

SAMPLING AND ANALYSIS OF HIGH-LEVEL WASTE AT WEST VALLEY

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ABSTRACT

Three samples of the supernatant in the main waste storage tank at the West Valley site were taken at different depths. Exhaustive chemical and radiological analyses were performed. The sampling was successfully done under several restraints using an air eductor device which could be lowered into the tank through an 200 cm riser opening. An assumption of homogeneity could reasonably be made based on the analytical and other data. Valuable design information was obtained from the analytical work. Inferences regarding the sludge composition could also be made from the supernatant analysis.

BACKGROUND AND HISTORICAL OVERVIEW

The Department of Energy facility at West Valley, New York was formerly operated by Nuclear Fuel Services Co., Inc. (NFS) as a commercial nuclear fuel reprocessing plant. West Valley Nuclear Services Co., a subsidiary of Westinghouse Electric Corporation, is now the prime contractor for site operations. The major task of this project involves solidification of 2.1 million litres of fuel reprocessing wastes.

The major portion (~98 percent) of these wastes are stored in a single vaulted underground storage tank. The bulk of its contents was formed by adding excess caustic (NaOH) to a nitric acid-based stream originating from the normal operation of the NFS reprocessing plant to reprocess uranium fuel using the PUREX process, although other additions of decontamination and cleanup wastes have been made. Concentration of the neutralized solution has resulted in the formation of a sludge layer at the bottom of the waste tank.

The current reference process consists of separate processing of the supernatant and sludge portions of the tank contents. For example, the scheme shown in Figure 1 assumes that the supernatant will be withdrawn from the waste tank (8D-2) and processed through an ion exchange system for removal of cesium, strontium, and actinide elements which are then routed to the solidification process. The decontaminated supernatant would then be concentrated and encapsulated. After removal of the supernatant, the sludge would be washed (in-tank) to lower Na^+ , NO_3^- , and SO_4^{2-} to specified levels. The wash water would also be routed through the ion exchange, concentration and encapsulation systems. Sludge remaining in 8D-2 would be slurried with water and concentrated to provide feed to the high-level waste solidification process. THOREX process waste, that is 35,000 litres of acidic waste resulting from processing a small batch of thorium-uranium fuel from Indian Point-1 reactor, will be blended with the slurried waste from 8D-2. Reliable chemical and radiological information on both solution and solids was desired for design purposes. The approach taken was to

take supernatant samples at different depths, in order to determine the degree of homogeneity. Overall solids composition could then be inferred with reasonable accuracy from plant processing records and fission yield calculations. Sampling of the sludge is planned in the near future to better establish its nature.

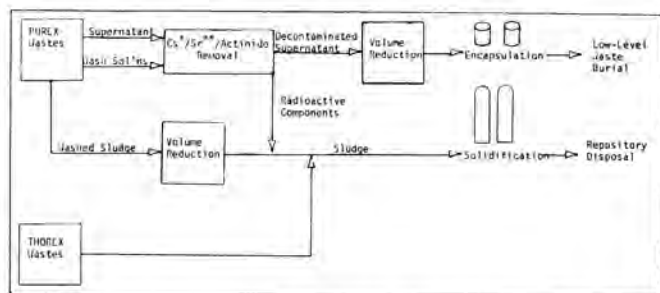


Fig. 1. Waste Processing Scheme for West Valley

PURPOSE OF SAMPLING

Although estimates of the tank contents had been previously made, the data were considered inadequate for design purposes. There had never been a complete analysis of the supernatant. The compositions reported were based on inference, using several sources of input data, such as plant analyses of input streams and plant chemical records. NFS surveillance records were required by New York State, but to be conservative, less than detectable limits were reported as being at the detection limit. Thus, several components were overstated.

Even in cases where it was felt that the total tank input was reasonably well known, the distribution between solids (sludge) and supernatant could only be inferred. Of critical importance is the distribution of radionuclides between the sludge and supernatant. As will be explained later, we now feel that we have a firm design basis on this distribution.

It was felt that multiple samples at different depths were needed for verification of solution

After the last sample was removed, a clean bottle was placed over the needle, and the needle block removed, bagged and placed in a shielded container. A water flush block was installed on the sampler, the samples lowered about two feet into the riser and the block, valves, tubing and eductor water-flushed. A water spray ring was fashioned to wash the externals of the apparatus every time it was brought to the surface. The items that were in contact with the liquid (weighted cable and tubes) were cranked into a wooden box (for beta shielding) which was equipped with a false bottom.

Analytical Work

The flow sheets for the analytical work are shown in Tables II and III. The sample vials were reheated to the tank temperature (85°C) and filtered through a 0.5 micron pore size hydrophilic teflon filter. The filter was washed with several rinses of ultrapure demineralized water, vacuum dried for 24 hours and then weighed. Specific gravity was determined by weighing a known volume to determine gms/cm³.

A general metal survey was done by evaporation of sample aliquots onto a carrier medium followed by mechanical blending and emission spectrographic analysis. Thirty-five elements, plus the rare earths were examined.

Sixteen elements were identified above the detection limit (Na, K, Cr, Cs, Mo, Rb, Al, Cu, Sr, Mg, B, Fe, Li, Pb, Si, and Sn) as can be seen in Table IV. Since accuracy of this method is 20-50 percent, the first ten of these elements were further analyzed by atomic absorption analysis. Percent relative standard deviation (percent RSD) ranged from 2.8 percent (K) to 17.8 percent (Cu). Metals that were searched for and not found are shown on Table V together with the detection limits.

The anions were measured by liquid ion chromatography using a "Dionex" instrument. Six anions (NO₃⁻, NO₂⁻, SO₄²⁻, Cl⁻, PO₄³⁻, and F⁻) were identified with percent RSD ranging from 3.6 percent (SO₄) to 5.0 percent (Cl, PO₄, F). All others were below the detection limit (Table VI).

Hydroxide content was determined by titrating with standard acid to the phenolphthalein end point after the addition of strontium chloride to precipitate dissolved carbonate and phosphate (ASTM Standard Test Method D-514-80). The total carbonate species were determined by titration using a pH electrode to monitor the titration. The amounts of bicarbonate, carbonate, carbonic acid, and free carbon dioxide were calculated using dissociation tables in ASTM D 513 for a pH value of 10.0 (See Table VII). This was a deviation from the original test plan (Tables I and II), in order to obtain excess hydroxyl ion information.

Radiochemistry

Gamma ray spectrometry was performed using two high resolution gamma ray detectors coupled to a Nuclear Data 6620 analyser standardized for several counting geometries with the NBS mixed-gamma standards. An aliquot of one of the dilutions was counted in one of the standardized geometries and all peaks identified. The activity concentration of the original sample was then calculated for each isotope detected. Radiochemical separation for ruthenium, antimony, and curium was made using car-

TABLE II
WEST VALLEY NUCLEAR SERVICES FLOW SHEET: WASTE TANK 80-2

SAMPLES RECEIVED 9/28/82

FILTRATION AND SOLUTION DENSITY DETERMINATION

STATUS REPORT

DILUTION	SPECIES MEASURED
SPECTROGRAPHIC	Elemental Impurities Rare Earths Noble Metals
ATOMIC ABSORPTION	Na, K, Cs, Sr
ION CHROMATOGRAPHY	F, Cl, NO ₂ , PO ₄ , NO ₃ , SO ₄ , Oxalate
CARBON	Organic, Inorganic
RADIOCHEMISTRY	See Radiochemistry Flow Sheet

STATUS REPORT

FINAL REPORT

TABLE III: RADIOCHEMISTRY FLOWSHEET

Sample	Species Measured
Dilute	
Diluted Sample	
Gamma Spectrometry	¹³⁷ Cs, ¹³⁴ Cs, ¹²⁵ Sb, ¹⁰⁶ Ru
Ruthenium Separation	¹⁰⁶ Ru
Antimony Separation	¹²⁵ Sb
Rare Earth Separation	Gamma Count, ¹⁴⁴ Ce Beta Count, Total Rare Earth
Strontium Separation	⁹⁰ Sr, ⁹⁰ Y
Alpha Spectrometry	All Significant Alpha Emitters. Would show whether U, Pu, Nd analysis is worthwhile.
Am, Cm Separation	²⁴¹ Am, ²⁴³ Am, ²⁴⁴ Cm
Mass Spectrometry (ASTM E-321)	Uranium, Plutonium and Neodymium

TABLE IV: MAJOR METALS

ELEMENT METHOD*	Micrograms per Gram of Filtered Sample			Percent RSD	
	1 ft.	5 ft.	15 ft.		
Sodium (Na)	113964	111382	108372	7.0	AA
Potassium (K)	5344	5276	5171	2.8	AA
Chromium (Cr)	476	478	488	6.1	AA
Cesium (Cs)	134	125	126	11.4	AA
Molybdenum (Mo)	106	117	121	12.2	AA
Ruthenium (Ru)	23.5	24.5	24.3	10.8	AA
Aluminum (Al)	10.6	6.8	8.6	5.0	FAA
Copper (Cu)	0.73	0.75	0.78	17.8*	AA
Strontium (Sr)	0.58	0.56	0.50	13.9*	AA
Magnesium (Mg)	0.17	0.13	0.12	13.4*	AA
Boron (B)	19.1	14.0	19.8	50.	ES
Iron (Fe)	3.9	3.4	3.1	50.	ES
Lithium (Li)	0.62	0.34	< 0.09	50.	ES
Lead (Pb)	10.	< 3.2	< 3.2	50.	ES
Silicon (Si)	10.6	5.9	8.2	50.	ES
Tin (Sn)	24.3	16.8	42.4	50.	ES

* - Method of Analysis: AA = flame atomic absorption
FAA = graphite furnace atomic absorption
ES = emission spectrography

+ - The analysis for these elements was at a level very close to the limit of detection.

TABLE V: MINOR METALS

Micrograms per Gram of Filtered Sample

ELEMENTS

Ag, Be	< 0.32
Mn, Ti	< 1.0
Ga, In	< 1.6
Sr, Y, Nb	< 1.7
Ba, Bi, Ca, Cd, Co, Ge	< 3.2
Nb, Ni, Sb, Th, Zr	< 3.2
As, Tl, Zn	< 9.7
Ni, Ir, Pd, Re, Rh	< 16.
Hg, W	< 32.
Ru	< 160.

This table shows the results of emission spectrography for trace elements. There was no significant difference in the detection limit for any one sample; so this table only shows one value.

TABLE VI: ANIONS

Micrograms per Gram of Filtered Sample

ANION	Micrograms per Gram of Filtered Sample			Percent RSD*
	1 ft.	5 ft.	15 ft.	
Nitrate (NO ₃)	166636	161841	165933	4.4
Nitrite (NO ₂)	76898	72177	76439	6.9
Sulfate (SO ₄)	18319	17721	18132	3.6
Chloride (Cl)	1085	955	946	5.0
Phosphate (PO ₄)	830	792	694	5.0
Fluoride (F)	96	92	107	5.0
Bromide (Br)	< 300	< 300	< 300	---
Oxalate (C ₂ O ₄)	< 39	< 39	< 39	---

* Relative Standard Deviation

TABLE VII: pH AND ALKALINITY

Micrograms per Gram of Filtered Sample

SPECIES	260B	—	—
Hydroxide (OH ⁻)	—	—	—
Carbonic Acid (H ₂ CO ₃)	—	3	3
Bicarbonate (HCO ₃ ⁻)	—	11156	10493
Carbonate (CO ₃ ²⁻)	—	5158	4852
Total Carbonate Species (as HCO ₃ ⁻)	—	16404	15429
Free Carbon Dioxide (CO ₂)	—	26	25
pH	9.93	9.93	10.19

riers and conventional chemical separation techniques for these elements.

Strontium-90 was chemically separated following addition of strontium carrier. The separated sample was mounted as strontium carbonate and beta counted with a gas flow proportional counter, standardized for strontium-90 as strontium carbonate using NBS standard solutions.

Four silicon surface barrier detectors mounted in vacuum chambers were used for alpha spectrometry. Quantitative results were obtained by spiking the sample aliquot with an alpha tracer of known activity. NBS standardized tracers were used for plutonium, americium, and curium. An aliquot was electroplated and counted for the identification of all isotopes present. Americium and curium isotopes were then separated from a separate aliquot of the sample for the measurement of Am-241, Am-243, and Cm-244. Mass spectrometry was used for the uranium and plutonium isotopes and neodymium according to ASTM-E-321.

Results and Interpretation

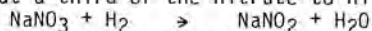
Calculated results and inferences from the data are presented in Tables VIII-XIV. The chemical data was reported as μ gms of component per gm of filtered supernatant. For clarity and as an aid for preparing simulated solutions, this data was converted to various salts. Some assumptions had to be made regarding the form of some of the elements. For example, Chromium (Cr) was assumed to be CrO₄²⁻ because of the distinctive yellow color of the solution.

In-tank measurements determined the vapor/liquid interface and specific gravity at tank temperature (1.270 at 89.8°C). This data, together with an estimate of solids content, gave an estimated supernatant content of 2,856,000 kg. Table VIII gives the chemical compositional data (average of 3 samples) in weight percent salt form and total kg in the supernatant. In order to derive this table, it was necessary to resolve the cation/anion imbalance. This was done by "adjusting" the Na⁺, NO₃⁻ and NO₂⁻ in proportion to the percent relative standard deviation (percent RSD) of the analysis. The "adjustment" did not exceed percent RSD for these components. Tellurium (Te as TeO₄) and Selenium (Se as SeO₄²⁻) were not determined analytically but were included in the indicated amounts (Table VIII) to be consistent with fission yield calculations.⁽¹⁾

The main components are those that can be identified with the PUREX process as applied to West Valley. The processing wastes were neutralized with sodium hydroxide before transfer to the tank which caused insoluble hydroxides of fission

products and metals to settle and form a sludge layer. The volume of the sludge is about seven percent of the total waste volume.

The main constituent of the supernatant is sodium nitrate. Reaction with hydrogen formed by radiolytic degradation resulted in conversion of about a third of the nitrate to nitrite:



Sulfate results from the addition of ferrous ammonium sulfate (FeNH₂(SO₃)₂) as a reducing agent. Phosphate came from destruction of the tributyl phosphate (TBP) used as the organic solvent. Sodium carbonate was used for removal of degradation products in the TBP. Potassium cations resulted from the use of potassium permanganate (KMnO₄) as a decontamination agent. Chloride probably resulted primarily from impurities in the caustic used. Fluoride was added by the use of ammonium fluoride (NH₄F) to dissolve zirconium fines in dissolver cleaning campaigns and to unplug lines.

Fission product yields were calculated from standard tables⁽¹⁾ for U-235 fission. A decay time of 14.4 years was calculated for use of this data by using cesium (assumed 100 percent soluble) as a tracer.

This agrees closely with processing data (Table XV) assuming ~1 year from removal from reactor to processing. Checks on other soluble components were reasonably close:

Element	μ gm/gm supernatant	
	Calculated	Analytical
Mo	128	113
Rb	18	24

The calculated fission product content of the waste tank is summarized in Table XI.

Although solubility of most of the fission metal hydroxide/sulfate/carbonate/fluoride was assumed to be negligible, this was not able to be confirmed in many cases because of detection limits. In the case of the rare earths, separation and beta counting of the isotopes compared to fission yield totals inferred a solubility of the rare earth hydroxides of <.02 percent. The low solubility of the rare earths was further confirmed by separation and determination of Nd-148. A detection limit of <.02 μ gm/gm of supernatant translates to <.15 percent of Nd-148 in solution.

For the transuranic (TRU) components, analytical results were able to give us the amount of plutonium in solution and the isotopic breakdown. A less-than-detectable amount of Am-241 (<1.5 x 10⁻⁷ nCi/gm), Am-243 (<2 x 10⁻⁷ nCi/gm) and Cm-244 (<6 x 10⁻⁸ nCi/gm) were found. Since the majority of the transuranics are found in the sludge, they were theoretically determined. The analysis used is similar to that given in Reference No. 4. A summary of the methodology and assumptions follows:

1. The fuel processed by NFS was grouped into three classifications according to the degree of burnup (MWD/MTU):

Group	Range (MWD/MTU)	Total MTU in Group
A	<3,200	362.8
B	>8,500 <15,794	185.4
C	>20,500	46.0

- Reference No. 6 lists data for actinide content for a PWR fuel enriched to 3.3 percent U-235 and exposed to a constant average specific power of 30 MW/MT of uranium charged to the core at the start of an equilibrium cycle. Data for irradiation times of 110 days, 330 days and 770 days were used to approximate Groups A, B and C respectively.
- The time between irradiation and processing was assumed to be one year.
- The decay time after processing was assumed to be 13.4 years to be consistent with fission yield calculations. Standard decay equations were used to calculate products.
- Fifty percent of the neptunium was assumed to be recovered in processing.
- The plutonium sent to waste was assumed to be that listed on the NFS Processing Summary.[3]

The results are summarized in Table XVI.

Comparison with other independent data is reasonably close:

At processing, the calculated total Pu input of 1,747,439 gms compares to the NFS processing total of 1,986,523 gms.[3]

The isotopic breakdown of the plutonium is compared to the analytical breakdown in the supernatant:

Isotope	Wt Percent (calculated)	Wt Percent (analytical)
Pu-238	0.35	1.62
Pu-239	85.24	78.21
Pu-240	12.46	15.70
Pu-241	1.50	3.32
Pu-242	0.45	1.27

Although we are comparing the isotopic breakdown in the supernatant with the total in the tank, one would expect them to be the same since solubility is a chemical phenomenon and all the isotopes should be chemically identical. For the purpose of Table X, the analytical isotopic breakdown was used for the plutonium.

A somewhat different approach was used to determine the chemical composition of the solids:

- Total iron, phosphate, aluminum, chromium, and nickel in the waste tank had been previously estimated.(2) Solids totals were determined by deducting amounts found in the supernatant.
- Total uranium in the tank was assumed to be that shown in the NFS Processing Summary.(3) A new amount (as $UO_2(OH)_2$) was calculated based on the amount of U found in the supernatant.
- Mercury (as $Hg(OH)_2$) and additional zirconium (in addition to fission-product Zr) were added as a result of process additions overlooked in reference 2.

The overall chemical solids composition is summarized in Table XIV.

There is considerable iron as the result of using carbon steel liners in the baskets used for fuel dissolution. Phosphate, as previously men-

tioned, is from the TBP organic solvent. Aluminum is from aluminum nitrate added to complex the fluoride used for dissolver cleaning and pipe unplugging. The manganese is from potassium permanganate used in decontamination. Mercury nitrate was used in an iodine scrubber. An estimated 117 kg of Zr was dissolved during cleanup campaigns.

In summary, the supernatant analytical results were able to be used in conjunction with NFS processing data, chemical purchasing records and theoretical fission yield calculations to give us estimates of chemical, fission product, and transuranic components in both the solid and liquid phases. In cases where independent data existed, the estimates were reasonably consistent.

Table VIII. 8D-2 Supernatant Chemical Composition

Compound	Wt. (a) Wet Basis	Wt. Dry Basis	Total Kg in Supernatant (b)
NaNO ₃	21.10	53.39	602,659
NaNO ₂	10.90	27.58	311,326
Na ₂ SO ₄	2.67	6.76	76,261
NaHCO ₃	1.49	3.77	42,557
KNO ₃	1.27	3.21	36,274
Na ₂ CO ₃	0.884	2.24	25,249
NaOH	0.614	1.55	17,537
K ₂ CrO ₄	0.179	0.45	5,113
NaCl	0.164	0.42	4,684
Na ₃ PO ₄	0.133	0.34	3,799
Na ₂ MoO ₄	0.0242	0.06	691
Na ₃ BO ₃	0.0209	0.05	597
CsNO ₃	0.0187	0.05	534
NaF	0.0176	0.05	503
Sn(NO ₃) ₄	0.00859	0.02	245
Na ₂ U ₂ O ₇	0.00808	0.02	231
Si(NO ₃) ₄	0.00806	0.02	230
RbNO ₃	0.00416	0.01	119
Na ₂ TeO ₄ (c)	0.00287	0.007	82
AlF ₃	0.00271	0.007	77
Fe(NO ₃) ₃	0.00152	0.004	43
Na ₂ SeO ₄ (c)	0.00054	0.001	15
Li(NO ₃)	0.00048	0.001	14
H ₂ CO ₃	0.00032	0.0008	9
Cu(NO ₃) ₃	0.00022	0.0006	6
Sr(NO ₃) ₂	0.00013	0.0003	4
Mg(NO ₃) ₂	0.00008	0.0002	2
TOTAL	39.52	100.00	1,128,861
H ₂ O (by diff.)	60.48		1,727,341

- To resolve cation/anion imbalance, additional sodium was added and NO₃/NO₂ subtracted in proportion to analytical percent relative standard deviation (percent RSD).
- Assumes 2.856×10^6 kg in tank 8D-2.
- From fission yield calculations.

TABLE IX: RADIOACTIVE ISOTOPE CONTENT (FISSION PRODUCT) IN TANK 80-2 (1982)

Isotope	T _{1/2}	Type of Decay	kg		Ci		Comments
			Supernatant	Sludge	Supernatant	Sludge	
Se-79	6.5 x 10 ⁶ yr	β	0.54	0	38	0	From fission yield calculations. Assumed 100 percent soluble.
Sr-90	29 yr	β	2.3 x 10 ⁻²	56.4	3,220	7.74 x 10 ⁶	Analytical data on supernatant. Total from fission yield calculations.
Y-90	64 hr	β	5.9 x 10 ⁻⁶	1.4 x 10 ⁻²	3,220	7.74 x 10 ⁶	Short-lived daughter of Sr-90.
Zr-93	1.53 x 10 ⁶ yr	β	9.0 x 10 ⁻²	90.7	0.23	230	Total from fission calculations yield assumed 99.9 percent insol. per Ref. 2.
Nb-93m	13.6 yr	γ	8.1 x 10 ⁻⁷	8.1 x 10 ⁻⁴	0.23	230	Short-lived daughter of Zr-93.
Tc-99	2.13 x 10 ⁵ yr	β	0	92.1	0	17.0	Total assumed in sludge per Ref. 5; to be verified by additional analysis.
Ru-106	368 d	β	1.0 x 10 ⁻⁵	1.0 x 10 ⁻³	35	3.5 x 10 ³	From Ref. 2, 99 percent assumed in sludge. Consistent with analytical (<1.5 x 10 ⁻⁵ m Ci/gm).
Rh-106	30 s	β	9.8 x 10 ⁻¹³	9.8 x 10 ⁻¹⁰	35	3.5 x 10 ³	Short-lived daughter of Ru-106.
Pd-107	6.5 x 10 ⁶ yr	β	2.4 x 10 ⁻²	2.41	5.2 x 10 ⁻³	0.51	Total from fission yield calculations assumed 99 percent insol. per Ref. 1.
Cd-113	9 x 10 ¹⁵ yr	β	2.6 x 10 ⁻³	0.26	3.5 x 10 ⁻¹²	3.5 x 10 ⁻¹⁰	* * * * *
Sb-125	2.73 yr	β	1.4 x 10 ⁻⁴	1.4 x 10 ⁻²	1.6	1.5 x 10 ⁴	Analytical data on supernatant. Total from App. 8.
Te-125m	58 d	γ	2.1 x 10 ⁻⁸	1.7 x 10 ⁻⁴	0.37	3.4 x 10 ³	Short-lived daughter of Sb-125, 23 percent * Te-125m, 77 percent * Te-125.
Sn-126	1.05 x 10 ⁵ yr	β	1.5 x 10 ⁻²	1.5	0.40	40	From Ref. 2.
Sb-126m	19 m	β/γ	3.4 x 10 ⁻¹³	3.4 x 10 ⁻¹¹	2.7 x 10 ⁻²	2.7	Short-lived daughter of Sn-126; 14 percent * Sb-126, 86 percent * Te-126.
Sb-126	12.5 d	β	3.2 x 10 ⁻¹⁰	3.2 x 10 ⁻⁸	2.7 x 10 ⁻²	2.7	From Ref. 2.
Cs-134	2.06 yr	β	0.38	0	6,670	0	Analytical - assumed 100 percent soluble.
Cs-135	3.0 x 10 ⁶ yr	β	135.1	0	110	0	From fission yield calculations.
Cs-137	30.2 yr	β	93.2	0	8.08 x 10 ⁶	0	Analytical - assume 100 percent soluble.
Ba-137m	2.5 m	γ	1.4 x 10 ⁻⁵	0	7.60 x 10 ⁶	0	Short-lived daughter of Cs-137.
Ce-144	284 d	β	-0	-0	-0	-0	Analytical showed <2.7 Ci Ce-144 in supernatant.
Pr-144	17 m	β	-0	-0	-0	-0	Short lived daughter of Ce-144.
Pm-147	2.62 yr	β	3.1 x 10 ⁻⁴	1.14	286	1.1 x 10 ⁶	Total rare earth activity in supernatant from analytical.
Sm-151	93 yr	β	3.2 x 10 ⁻⁴	8.0	8	2.0 x 10 ⁵	Proportioned assuming equal solubility products.
Eu-152	13.4 yr	β	3.2 x 10 ⁻⁴	3.0 x 10 ⁻³	56	481	Total from fission yield calculations.
Eu-154	8.2 yr	β	3.2 x 10 ⁻⁴	0.70	91	2.0 x 10 ⁵	and Ref. 2.
Eu-155	4.76 yr	β	3.2 x 10 ⁻⁴	9.4 x 10 ⁻²	157	4.5 x 10 ⁴	
TOTAL			229.4	253.3	1.57 x 10 ⁷	1.70 x 10 ⁷	

TABLE X: TRU CONTENT OF 80-2 (1982)

Isotope	Type of Decay	T _{1/2}	Sludge		Supernatant		Comments
			gm(a)	Ci	gm(b)	Ci	
Np-237	β	2.1 x 10 ⁶ yr	15,558	11	-0(c)	-0	Short-lived daughter of Am-243.
Np-239	β	2.4 d	1.0 x 10 ⁻³	233	-0	-0	
Pu-238	α	87.7 yr	530	9,088	7.8	134	
Pu-239	α	2.4 x 10 ⁴ yr	26,528	1,588	409.3	25	
Pu-240	α	6,537 yr	5,128	1,171	82.2	19	
Pu-241	β	14.7 yr	1,075	108,802	17.4	1,881	.0024 percent of decays are α.
Pu-242	α	3.8 x 10 ⁵ yr	422	1.7	6.6	2.5 x 10 ⁻²	
Am-241	β	432 yr	3,500	12,046	-0	-0	<0.1 grams in supernatant (detection limit).
Am-242m	β	152 yr	21.6	210	-0	-0	
Am-243	α	7,380 yr	1,189	238	-0	-0	<3 grams in supernatant (detection limit).
Cm-242	α	162.8 d	6.4 x 10 ⁻²	212	-0	-0	Short-lived daughter of Am-242m.
Cm-243	α	28.5 yr	0.66	34	-0	-0	
Cm-244	α	18.1 yr	128	10,329	-0	-0	
Cm-245	α	8.5 x 10 ³ yr	10.3	1.7	-0	-0	<.002 grams in supernatant (detection limit).
Cm-246	α	4.7 x 10 ⁷ yr	0.71	0.2	-0	-0	
TOTAL			53,091	109,242 β	523.3	1,881a	
				34,723 α		176a	

- (a) Total based on NPS processing summary [3] and Ref. 8 (See Appendix D).
- (b) Assumes 2.85 x 10⁶ kg in tank 80-2.
- (c) Assumed to be insoluble per Ref. 1; Np separation was not done.

TABLE XI: FISSION PRODUCT CONTENT OF 80-2

Element	Atomic Weight (Avg.)	Kg of Element in Supernatant	Assumed (a) Form	Kg of Element in Sludge	Assumed (c) Form	Comments
Se	81.0	6.5	Se ⁺⁶	0.0	-	Assumed 100 percent soluble per Ref. 2.
Rb	86.3	68.7	Rb ⁺	0.0	-	Analytical; assumed 100 percent soluble.
Sr	89.1	1.6	Sr ⁺	103.0	SrSO ₄	
Y	89.0	-0	-	65.7	Y(OH) ₃	
Zr	93.2	-0	-	465.2	Zr(OH) ₄	<9.1 kg in supernatant (detection limit).
Mo	97.5	322.0	MoO ₄	0.0	-	Analytical; Assumed 100 percent soluble.
Tc	99.0	-	-	92.1	Ba(TcO ₄) ₂	Assumed to be all in sludge [5].
Ru	101.2	-0	-	274.2	Ru(OH) ₂	<456 kg in supernatant (detection limit).
Rh	103.0	-0	-	48.2	Rh(OH) ₃	<456 kg in supernatant (detection limit).
Pd	105.6	-0	-	25.9	Pd(OH) ₂	<456 kg in supernatant (detection limit).
Ag	109.0	-0	-	0.6	AgOH	<0.9 kg in supernatant (detection limit).
Cd	113.1	-0	-	1.3	Cd(OH) ₂	<9.1 kg in supernatant (detection limit).
In	115.0	-0	-	0.2	In(OH) ₃	<4.6 kg in supernatant (detection limit).
Sn	120.7	-0	-	1.6	Sn(OH) ₄	Analytical shows 79.3 kg in supernatant (b).
Sb	122.1	-0	-	0.5	Sb(OH) ₃	<9.1 kg in supernatant (detection limit).
Te	129.5	44.3	Te ⁺⁶	0.0	-	Assumed 100 percent soluble per Ref. 2.
Cs	134.8	365.0	Cs ⁺	0.0	-	Assumed 100 percent soluble.
Ba	137.8	-	-	178.4	Ba(TcO ₄) ₂ / BaSO ₄	<9.1 kg in supernatant (detection limit).
La	139.0	-0	-	135.2	La(OH) ₃	<48.7 kg in supernatant (detection limit).
Ce	141.0	-0	-	260.3	Ce(OH) ₃	* * * * *
Pr	Rare	-0	-	125.1	Pr(OH) ₃	* * * * *
Nd	Earths	144.7	-0	458.8	Nd(OH) ₃	<.08 kg in supernatant (detection limit).
Pm		147.0	-0	1.1	Pm(OH) ₃	<48.7 kg in supernatant (detection limit).
Sm		148.6	-0	106.3	Sm(OH) ₃	<48.7 kg in supernatant (detection limit).
Eu		152.6	-0	4.9	Eu(OH) ₃	<48.7 kg in supernatant (detection limit).
Gd		155.7	-0	1.3	Gd(OH) ₃	<4.8 kg in supernatant (detection limit).
TOTAL		808.1		2,349.9		

- (a) Only those >0.1 kg listed
- (b) Evidently there was Sn input other than fission product.
- (c) No firm basis for these assumptions; may also be carbonates and fluorides present.

TABLE XII: URANIUM ISOTOPE SUMMARY^(a)

Isotope	T _{1/2}	Form of Decay	RD-2 Sludge		RD-2 Supernatant	
			kg ^(b)	C1	kg ^(c)	C1
U-233	1.6 x 10 ⁵ yr	α	0.75	7.2	0.05	0.5
U-234	2.4 x 10 ⁵ yr	α	0.63	4.0	0.04	0.3
U-235	7.1 x 10 ⁸ yr	α	41.7	0.09	3.0	6.5 x 10 ⁻³
U-236	2.3 x 10 ⁷ yr	α	4.1	0.26	0.29	2.0 x 10 ⁻²
U-238	4.5 x 10 ⁹ yr	α	7370.2	0.80	169.2	5.8 x 10 ⁻²
TOTAL			2417.4	12.35	176.2	0.88

(a) Assumes same isotopic composition in supernatant and sludge.

(b) NFS Processing Summary^[3] used for total in Tank.(c) Assumes 2.856 x 10⁶ kg in tank RD-2.

TABLE XIII: CESIUM ISOTOPE SUMMARY

Isotope	µgm Cs/gm Supernatant	Percent Fission Yield ^(a)	Kg in RD-2 ^(b)	C1 in RD-2
Cs-133	47.9	6.69	136.52	Stable
Cs-134 ^(e)	1.25 x 10 ⁻⁴	Incl. with Cs-133 ^(e)	0.38	6,659
Cs-135	47.4	6.53	135.09 ^(c)	109.7
Cs-137	32.7	6.18	93.20	8.075 x 10 ⁸
TOTAL	128.0 ^(d)	19.40	365.2	8.08 x 10 ⁸

Atomic weight avg. = 134.76

(a) From Ref. 1.

(b) Assumes 2.85 x 10⁶ kg supernatant.

(c) Calculated from Fission yield data.

(d) Total analytical Cs.

(e) Formed by irradiation of Cs-133.

TABLE XIV: REFERENCE RD-2 SOLIDS CHEMICAL COMPOSITION

Component	Kg in Solids
Fe(OH) ₃	52,059
FePO ₄	26,110
Cr(OH) ₃	3,290
UO ₂ (OH) ₂	3,087
Al(OH) ₃	2,759
Ni(OH) ₂	2,266
MnO ₂	2,200
Hg(OH) ₂	117
R.E.(OH) ₃ ^(a)	1,483
Other Fission Products:	
F.P. ₄ ^(b)	402
F.P. Hydroxides ^(b)	1,652
Ba(TcO ₄) ₂	215
Actinides:	
PuO ₂	37
AO ₂ ^(c)	23
TOTAL	95,700

(a) Rare earth fission products; see Table 11 for breakdown.

(b) See Table 11 for breakdown.

(c) TRU other than plutonium; see Table 10 for breakdown.

TABLE XV: SUMMARY OF FUEL PROCESSED AT NFS REPROCESSING PLANT

Lot No.	Reactor	Commencement Date	MTU	Total Pu kg	Average Mg/MTU	MWD
2	NPR	04/22/66	19.7	1.7	75	1,476
1	NPR	05/20/66	28.8	2.3	75	2,160
3	NPR	07/15/66	46.7	50.9	1,287	60,100
4	Dresden-1	11/12/66	50.0	191.0	6,500	426,200
5	Yankee Rowe	05/07/67	49.8	285.1	11,200	558,400
6	NPR	09/02/67	26.6	52.6	2,700	71,190
7	NPR	12/02/67	26.1	47.4	2,700	70,200
8	NPR	01/06/68	42.4	75.4	2,700	114,200
9	NPR	05/05/68	28.8	79.1	2,850	111,200
10	NPR	06/29/68	55.3	115.7	2,870	156,700
11	Indian Point-1	11/15/68	Special Case - 16 MT uranium + thorium			
12	NPR	02/13/69	48.9	102.5	2,850	139,100
13	Yankee Rowe	05/14/69	19.6	176.0	20,500	400,000
14	NPR	08/16/69	30.3	-	Unirradiated	
15	Dresden-1	10/01/69	21.5	104.6	10,900	235,000
16	Indian Point-1	11/23/69	15.6	107.6	15,794	247,966
17	Yankee Rowe	08/02/70	9.3	95.6	24,381	228,307
18	Pathfinder	08/14/70	9.6	7.1	2,231	14,685
19	Big Rock Point	11/26/70	18.4	72.8	9,212	171,361
20	Indian Point-1	01/11/71	7.6	68.1	23,455	177,502
21	NPR	02/25/71	15.8	25.4	2,868	45,432
22	Bonus Superheater	04/15/71	1.7	0.9	1,552	2,646
23	Bonus Boiler	04/18/71	2.4	4.0	3,230	7,865
24	Humboldt Bay	05/02/71	20.8	87.2	10,486	219,633
25	Yankee	07/16/71	9.5	95.7	23,652	224,730
26	CWPA-Parr	10/04/71	3.5	11.6	2,783	34,408
27	Big Rock Point	11/30/71	5.8	27.9	13,567	80,483
28	SEFOR	12/12/71	-	95.5	Unirradiated Scrap	

TABLE XVI: TRU CALCULATION SUMMARY
(all weights in grams)

Isotope	At Reactor Discharge	Initial ^(a) Adjustment	1 year out-of-Reactor	After Processing	After 13.6 years Decay	T _{1/2}	C1 (1982)
U-239	177	0	0	0	0	-	0
Np-237	30,971	30,971	30,974	15,487	15,558	7.14 x 10 ⁶ yr	11
Np-238	81	81	0	0	0	2.12 d	0
Np-239	3,277	0	0.001	0.001	0.001	7.35 d	233
Np-240	0.94	0	0	0	0	-	0
Pu-238	4,449	4,449	4,439	96 ^(b)	117	87.74 yr	2,008
Pu-239	1,471,357	1,474,811	1,474,768	26,624 ^(b)	26,615	24,110 yr	1,779
Pu-240	211,543	211,544	211,530	4,108 ^(b)	4,104	6,537 yr	956
Pu-241	51,012	51,012	46,662	945 ^(b)	502	14.7 yr	50,774
Pu-242	7,846	7,846	7,840	152 ^(b)	152	3.76 x 10 ⁵ yr	0.60
Pu-243	2.6	0	0	0	0	-	0
Am-241	783	783	3,130	3,130	3,500	432 yr	12,046
Am-242m	23.1	23.1	23.0	23.0	21.8	152 yr	210
Am-242	1.6	0	0	0	0	16 h	210
Am-243	1,187	1,190	1,190	1,190	1,189	7,300 yr	238
Cm-242	182.5	184.1	38.9	38.9	0.064	162.8 d	232
Cm-243	0.94	0.94	0.92	0.92	0.46	28.5 yr	34
Cm-244	227	232	234	234	188	18.11 yr	10,329
Cm-245	10.3	10.3	10.3	10.3	10.3	8.5 x 10 ³ yr	1.7
Cm-246	0.71	0.71	0.71	0.71	0.71	4.73 x 10 ³ yr	0.2

(a) Short half-life isotopes allowed to decay.

(b) Using NFS Process Summary^[3] total of 33,917 grams of Pu to RD-2.

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