-01	0.000	Ac-227	5.83E-09			
4.05E+02	0.000	Th-229	1.84E-05			
4.09E+02	0.000	Th-230	1.86E-05			
6.92E+02	0.000	Th-232	3.14E-05			
1.28E-01	0.000	Pa-231	5.83E-09			
4.28E+05	0.004	U-233	1.94E-02			
3.88E+05	0.003	U-234	1.76E-02			
6.08E+02	0.000	U-235	2.76E-05			
1.46E+04	0.000	U-236	6.63E-04			
1.21E+05	0.001	U-238	5.47E-03			
1.10E+05	0.001	Np-237	4.99E-03			
6.44E+08	5.637	Pu-238	2.92E+01			
5.05E+07	0.442	Pu-239	2.29E+00			
2.55E+07	0.223	Pu-240	1.16E+00			
9.89E+07	0.866	Pu-241	4.49E+00			
5.09E+04	0.000	Pu-242	2.31E-03			
9.44E+07	0.826	Am-241	4.28E+00			
1.62E+06	0.014	Am-243	7.36E-02			
3.61E+04	0.000	Cm-243	1.64E-03			
2.25E+08	1.966	Cm-244	1.02E+01			
1.34E+04	0.000	Cm-245	6.07E-04			
1.39E+05	0.001	Cm-246	6.28E-03			
7.31E-01	0.000	Cm-247	3.32E-08			
1.82E+01	0.000	Cm-248	8.25E-07			
1.14E+10			5.18E+02			

Table 4

		Radionuclides in Waste Glass, Half Life > 10y (After 40 Years)				
Decayed	Decayed			Time,yr	40	
Activity, Bq/kg	Activity, %	Nuclide	Ci/Can			
7.17E+05	0.012	Ni-59	3.25E-02			
9.39E+07	1.596	Ni-63	4.26E+00			
1.75E+05	0.003	Se-79	7.94E-03			
4.48E+09	76.227	Sr/Y-90	2.03E+02			
7.30E+05	0.012	Zr-93	3.31E-02			
6.03E+05	0.010	Nb-93m	2.74E-02			
2.42E+06	0.041	Tc-99	1.10E-01			
3.99E+03	0.000	Pd-107	1.81E-04			
6.82E+04	0.001	Sn/Sb-126	3.09E-03			
2.58E+03	0.000	Cs-135	1.17E-04			
2.81E+08	4.775	Cs/Ba-137	1.27E+01			
2.45E+08	4.159	Sm-151	1.11E+01			
5.14E-01	0.000	Ac-227	2.33E-08			
1.62E+03	0.000	Th-229	7.33E-05			
4.54E+02	0.000	Th-230	2.06E-05			
6.92E+02	0.000	Th-232	3.14E-05			
5.14E-01	0.000	Pa-231	2.33E-08			
4.28E+05	0.007	U-233	1.94E-02			
4.37E+05	0.007	U-234	1.98E-02			
6.08E+02	0.000	U-235	2.76E-05			
1.46E+04	0.000	U-236	6.63E-04			
1.21E+05	0.002	U-238	5.47E-03			
1.10E+05	0.002	Np-237	5.01E-03			
5.08E+08	8.636	Pu-238	2.30E+01			
5.05E+07	0.858	Pu-239	2.29E+00			
2.59E+07	0.439	Pu-240	1.17E+00			
2.34E+07	0.397	Pu-241	1.06E+00			
5.09E+04	0.001	Pu-242	2.31E-03			
9.24E+07	1.571	Am-241	4.19E+00			
1.62E+06	0.028	Am-243	7.34E-02			
1.83E+04	0.000	Cm-243	8.29E-04			
7.12E+07	1.211	Cm-244	3.23E+00			
1.55E+04	0.000	Cm-245	7.04E-04			
1.48E+05	0.003	Cm-246	6.71E-03			
8.58E-01	0.000	Cm-247	3.89E-08			
2.15E+01	0.000	Cm-248	9.75E-07			
5.88E+09			2.67E+02			

Table 5

		Radionuclides in Waste Glass, Half Life > 10y (After 100 Years)				
Decayed	Decayed			Time,yr	100	
Activity, Bq/kg	Activity, %	Nuclide	Ci/Can			
7.17E+05	0.039	Ni-59	3.25E-02			
6.20E+07	3.394	Ni-63	2.81E+00			
1.75E+05	0.010	Se-79	7.94E-03			
1.04E+09	57.121	Sr/Y-90	4.73E+01			
7.30E+05	0.040	Zr-93	3.31E-02			
6.89E+05	0.038	Nb-93m	3.13E-02			
2.42E+06	0.132	Tc-99	1.10E-01			
3.99E+03	0.000	Pd-107	1.81E-04			
6.82E+04	0.004	Sn/Sb-126	3.09E-03			
2.58E+03	0.000	Cs-135	1.17E-04			
7.09E+07	3.884	Cs/Ba-137	3.22E+00			
1.56E+08	8.574	Sm-151	7.10E+00			
1.28E+00	0.000	Ac-227	5.82E-08			
4.03E+03	0.000	Th-229	1.83E-04			
5.78E+02	0.000	Th-230	2.62E-05			
6.92E+02	0.000	Th-232	3.14E-05			
1.28E+00	0.000	Pa-231	5.82E-08			
4.28E+05	0.023	U-233	1.94E-02			
5.05E+05	0.028	U-234	2.29E-02			
6.08E+02	0.000	U-235	2.76E-05			
1.46E+04	0.001	U-236	6.63E-04			
1.21E+05	0.007	U-238	5.47E-03			
1.11E+05	0.006	Np-237	5.02E-03			
3.16E+08	17.321	Pu-238	1.43E+01			
5.04E+07	2.760	Pu-239	2.28E+00			
2.59E+07	1.417	Pu-240	1.17E+00			
1.30E+06	0.071	Pu-241	5.90E-02			
5.09E+04	0.003	Pu-242	2.31E-03			
8.46E+07	4.637	Am-241	3.84E+00			
1.61E+06	0.088	Am-243	7.30E-02			
4.25E+03	0.000	Cm-243	1.93E-04			
7.16E+06	0.392	Cm-244	3.25E-01			
1.54E+04	0.001	Cm-245	7.00E-04			
1.47E+05	0.008	Cm-246	6.66E-03			
8.58E-01	0.000	Cm-247	3.89E-08			
2.16E+01	0.000	Cm-248	9.79E-07			
1.83E+09			8.28E+01			

Table 6

		Radionuclides in Waste Glass, Half Life > 10y (After 200 Years)				
Decayed	Decayed			Time,yr	200	
Activity, Bq/kg	Activity, %	Nuclide	Ci/Can			
7.16E+05	0.142	Ni-59	3.25E-02			
3.10E+07	6.153	Ni-63	1.41E+00			
1.75E+05	0.035	Se-79	7.93E-03			
9.16E+07	18.203	Sr/Y-90	4.16E+00			
7.30E+05	0.145	Zr-93	3.31E-02			
6.94E+05	0.138	Nb-93m	3.15E-02			
2.42E+06	0.480	Tc-99	1.10E-01			
3.99E+03	0.001	Pd-107	1.81E-04			
6.81E+04	0.014	Sn/Sb-126	3.09E-03			
2.58E+03	0.001	Cs-135	1.17E-04			
7.15E+06	1.419	Cs/Ba-137	3.24E-01			
7.43E+07	14.754	Sm-151	3.37E+00			
2.56E+00	0.000	Ac-227	1.16E-07			
8.02E+03	0.002	Th-229	3.64E-04			
8.45E+02	0.000	Th-230	3.83E-05			
6.92E+02	0.000	Th-232	3.14E-05			
2.56E+00	0.000	Pa-231	1.16E-07			
4.28E+05	0.085	U-233	1.94E-02			
5.67E+05	0.113	U-234	2.57E-02			
6.08E+02	0.000	U-235	2.76E-05			
1.46E+04	0.003	U-236	6.63E-04			
1.21E+05	0.024	U-238	5.47E-03			
1.11E+05	0.022	Np-237	5.02E-03			
1.43E+08	28.479	Pu-238	6.50E+00			
5.02E+07	9.978	Pu-239	2.28E+00			
2.56E+07	5.087	Pu-240	1.16E+00			
1.06E+04	0.002	Pu-241	4.80E-04			
5.09E+04	0.010	Pu-242	2.31E-03			
7.22E+07	14.332	Am-241	3.27E+00			
1.59E+06	0.317	Am-243	7.23E-02			
3.73E+02	0.000	Cm-243	1.69E-05			
1.56E+05	0.031	Cm-244	7.06E-03			
1.53E+04	0.003	Cm-245	6.94E-04			
1.45E+05	0.029	Cm-246	6.56E-03			
8.58E-01	0.000	Cm-247	3.89E-08			
2.15E+01	0.000	Cm-248	9.74E-07			
5.03E+08			2.28E+01			

Table 7

		Radionuclides in Waste Glass, Half Life > 10y (After 500 Years)				
Decayed	Decayed			Time,yr	500	
Activity, Bq/kg	Activity, %	Nuclide	Ci/Can			
7.14E+05	0.469	Ni-59	3.24E-02			
3.87E+06	2.543	Ni-63	1.76E-01			
1.74E+05	0.114	Se-79	7.90E-03			
6.22E+04	0.041	Sr/Y-90	2.82E-03			
7.30E+05	0.479	Zr-93	3.31E-02			
6.94E+05	0.455	Nb-93m	3.15E-02			
2.41E+06	1.584	Tc-99	1.09E-01			
3.99E+03	0.003	Pd-107	1.81E-04			
6.80E+04	0.045	Sn/Sb-126	3.08E-03			
2.58E+03	0.002	Cs-135	1.17E-04			
7.32E+03	0.005	Cs/Ba-137	3.32E-04			
7.94E+06	5.214	Sm-151	3.60E-01			
6.39E+00	0.000	Ac-227	2.90E-07			
1.97E+04	0.013	Th-229	8.96E-04			
1.80E+03	0.001	Th-230	8.18E-05			
6.92E+02	0.000	Th-232	3.14E-05			
6.39E+00	0.000	Pa-231	2.90E-07			
4.28E+05	0.281	U-233.	1.94E-02			
6.13E+05	0.402	U-234	2.78E-02			
6.08E+02	0.000	U-235	2.76E-05			
1.46E+04	0.010	U-236	6.63E-04			
1.21E+05	0.079	U-238	5.47E-03			
1.11E+05	0.073	Np-237	5.02E-03			
1.34E+07	8.778	Pu-238	6.07E-01			
4.98E+07	32.689	Pu-239	2.26E+00			
2.48E+07	16.283	Pu-240	1.13E+00			
5.68E-03	0.000	Pu-241	2.58E-10			
5.08E+04	0.033	Pu-242	2.31E-03			
4.46E+07	29.287	Am-241	2.02E+00			
1.55E+06	1.018	Am-243	7.03E-02			
2.54E-01	0.000	Cm-243	1.15E-08			
1.60E+00	0.000	Cm-244	7.25E-08			
1.49E+04	0.010	Cm-245	6.78E-04			
1.38E+05	0.091	Cm-246	6.28E-03			
8.58E-01	0.000	Cm-247	3.89E-08			
2.15E+01	0.000	Cm-248	9.74E-07			
1.52E+08			6.91E+00			

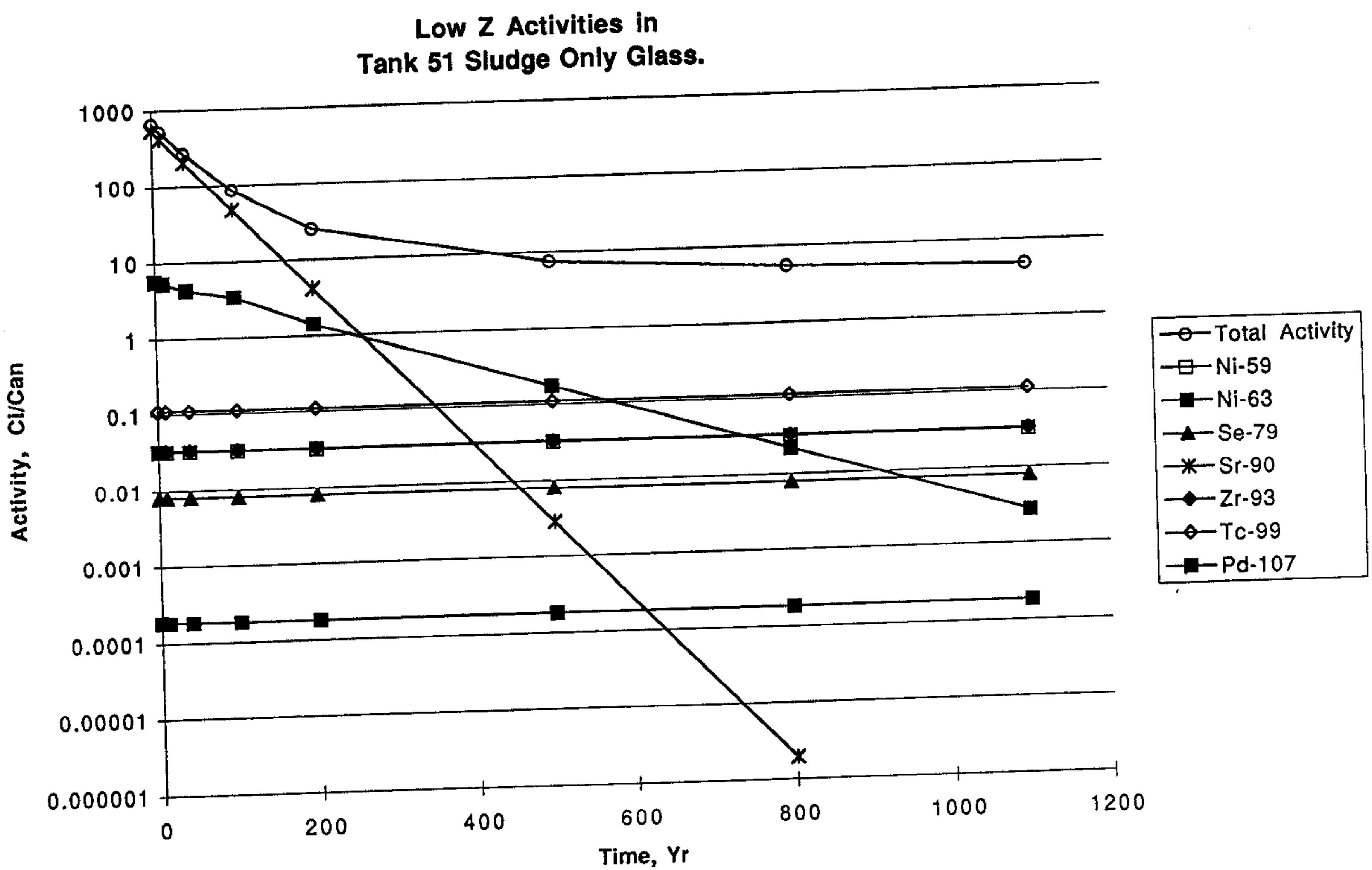
Table 8

		Radionuclides in Waste Glass, Half Life > 10y (After 800 Years)				
Decayed	Decayed			Time,yr	800	
Activity, Bq/kg	Activity, %	Nuclide	Ci/Can			
7.12E+05	0.639	Ni-59	3.23E-02			
4.85E+05	0.435	Ni-63	2.20E-02			
1.74E+05	0.156	Se-79	7.88E-03			
4.23E+01	0.000	Sr/Y-90	1.92E-06			
7.30E+05	0.655	Zr-93	3.31E-02			
6.93E+05	0.622	Nb-93m	3.14E-02			
2.41E+06	2.165	Tc-99	1.09E-01			
3.99E+03	0.004	Pd-107	1.81E-04			
6.79E+04	0.061	Sn/Sb-126	3.08E-03			
2.58E+03	0.002	Cs-135	1.17E-04			
7.49E+00	0.000	Cs/Ba-137	3.40E-07			
8.50E+05	0.762	Sm-151	3.85E-02			
1.02E+01	0.000	Ac-227	4.62E-07			
3.11E+04	0.028	Th-229	1.41E-03			
2.81E+03	0.003	Th-230	1.27E-04			
6.92E+02	0.001	Th-232	3.14E-05			
1.02E+01	0.000	Pa-231	4.62E-07			
4.27E+05	0.383	U-233	1.94E-02			
6.17E+05	0.554	U-234	2.80E-02			
6.08E+02	0.001	U-235	2.76E-05			
1.46E+04	0.013	U-236	6.63E-04			
1.21E+05	0.108	U-238	5.47E-03			
1.11E+05	0.099	Np-237	5.02E-03			
1.25E+06	1.120	Pu-238	5.66E-02			
4.94E+07	44.319	Pu-239	2.24E+00			
2.40E+07	21.572	Pu-240	1.09E+00			
3.05E-09	0.000	Pu-241	1.38E-16			
5.08E+04	0.046	Pu-242	2.30E-03			
2.76E+07	24.768	Am-241	1.25E+00			
1.51E+06	1.353	Am-243	6.84E-02			
1.72E-04	0.000	Cm-243	7.81E-12			
1.64E-05	0.000	Cm-244	7.45E-13			
1.46E+04	0.013	Cm-245	6.61E-04			
1.32E+05	0.119	Cm-246	6.01E-03			
8.58E-01	0.000	Cm-247	3.89E-08			
2.15E+01	0.000	Cm-248	9.73E-07			
1.11E+08			5.05E+00			

Table 9

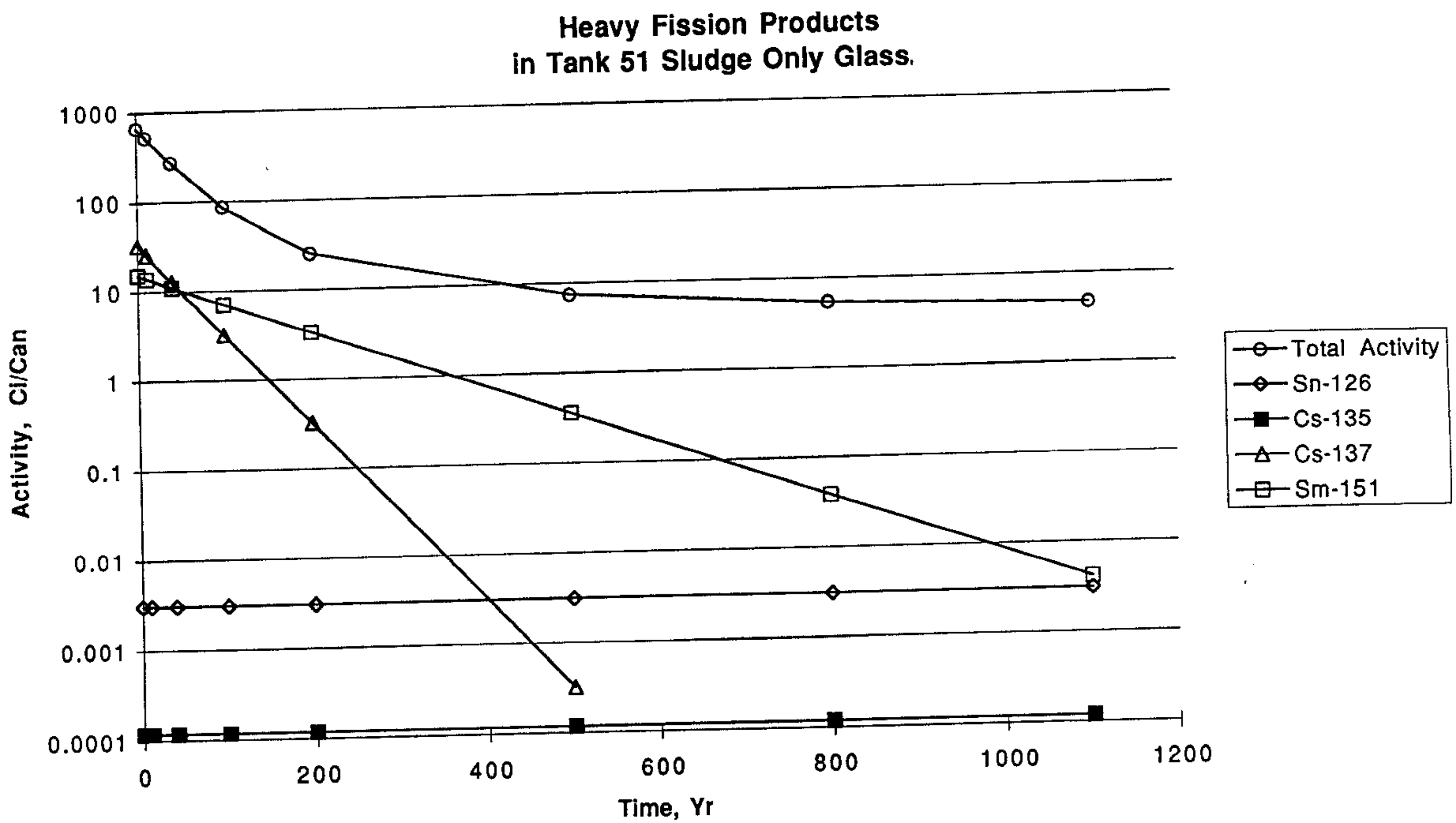
		Radionuclides in Waste Glass, Half Life > 10y (After 1100 Years)				
Decayed	Decayed			Time,yr	1100	
Activity, Bq/kg	Activity, %	Nuclide	Ci/Can			
7.10E+05	0.730	Ni-59	3.22E-02			
6.06E+04	0.062	Ni-63	2.75E-03			
1.73E+05	0.178	Se-79	7.85E-03			
2.87E-02	0.000	Sr/Y-90	1.30E-09			
7.30E+05	0.750	Zr-93	3.31E-02			
6.93E+05	0.712	Nb-93m	3.14E-02			
2.41E+06	2.475	Tc-99	1.09E-01			
3.99E+03	0.004	Pd-107	1.81E-04			
6.77E+04	0.070	Sn/Sb-126	3.07E-03			
2.58E+03	0.003	Cs-135	1.17E-04			
7.67E-03	0.000	Cs/Ba-137	3.48E-10			
9.08E+04	0.093	Sm-151	4.12E-03			
1.40E+01	0.000	Ac-227	6.34E-07			
4.22E+04	0.043	Th-229	1.91E-03			
3.82E+03	0.004	Th-230	1.73E-04			
6.92E+02	0.001	Th-232	3.14E-05			
1.40E+01	0.000	Pa-231	6.34E-07			
4.26E+05	0.438	U-233	1.93E-02			
6.17E+05	0.634	U-234	2.80E-02			
6.08E+02	0.001	U-235	2.76E-05			
1.46E+04	0.015	U-236	6.63E-04			
1.21E+05	0.124	U-238	5.47E-03			
1.11E+05	0.114	Np-237	5.02E-03			
1.16E+05	0.120	Pu-238	5.28E-03			
4.90E+07	50.285	Pu-239	2.22E+00			
2.33E+07	23.916	Pu-240	1.06E+00			
1.64E-15	0.000	Pu-241	7.42E-23			
5.08E+04	0.052	Pu-242	2.30E-03			
1.71E+07	17.529	Am-241	7.74E-01			
1.47E+06	1.505	Am-243	6.65E-02			
1.17E-07	0.000	Cm-243	5.30E-15			
1.69E-10	0.000	Cm-244	7.65E-18			
1.42E+04	0.015	Cm-245	6.45E-04			
1.27E+05	0.130	Cm-246	5.75E-03			
8.58E-01	0.000	Cm-247	3.89E-08			
2.14E+01	0.000	Cm-248	9.73E-07			
9.74E+07			4.42E+00			

Figure 1a



Low Z Activities in
Tank 51 Sludge Only Glass.
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
Activity, Ci/Can
0
200
400
600
800
1000
1200
Time, Yr
Total Activity
Ni-59
Ni-63
Se-79
Sr-90
Zr-93
Tc-99
Pd-107

Figure 1b



Heavy Fission Products
in Tank 51 Sludge Only Glass.
1000
100
10
1
0.1
0.01
0.001
0.0001
Activity, Ci/Can
0
200
400
600
800
1000
1200
Time, Yr
Total Activity
Sn-126
Cs-135
Cs-137
Sm-151

Figure 1c

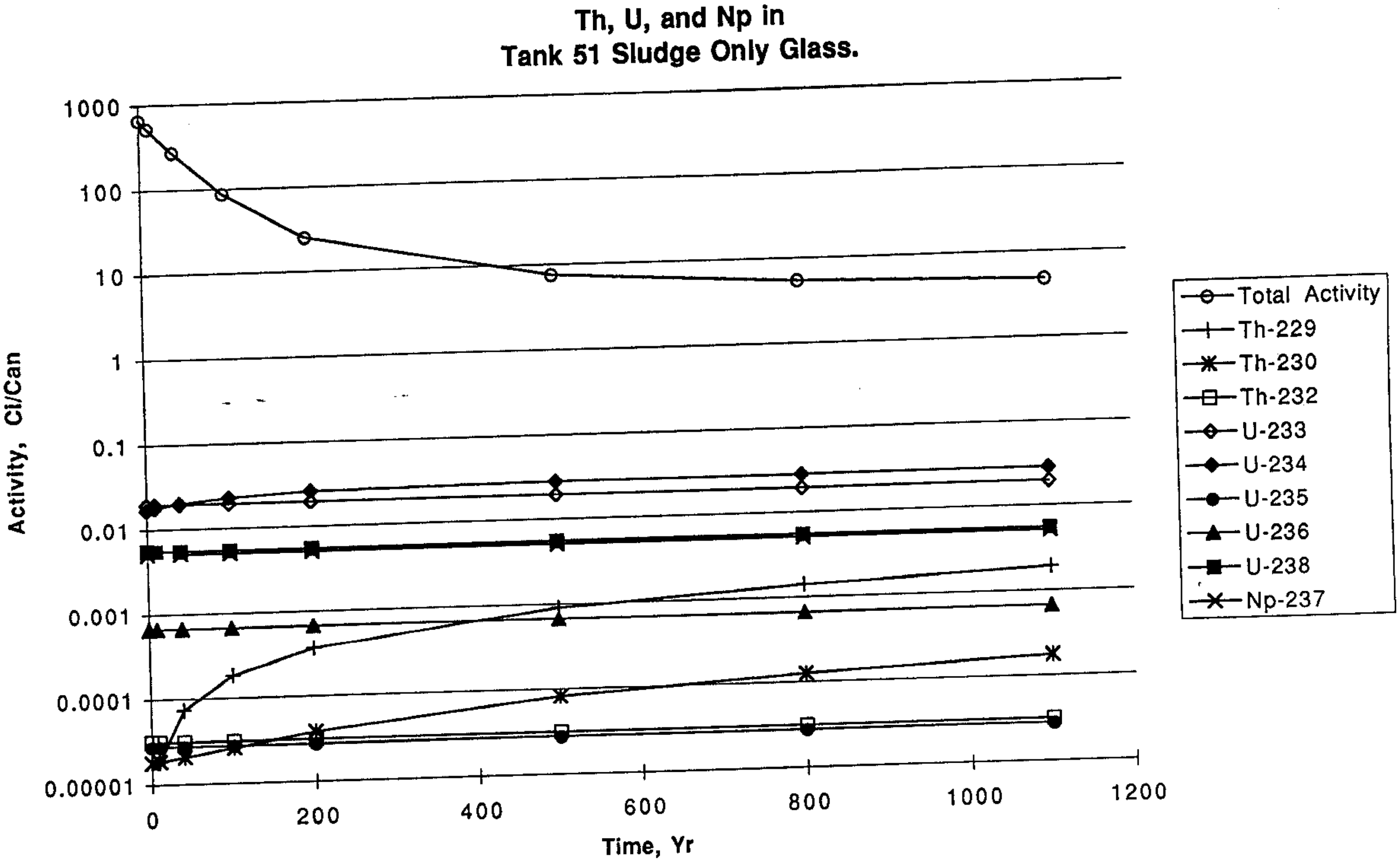
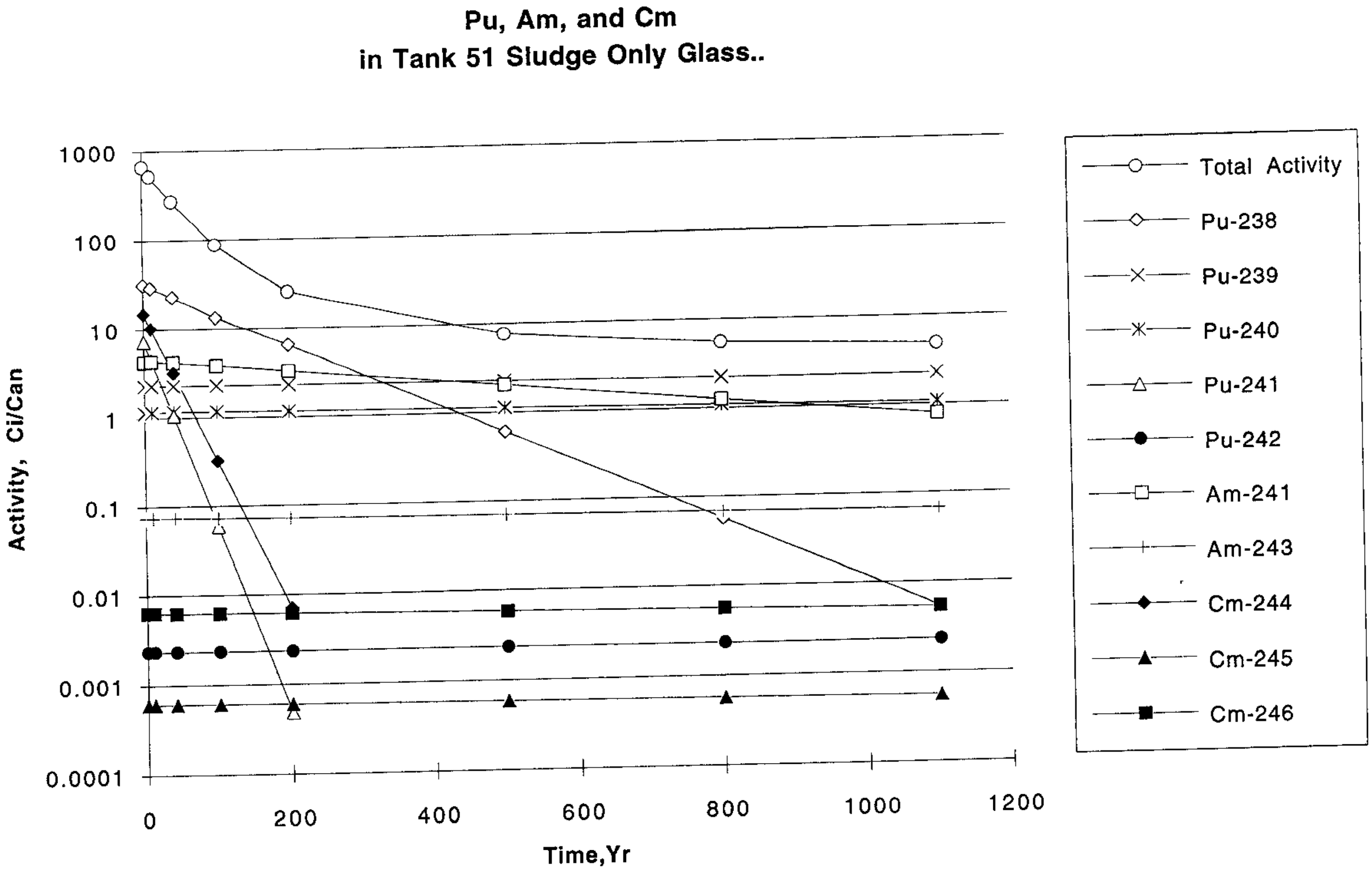

Th, U, and Np in
Tank 51 Sludge Only Glass.
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
Activity, Ci/Can
0
200
400
600
800
1000
1200
Time, Yr
Total Activity
Th-229
Th-230
Th-232
U-233
U-234
U-235
U-236
U-238
Np-237

Figure 1d



Pu, Am, and Cm
in Tank 51 Sludge Only Glass..
1000
100
10
1
0.1
0.01
0.001
0.0001
Activity, Ci/Can
0
200
400
600
800
1000
1200
Time,Yr
Total Activity
Pu-238
Pu-239
Pu-240
Pu-241
Pu-242
Am-241
Am-243
Cm-244
Cm-245
Cm-246

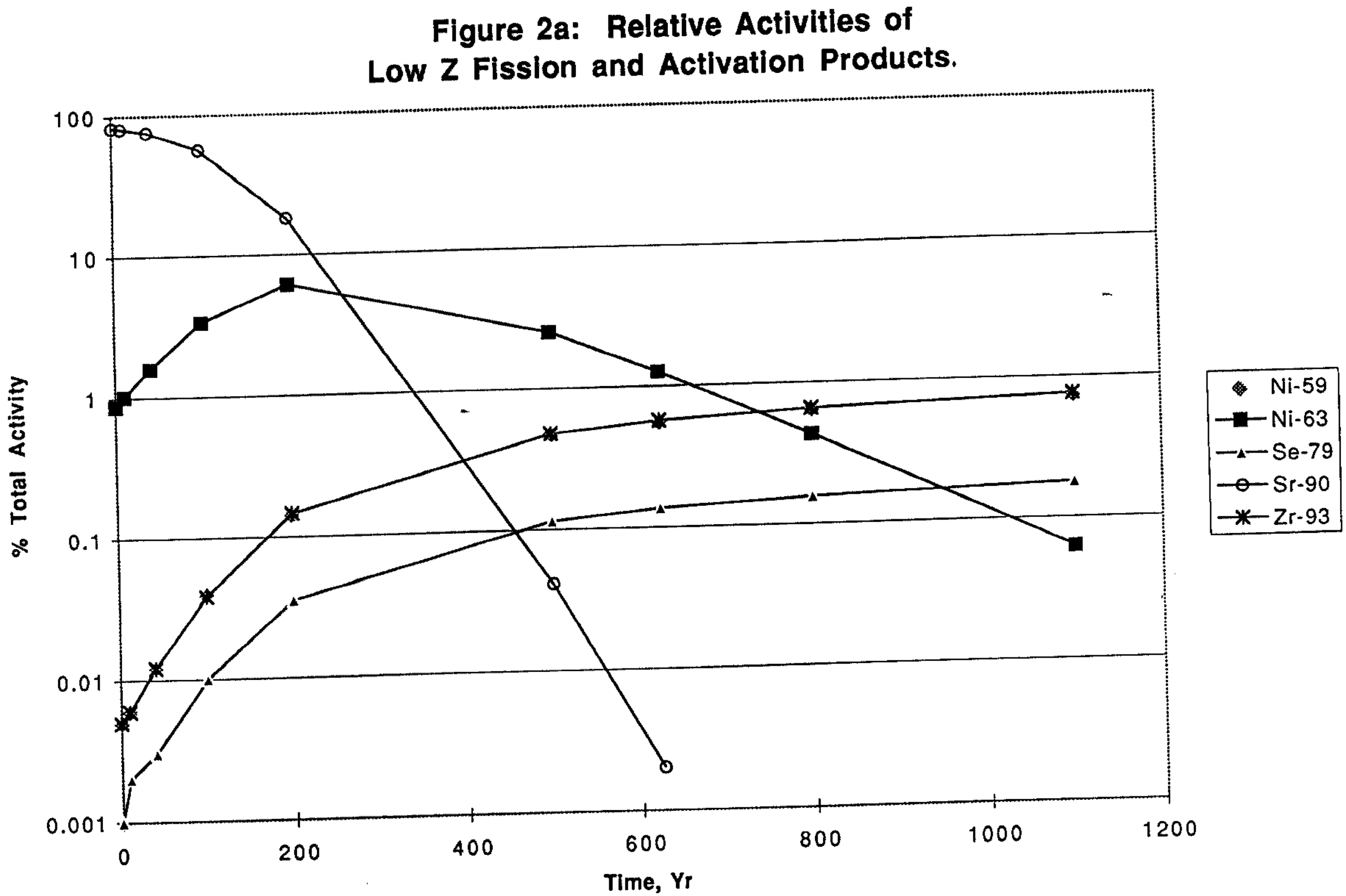
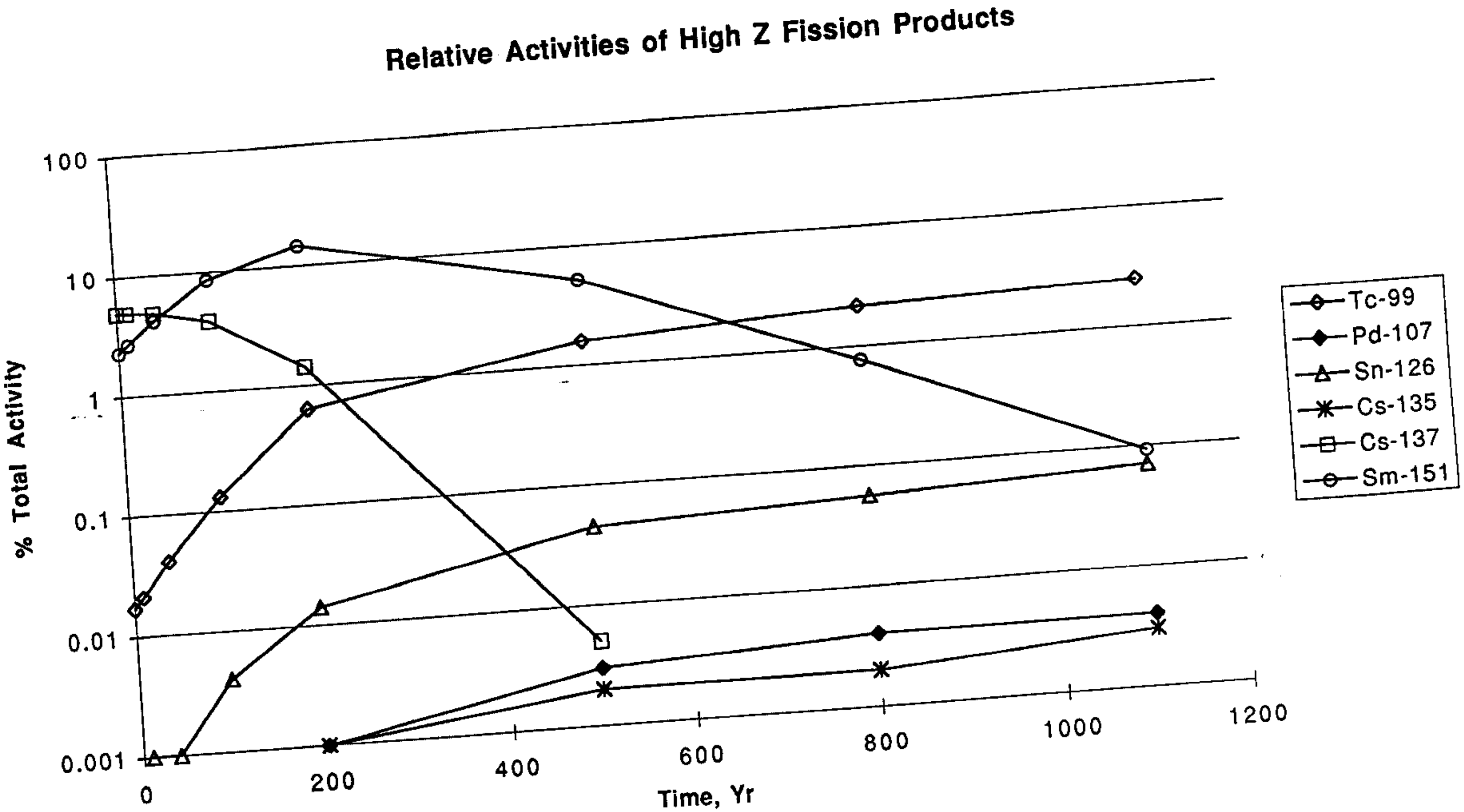


Figure 2a: Relative Activities of
Low Z Fission and Activation Products.
100
10
1
0.1
0.01
0.001
% Total Activity
0
200
400
600
800
1000
1200
Time, Yr
Ni-59
Ni-63
Se-79
Sr-90
Zr-93

Figure 2b



Relative Activities of High Z Fission Products
100
10
1
0.1
0.01
0.001
% Total Activity
0
200
400
600
800
1000
1200
Time, Yr
Tc-99
Pd-107
Sn-126
Cs-135
Cs-137
Sm-151

Figure 2c

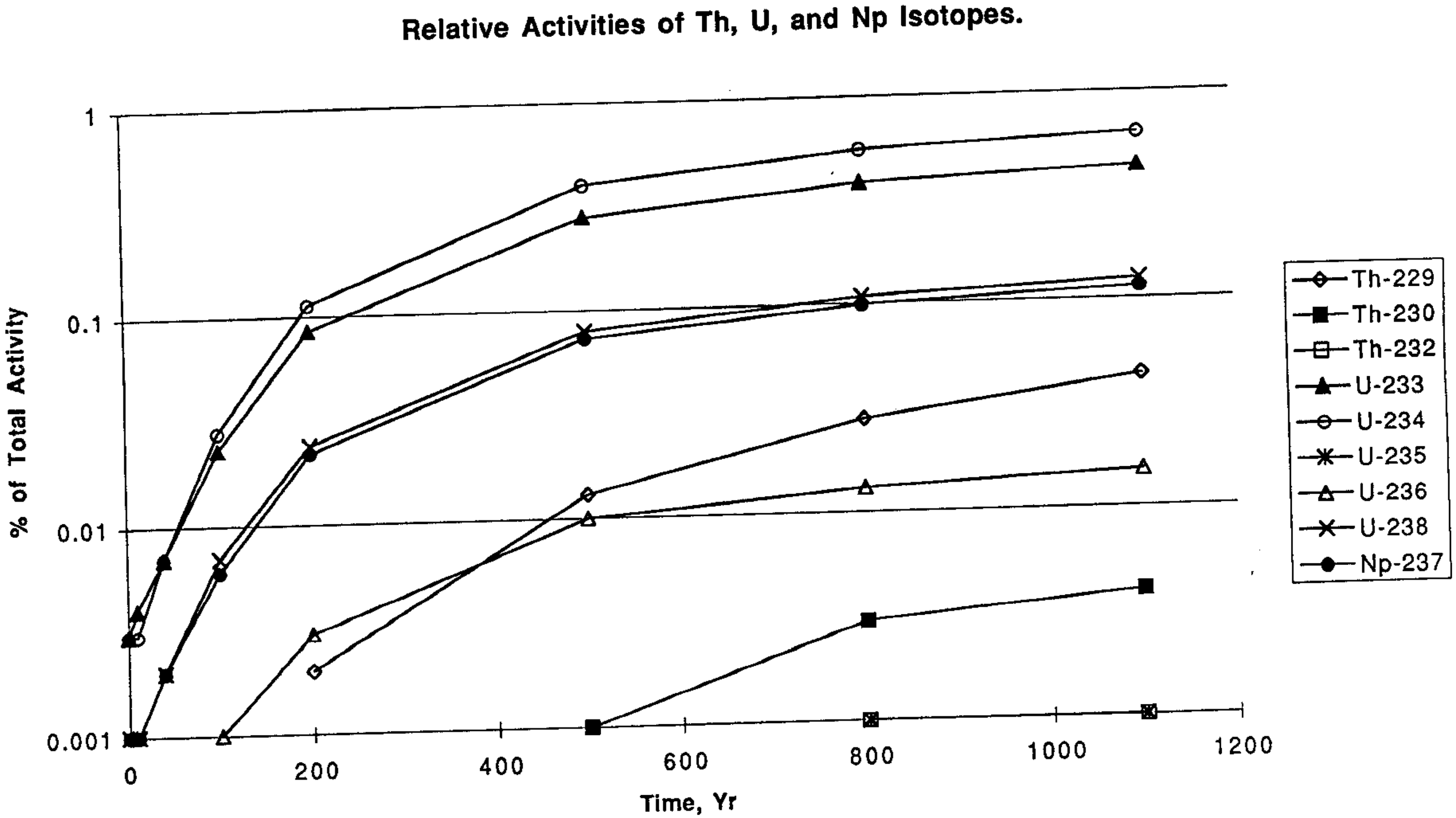
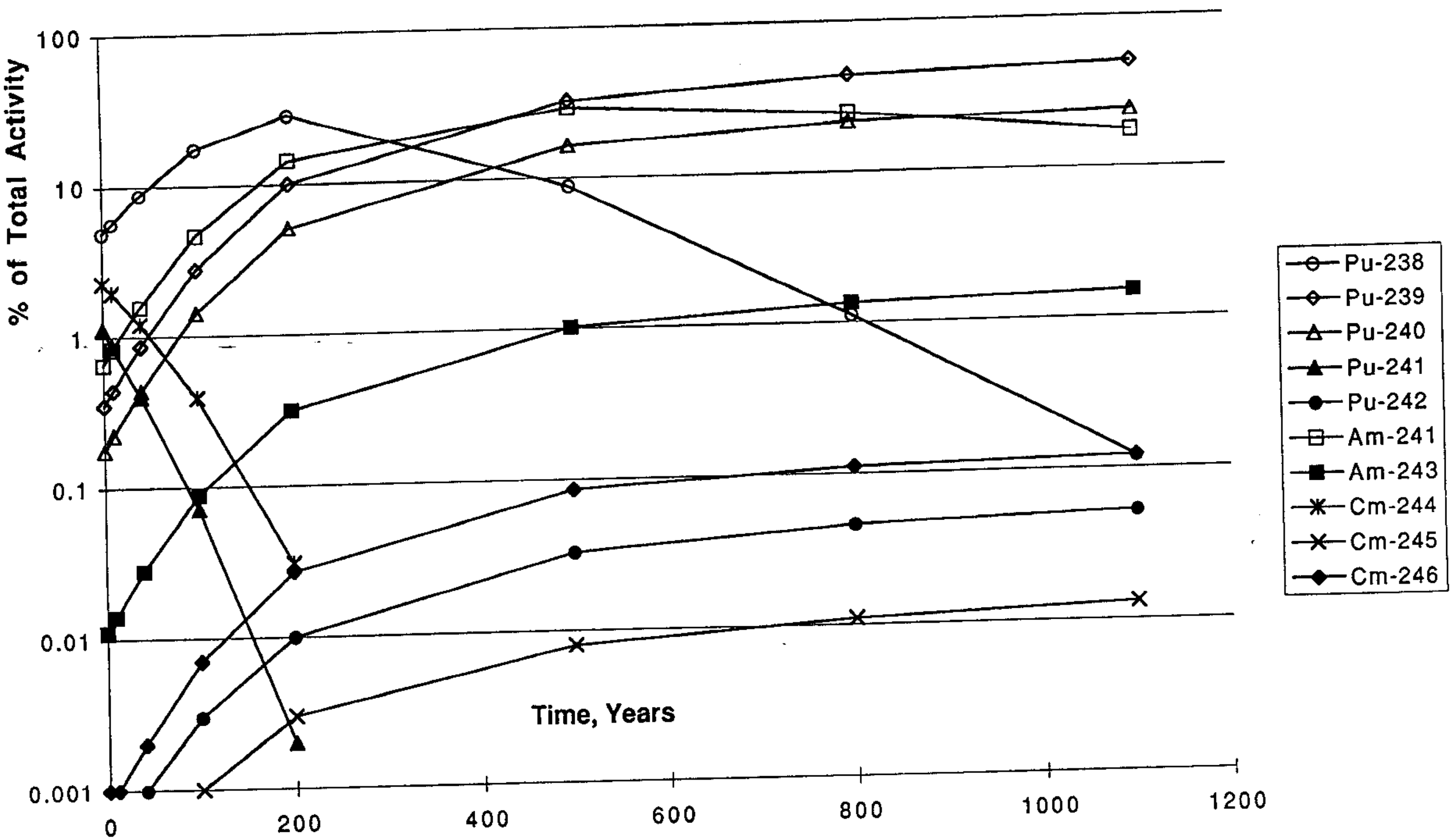

Relative Activities of Th, U, and Np Isotopes.
% of Total Activity
1
0.1
0.01
0.001
0
200
400
600
800
1000
1200
Time, Yr
Th-229
Th-230
Th-232
U-233
U-234
U-235
U-236
U-238
Np-237

Figure 2d

Relative Activities of Pu, Am, and Cm Isotopes.



APPENDIX A

Table 1. Isotopic Analyses of Curium Oxide Lot CMP-576

Part A. Curium Isotopes

Sample Idenfitication	ST-CM-171
Date Performed	79 Mar 19
Isotope	Atom %
^{243}Cm	0.017[a]
^{244}Cm	92.92
^{245}Cm	1.09
^{246}Cm	5.80
^{247}Cm	0.11
^{248}Cm	0.06
Ave. Mol. Weight	244.195
Wt. % ^{244}Cm	92.889
Wt. % Cm in $CmO_{1.73}$	89.819

[a]by γ-ray spectroscopy.

Part B. Americium Isotopes

Sample Identification	ST-CM-171
Date Performed	79 Mar 19
Isotope	Atom %
^{241}Am	0.40
^{242}Am	0.08
^{243}Am	99.52
Ave. Mol. Weight	243.052
Wt. % ^{243}Am	99.524
Wt. % Am in AmO_2	88.366

Appendix B:

Formulas Used in Spreadsheet Calculations

In the following formulas reference is made to the cell numbers in the spreadsheets from which Tables 2 through 11 are derived. Identifiers are as follows:

eln = the base of natural logarithms, e
Time = decay time in years
Sec = seconds per year, 365.25 * 24 * 3600
Avno = Avagadro's number, 6.02 x 10^{23}
Column B: Half life in years
Column C: Characteristic decay constant in reciprocal seconds
Column E: Weight per cent of the isotope
Column F: Molecular weight in grams
Column G: Activity in Bq/kg at zero decay time
Row 8: Zr-93
Row 9: Zr-93m
Row 17: Th-229
Row 18: Th-230
Row 20: Pa-231
Row 21: U-233
Row 22: U-234
Row 23: U-235
Row 26: Np-237
Row 27: Pu-238
Row 29: Pu-240
Row 30: Pu-241
Row 32: Am-241
Row 35: Cm-244

Isotopic Concentrations as a Function of Time. These are calculated in Row I; here the spreadsheet designators Ii have been replaced by the isotopes themselves.

Nb-93m =0.95*(G9*eln^(Time*(-0.693)/B9)+(C8/(C9-C8))*(E8*Avno*10/F8)*((eln^(-1*C8*Sec*Time))-(eln^(-1*C9*Sec*Time)))*C9)

Th-229 =(C21/(C17-C21))*(E21*Avno*10/F21)*((eln^(-1*C21*Sec*Time))-(eln^(-1*C17*Sec*Time)))*C17

Th-230 =((C22/(C18-C22))*(E22*Avno*10/F22)*((eln^(-1*C22*Sec*Time))-(eln^(-1*C18*Sec*Time)))*C18)+G18*eln^(-1*C18*Time*Sec)+(C18*E27*Avno*10/F27)*((eln^(-1*C27*Time*Sec))*C27*C22/((C22-C27)*(C18-C27))+((eln^(-1*C22*Time*Sec))*C27*C22*((C27-C22)*C18-C22))+(eln^(-1*C18*Sec*Time))*C27*C22*((C27-C18)*(C22-C18)))

Pa-231=(C23/(C20-C23))*(E23*Avno*10/F23)*((eln^(-1*C23*Sec*Time))-(eln^(-1*C20*Sec*Time)))*C20

U-234 =((C27/(C22-C27))*(E27*Avno*10/F27)*((eln^(-1*C27*Sec*Time))-(eln^(-1*C22*Sec*Time)))*C22)+G22*eln^(-1*C22*Time*Sec)

Np-237 =G26*eln^(-1*C26*Sec*Time)+(C30/(C26-C30))*(E30*Avno*10/F30)*((eln^(-1*C30*Sec*Time))-(eln^(-1*C26*Sec*Time)))*C26

Pu-240 =((C35/(C29-C35))*(E35*Avno*10/F35)*((eln^(-1*C35*Sec*Time))-(eln^(-1*C29*Sec*Time)))*C29)+G29*eln^(-1*C29*Time*Sec)

Pu 241 =G32*eln^(Time*(-0.693)/B32)+((C30/(C32-C30))*(E30*Avno*10/F30)*((eln^(-1*C30*Sec*Time))-(eln^(-1*C32*Sec*Time)))*C32)

Other Calculations:

Column G is calculated using the following formula, with row 8 as an example:

G8 = E29*10*Avno*C29/F29

and H8 = G8*100/Atotal

where Atotal is the sum of all entries in column G.

Items in Column I (decayed activity) which are not daughters of other isotopes are calculated by the relationship (with row 4 as an example):

I4 = G4*eln^(Time*(-0.693)/B4)

and the activity percentages in row J are calculated as

J4 = I4 * 100/Dtotal

where Dtotal is the sum of activity in column I.

Curies per can, column L, are calculated as

L4 = I4 * 1678/3.7 x 10^{10}

The total heat output in Table 10 was calculated by converting L4 to Bq, and multiplying it by radiation energy converted to watts, thus:

P4 = L4*(M4+N4+O4)*3.7 x 10^{10}*1.6 x 10^{-13}

This is summed over all rows to get the total heat.

Distribution List:

M. K. Andrews, 773-A
B. N. Attaway, 773-A
N. E. Bibler, 773-A
J. T. Carter, 704-25S
D. A. Crowley, 773-23A
E. F. Duhn, 773-A
H. H. Elder, 704-S
R. E. Edwards, 704-25S
D. M. Ferrara, 773-A
B. C. Ha, 773-A
J. R. Harbour, 773-43A
M. S. Hay, 773-A
E. W. Holtzscheiter, 773-A
L. F. Landon, 704-1T
S. L. Marra, 704-25S
J. F. Ortaldo, 704-S
L. M. Papouchado, 773-A
S. F. Piccolo, 704-S
M. J. Plodinec, 773-43A
C. T. Randall, 704-T
F. G. Smith III, 704-1T
WV&AA(12)
STI Records