Estimation of Plutonium in Hanford Site Waste Tanks Based on Historical Records

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APPROVAL PAGE

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TANKS BASED ON HISTORICAL RECORDS

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TERMS

PFP	Plutonium Finishing Plant (Z Plant)
PUREX	Plutonium Uranium Extraction (Facility)
REDOX	Reduction oxidation (S Plant)
TRAC	Track radioactive components

ESTIMATION OF PLUTONIUM IN HANFORD SITE WASTE TANKS BASED ON HISTORICAL RECORDS

1.0 INTRODUCTION

An estimation of plutonium in the Hanford Site waste storage tanks is important to nuclear criticality concerns. A reasonable approach for estimating the plutonium in the tanks can be established by considering the recovery efficiency of the chemical separation plants on the plutonium produced in the Hanford reactors. The waste loss from the separation processes represents the bulk of the plutonium in the waste tanks. The lesser contributor of plutonium to the waste tanks was the Plutonium Finishing Plant (PFP). When the PFP waste is added to the plutonium waste from separations, the result is the total estimated amount of plutonium discharged to the waste tanks at the Hanford Site. This estimate is for criticality concerns, and therefore is based on conservative assumptions (giving higher plutonium values). The estimate has been calculated to be ≈ 981 kg of plutonium in the single- and double-shell high-level waste tanks.

2.0 BACKGROUND

Nine different plutonium production reactors operated between 1944 and 1987. These reactors used uranium metal fuel and converted a small fraction of the ^{238}U in the fuel into plutonium (primarily ^{239}Pu). The plutonium was extracted from the irradiated uranium fuel by chemical means, and four processing plants were built to accomplish this: T Plant, B Plant, REDOX (REDuction OXidation), and PUREX (Plutonium URanium EXtraction). The processes that separated the plutonium from the uranium generated large volumes of radioactive liquid waste, which was stored in underground waste tanks. The separation processes were not 100% efficient and some of the plutonium was discharged to the waste tanks.

There have been various efforts to estimate the amount of plutonium in the Hanford waste tanks. One of these methods used the results from a comprehensive waste tracking model called TRAC. TRAC stands for Track RadioActive Components and was a computer program that modeled waste streams from the processing plants into the individual tanks, and then followed tank transfers through 1980. The results of the TRAC computer model were estimates of various chemical compounds and radioisotopes in each waste tank. The total estimated value of plutonium in the tanks, as reported by TRAC, is ≈ 385 kg. Some scientists and engineers think this estimate is too low. However, it is

important to understand that in order to comply with classification requirements in place at the time, TRAC used established plutonium values from old, unclassified records and old special nuclear material accountability records, and was not intended to calculate accurate plutonium amounts.

As a result of the inconsistency of past estimates, an attempt to obtain a realistic upper-limit estimate of the total plutonium content in the waste tanks was undertaken by the authors of this document.

3.0 APPROACH

Much of the information, data, and assumptions used in this estimation were gathered from conversations with experienced employees who thoroughly comprehend the processes involved, such as PFP, PUREX, REDOX, the 242-T Evaporator, and the plutonium production reactors. They also understand the waste streams associated with these facilities. They were able to suggest sources of information (documents and publications), supply data (such as PFP waste discharged to the double-shell tanks, or the plutonium content in Tank SY-102) and give insights into how the facilities handled their waste. The analysis in this document utilizes this information.

The amount of plutonium produced in the Hanford reactors must be known in order to estimate the unrecovered plutonium in the waste tanks. There were nine plutonium production reactors operating at Hanford from the startup of the historic B Reactor in 1944 to the shutdown of N Reactor in 1987.

The amount of plutonium generated was calculated from the average exposure of monthly fuel discharges. These data and the production calculations were performed by Steven P. Roblyer in *Plutonium and Tritium Produced in the Hanford Site Production Reactors* (Roblyer 1994). The result of the calculation is the amount of plutonium discharged from each of the reactors by month. For purposes of this calculation, a cooling time of 4 months after discharge was assumed before the values were assigned a date. The combined plutonium production of all nine reactors is shown in Figure 1. The cumulative plutonium production is displayed in Figure 2, with a total of ≈ 67 metric tons of plutonium produced by the Hanford reactors. Of the 67 metric tons, ≈ 4 metric tons of plutonium remain unprocessed in the K Basins, and 528 kg of plutonium were sent offsite to be processed at West Valley, New York, making the total amount of plutonium processed at Hanford to be ≈ 62.7 metric tons.

Figure 1. Annual Plutonium Production (All Hanford Reactors).

Figure 2. Cumulative Plutonium Production (All Hanford Reactors).

There were four reprocessing facilities at Hanford: T Plant, B Plant, REDOX, and PUREX. The purpose of these facilities was to dissolve irradiated reactor fuel and to separate the plutonium from the uranium and fission products.

The first processing facility to separate plutonium from irradiated uranium fuel was T Plant, which started operations in December 1944. B Plant started operations in April 1945. Both T Plant and B Plant used the bismuth phosphate process for plutonium recovery, and did not recover the uranium. B Plant was shut down in October 1952 for modifications, but was never reused for fuel processing. T Plant was shut down in August 1956 because PUREX and REDOX were able to handle the fuel load, extracting uranium as well as plutonium.

The REDOX plant started operations in January 1952 and operated until December 1966 when it was shut down. From 1958 to December 1966, all the irradiated enriched uranium fuel (uranium metal enriched in ^{235}U) was sent to REDOX and the natural uranium fuel was processed at PUREX. In its last year, REDOX processed N Reactor fuel as a pilot for PUREX.

PUREX was the most efficient of the four plants. It started reprocessing irradiated fuel in January 1956, and operated until June 1972, when it was shut down for eleven years. It was restarted in November 1983 and operated until December 1988. There was a short cleanout run in 1990 for stabilization. The plant was officially closed in 1992.

Figure 3 shows the cumulative reactor production with the operating years of the four recovery plants overlaid. From this, we can determine that the bulk of the plutonium was produced after the bismuth phosphate process (T and B Plants) had been shut down, and before 1970.

Because no separation process is 100% efficient, not all of the plutonium in the irradiated reactor fuel was recovered. Some of the plutonium was discharged to the waste tanks along with fission and activation products and process chemicals. Table 1 shows the estimated annual waste loss values for each of the separation facilities, as derived from the monthly operating data reported in *Selected Monthly Operating Data for B and T Plants, REDOX and PUREX (1944 - 1972)* (Gydesen 1992a) and the early General Electric monthly reports (GE 1945 through GE 1953a). The shaded values were estimated because no information on the waste loss in the 1980s could be located. There are three sets of values reported in Table 1. The first set contains the maximum monthly waste loss values reported for the given year. The second set contains the second-largest waste loss values reported for the given year. The third set contains the annual average plutonium waste loss calculated from the reported monthly values.

Figure 3. Cumulative Reactor Production with Process Operating Years.

Table 1. Annual Plutonium Waste Loss.

Year	Annual Maximum			Annual 2nd Largest			Annual Average		
	T and B			T and B			T and B		
	Plants	REDOX	PUREX	Plants	REDOX	PUREX	Plants	REDOX	PUREX
45	9.60%			7.90%			7.02%		
46	7.00%			6.80%			6.10%		
47	5.00%			4.60%			3.30%		
48	2.70%			2.70%			2.56%		
49	2.90%			2.70%			2.57%		
50	3.90%			3.40%			3.25%		
51	3.40%			3.40%			2.44%		
52	3.20%	4.56%		3.20%	3.73%		2.77%	1.51%	
53	2.90%	2.10%		2.60%	2.05%		2.28%	1.28%	
54	6.10%	2.15%		4.00%	1.17%		3.03%	0.70%	
55	4.30%	2.01%		4.00%	1.82%		3.50%	0.94%	
56	5.10%	2.16%	5.10%	3.10%	1.39%	4.10%	2.78%	0.61%	2.06%
57		0.87%	1.29%		0.85%	1.27%		0.62%	0.81%
58		0.74%	2.36%		0.68%	0.56%		0.41%	0.32%
59		0.72%	0.53%		0.64%	0.53%		0.50%	0.26%
60		1.16%	1.83%		0.98%	1.33%		0.43%	0.51%
61		0.29%	0.58%		0.28%	0.52%		0.21%	0.33%
62		0.87%	0.70%		0.56%	0.64%		0.41%	0.42%
63		0.73%	2.20%		0.71%	0.90%		0.38%	0.40%
64		1.40%	1.28%		0.54%	0.50%		0.33%	0.36%
65		2.19%	0.56%		1.07%	0.53%		0.52%	0.40%
66		1.03%	1.20%		1.00%	0.92%		0.46%	0.44%
67			1.34%			0.48%			0.36%
68			0.81%			0.46%			0.36%
69			1.88%			0.65%			0.40%
70			1.45%			1.45%			0.52%
71			1.09%			0.69%			0.49%
No fuel was processed between 1972 and 1982.									
83			1.50%			1.00%			0.50%
84			1.50%			1.00%			0.50%
85			1.50%			1.00%			0.50%
86			1.50%			1.00%			0.50%
87			1.50%			1.00%			0.50%
88			1.50%			1.00%			0.50%

Using the maximum (worst-case) values is a method of maintaining a conservative estimate for criticality concerns. Essentially, this method assumes the separation plants operated at their worst, which provides the worst-case estimate. The other two sets are included for comparison. The second-largest set is included because the maximum values may not represent the year because of unusual operating conditions during a given month, or because the maximum values were reported in a month when very little fuel was processed, and therefore do not represent the plutonium waste for that year. Because the processing facilities became more reliable and recovered more plutonium as the process became more refined, the waste loss was generally smaller in the later years than in the early years. An exception was PUREX, which initially reprocessed irradiated aluminum-clad production fuels, but in the late 1960s it started reprocessing zirconium alloy clad fuel from N Reactor. The waste loss from the zirconium alloy clad fuels was greater than from the aluminum clad fuels. Different results can be obtained from different assumptions. The information in Table 1 is based on monthly waste loss records, but similar calculations could be based on annual waste loss values, or even an assumed constant waste loss efficiency for each process. Some other waste loss values were considered, but were rejected in favor of the data in Table 1.

Table 2 displays the estimated amount of fuel processed by each facility in a given year. These values were calculated from the reported amount of irradiated fuel processed by each facility in the monthly operating data (Gydesen 1992a). Using these values, it can be estimated that the T and B Plants processed 4.3% (2.7 metric tons), REDOX processed 18.0% (11.3 metric tons), and PUREX processed 77.7% (48.7 metric tons) of the total plutonium processed at Hanford.

Table 2. Percent Irradiated Fuel Reprocessed by Facility.

Year	T and B		
	Plants	REDOX	PUREX
44	100%	0%	0%
45	100%	0%	0%
46	100%	0%	0%
47	100%	0%	0%
48	100%	0%	0%
49	100%	0%	0%
50	100%	0%	0%
51	100%	0%	0%
52	33%	67%	0%
53	15%	85%	0%
54	39%	61%	0%
55	34%	66%	0%
56	1%	48%	51%
57	0%	29%	71%
58	0%	21%	79%
59	0%	16%	84%
60	0%	12%	88%
61	0%	17%	83%
62	0%	14%	86%
63	0%	17%	83%
64	0%	23%	77%
65	0%	23%	77%
66	0%	24%	76%
67	0%	0%	100%
68	0%	0%	100%
69	0%	0%	100%
70	0%	0%	100%
71	0%	0%	100%
No fuel was processed between 1972 and 1982.			
83	0%	0%	100%
84	0%	0%	100%
85	0%	0%	100%
86	0%	0%	100%
87	0%	0%	100%
88	0%	0%	100%

By multiplying the plutonium processed each year by the percent loss from the separation facility, the amount of plutonium discharged to the waste tanks can be estimated. The column labeled "Annual Maximum" of Table 3 shows the estimated maximum waste generated by the plutonium separation facilities at Hanford, which is estimated to be ≈ 951 kg of plutonium.

There are other sources of plutonium in the waste tanks, such as laboratories and the washing of contaminated materials. By far the most significant of these is PFP (Z Plant or 234-5Z). The purpose of PFP was to convert the plutonium nitrate solution from the separation facilities to metallic plutonium in a button form. Built in the late 1940s, PFP started operations in 1949, shut down in 1976, restarted in 1978, and has operated in various capacities since then.

Because PFP processed separated onsite plutonium as well as offsite plutonium, the waste generated at PFP is added to the waste from the separation facilities. PFP discharged its waste to burial drums or to cribs (to the ground) until 1973. In May 1973, the waste from PFP was diverted to tank farms because of a criticality concern in the cribs. The waste was sent to the 242-T Evaporator from 1973 until 1976 when the evaporator was shut down. With the restart of PFP in 1978, the waste was sent to the TX Tank Farm until 1981, when the PFP waste was diverted to the double-shell tanks.

According to located records, there were about 8 kg of plutonium discharged to the TX Tank Farm between 1973 and 1978, and ≈ 23 kg of plutonium discharged to the double-shell tanks after 1981 (see Table 4 and Figure 4). Added together, a total of about 31 kg of plutonium were discharged to the waste tanks from PFP. This information came from several different sources, including *Plutonium Reclamation Source Data* monthly records (Murphy 1973a through 1978), *Z Plant to 244-TX Transfer* data sheets (RHO 1982-1984, and RHO 1984-1985) and information received from PFP Engineering. As these values reflect only the records located, it is possible additional information exists. Therefore, these records may not be complete, and the waste contribution could be larger. The amount of plutonium estimated to be in Tank 102-SY and the amount of plutonium recovered from crib Z-9 casts some doubt on the 31 kg estimate. However, it is also possible that no additional discharges were made other than those located. Therefore, until other discharge information can be located, the 31 kg value will be used in this estimation.

An estimate of the total amount of plutonium waste in the Site high-level waste tanks is ≈ 981 kg, which consists of 950 kg from the separation processes plus 31 kg from PFP (see Table 3).

Table 3. Annual Reactor Plutonium Production and Plutonium Waste Generation.

Year	Plutonium Production in Metric Tons		Adjusted Plutonium Production (Metric Tons)	Metric Tons Plutonium Processed by Facility			Kilograms PFP Waste	Total Estimated Plutonium Waste		
	Annual Total	Cumulative Total		T and B Plants	REDOX	PUREX		Annual Maximum (kg)	Second Largest (kg)	Annual Average (kg)
44	0.00	0.00	0.00	0.00	0.00	0.00		0	0	0
45	0.06	0.06	0.06	0.06	0.00	0.00		5	4	4
46	0.21	0.27	0.21	0.21	0.00	0.00		15	14	13
47	0.14	0.40	0.14	0.14	0.00	0.00		7	6	5
48	0.14	0.55	0.14	0.14	0.00	0.00		4	4	4
49	0.18	0.73	0.18	0.18	0.00	0.00		5	5	5
50	0.28	1.01	0.28	0.28	0.00	0.00		11	10	9
51	0.39	1.40	0.39	0.39	0.00	0.00		13	13	9
52	0.69	2.09	0.69	0.23	0.46	0.00		28	24	13
53	0.82	2.91	0.82	0.12	0.70	0.00		18	17	12
54	1.19	4.09	1.19	0.46	0.72	0.00		44	27	19
55	1.37	5.47	1.37	0.47	0.90	0.00		38	35	25
56	1.96	7.43	1.96	0.02	0.93	1.01		73	55	27
57	3.03	10.46	3.03	0.00	0.89	2.14		35	35	23
58	3.29	13.75	3.29	0.00	0.68	2.60		67	19	11
59	3.54	17.29	3.54	0.00	0.55	2.99		20	19	11
60	4.25	21.54	4.25	0.00	0.49	3.76		74	55	21
61	4.42	25.96	4.42	0.00	0.77	3.65		23	21	14
62	4.24	30.20	4.24	0.00	0.59	3.65		31	27	18
63	4.21	34.41	4.21	0.00	0.74	3.47		82	36	17
64	4.64	39.05	4.64	0.00	1.09	3.55		61	24	17
65	4.52	43.57	4.26 (1)	0.00	0.96	3.30		40	28	18
66	3.50	47.07	3.24	0.00	0.78	2.46		38	30	14
67	3.86	50.94	3.86	0.00	0.00	3.86		52	19	14
68	3.24	54.18	3.24	0.00	0.00	3.24		26	15	12
69	2.45	56.63	2.45	0.00	0.00	2.45		46	16	10
70	1.84	58.47	1.84	0.00	0.00	1.84		27	27	10
71	0.72	59.19	0.72 (2)	0.00	0.00	0.72		8	5	3
72	0.46	59.65	0.00	0.00	0.00	0.00		0	0	0
73	0.47	60.13	0.00	0.00	0.00	0.00	2.0	2	2	2
74	0.63	60.75	0.00	0.00	0.00	0.00	3.0	3	3	3
75	0.49	61.24	0.00	0.00	0.00	0.00	2.1	2	2	2
76	0.48	61.72	0.00	0.00	0.00	0.00	0.7	1	1	1
77	0.57	62.30	0.00	0.00	0.00	0.00	0.2	0	0	0
78	0.51	62.80	0.00	0.00	0.00	0.00		0	0	0
79	0.53	63.33	0.00	0.00	0.00	0.00		0	0	0
80	0.58	63.91	0.00	0.00	0.00	0.00		0	0	0
81	0.05	63.96	0.00	0.00	0.00	0.00		0	0	0
82	0.50	64.46	0.00	0.00	0.00	0.00	0.1	0	0	0
83	0.77	65.23	0.67 (3)	0.00	0.00	0.67	0.1	10	7	3
84	0.58	65.81	0.67	0.00	0.00	0.67	6.3	16	13	10
85	0.70	66.50	0.67	0.00	0.00	0.67	5.4	16	12	9
86	0.38	66.88	0.67	0.00	0.00	0.67	5.6	16	12	9
87	0.38	67.26	0.67	0.00	0.00	0.67	2.4	12	9	6
88		67.26	0.67	0.00	0.00	0.67	1.8	12	9	5
89							0.3	0	0	0
90							0.2	0	0	0
91				Percent Plutonium Processed				0	0	0
92				4.3%	18.0%	77.7%	0.0	0	0	0
93							0.5	1	1	1
Totals:			62.70	2.70	11.27	48.73	31	981	662	407

Notes:

- (1) 528 kilograms of plutonium were processed offsite and therefore were subtracted from the 1965 and 1966 plutonium production years.
- (2) The separation waste from the plutonium produced after 1971 would go to the double shell tanks.
- (3) There are 4 metric tons of plutonium in the K basins yet unprocessed. The plutonium produced after 1971, less the 4 metric tons, was processed between 1983 and 1988.

Figure 4. Plutonium from the Plutonium Finishing Plant to Tank Farms.

Another fissionable material of criticality concern is ^{233}U . The thorium irradiation process resulted in the direct production of ^{233}U , which was then recovered by the PUREX process. The waste from the PUREX recovery process was discharged to the waste tanks. Because the recovery of ^{233}U from thorium was much more difficult than the separation of plutonium from uranium, the recovery efficiency was less: $\approx 95\%$. Approximately 45 kg of ^{233}U were discharged to the Hanford waste tanks from the 1966 and 1970 thorium campaigns.

Because of losses in the uranium recovery process, there is a significant amount of unrecovered uranium in the waste tanks from the processed reactor fuel. However, considering the small amounts of ^{235}U with respect to ^{238}U , which is not fissile, there is no criticality concern associated with uranium in the waste tanks. Therefore, uranium losses are not addressed in this calculation.

4.0 ASSUMPTIONS

Several assumptions were made in the compilation of this approximation. After the exposed fuel was removed from a reactor, it was usually left to cool before it was processed. The cooling time lasted anywhere from 30 days to a year or more. Generally, the cooling time was 90 to 180 days, being shorter during the early years at Hanford, and longer in the later years. An average cooling time of 4 months (120 days) is assumed in this calculation.

On rare occasions, PUREX reprocessed fuel that was not exposed in the Hanford reactors. However, because this amounted to only a few tons of irradiated uranium fuel and therefore only a few kilograms of plutonium in the fuel with only a few grams discharged to the waste tanks, it was ignored.

No information could be located for waste sent from PFP to the tank farms between the years 1978 and 1981. No waste discharge values were stated in the 1978 source documents, even though PFP restarted in 1978, and it may be that no waste was sent to the tank farms that year. Because only about 8 kg of plutonium were discharged to the tank farms between 1973 and 1976, it is assumed that little would have been discharged between 1978 and 1980. It is also assumed, for the purposes of this calculation, that the value of 31 kg discharged to the waste tanks is complete.

The final assumption made in this approximation is that the plutonium discharged into the waste tanks remains in the waste tanks. In the early days of Hanford, some waste was cascaded through the tanks, to allow solids to fall out, and discharged to the soil in cribs. Theoretically, the plutonium will precipitate out of a caustic solution. Because the tank waste is highly caustic, it can be assumed that most of the plutonium initially discharged into the waste tanks is still in the waste tanks. If this were not the case, then some plutonium could be in a few smaller transfer or holding tanks or could have ended up in cribs.

Table 4.
Plutonium from
the Plutonium
Finishing Plant
to Tank Farms.

Year	Plutonium (kg)
72	
73	1.974
74	3.045
75	2.066
76	0.692
77	0.229
78	
79	
80	
81	
82	0.109
83	0.109
84	6.343
85	5.443
86	5.556
87	2.373
88	1.768
89	0.306
90	0.151
91	
92	0.047
93	0.517
94	
Total	30.728

5.0 EVALUATION

Based on current calculations and approximations, there are three different estimates of the amount of plutonium discharged to the waste tanks from the separation processes:

- 951 kg based on the annual maximum waste loss approximation.
- 631 kg based on the annual second-largest waste loss approximation.
- 376 kg based on the annual average estimate.

The annual average is included mostly for perspective, because this is more or less the reported efficiency of the separation facilities. For nuclear criticality concerns, it is more important to have a conservative, or large, estimate to ensure safety.

Using the maximum reported monthly waste loss for a given year results in varying annual values for the discharged plutonium. Although this is probably not representative of the annual waste stream, the sum total is of interest for criticality concerns. The maximum annual waste loss method takes into consideration the largest reported monthly waste loss for a given calendar year along with the amount of plutonium processed during that year. This also takes the waste loss values from a reported source (Gydesen 1992a and the early monthly reports) as opposed to an assumption or estimation.

Adding the 31 kg of PFP plutonium to the separation plant estimate of 951 kg gives a total estimate of ≈ 981 kg of plutonium in the high-level waste tanks at Hanford. This is a conservative estimate because the processing plants probably recovered more than the maximum reported values reflect. However, it was not known exactly how much plutonium was sent to the waste tanks, as the recovery efficiencies were often based on reactor production values, which were sometimes uncertain and were adjusted only periodically. This would give inconsistent values for the plutonium recovery efficiency. Also, the laboratory methods for measuring plutonium concentration were sometimes not very accurate, shedding more doubt on the reported waste loss values.

Figure 5 provides the annual amount of estimated plutonium discharged to the waste tanks based on the maximum annual waste method. Figure 6 shows the same but is based on the second-largest annual waste loss estimate, and Figure 7 shows the average annual waste loss. Figure 8 shows the annual maximum estimate with an overlay of the operational status of the tank farms,

and an overlay of the relative volumes of the tank farms. This gives a perspective of the annual amount of plutonium discharged to the various tank farms, and which farms the plutonium could have potentially entered. The annual maximum waste loss method is probably the best choice in a conservative estimate of the total plutonium waste in the tanks, but the graph shown in Figure 5 may not represent the actual annual waste loss, because of high losses one year, and low losses in another. Figure 7 is probably more representative of the annual waste, even though the total may not be as reliable. Although the purpose of this calculation is to estimate the total plutonium waste, the annual amounts are shown to give a graphical perspective over all the Hanford years.

6.0 CONCLUSION

Although there were several assumptions made during the completion of this document, it still represents a maximum estimate of the amount of plutonium in the Hanford Site waste tanks at the present time, as needed for criticality considerations.

Figure 5. Annual Estimated Plutonium to Waste Tanks from the Annual Maximum Estimation Method.

Figure 6. Annual Estimated Plutonium to Waste Tanks from the Annual Second-Largest Estimation Method.

Figure 7. Annual Estimated Plutonium to Waste Tanks from the Annual Average Estimation Method.

Figure 8. Annual Plutonium Waste and Tank Farm Activity.

Because ≈ 67 metric tons of plutonium were produced at Hanford, 4 metric tons remain in unprocessed reactor fuel, and 0.5 metric tons were processed offsite, it is determined that ≈ 63 metric tons of plutonium were processed in the four plutonium separation facilities. Judging from the recovery rates of these processes, it can be concluded that ≈ 951 kg of plutonium would have been discharged to the high-level waste tanks from the separation facilities. When added to the estimated 31 kg of PFP plutonium also discharged to the waste tanks, a total estimate of ≈ 981 kg of plutonium is determined to be in all the Hanford Site high-level waste tanks.

To better define the plutonium value, the sampling of tank waste, as well as other methods for measuring the fissionable material content in the waste tanks, should be carried out. Also, with the continued declassification of Hanford production information, more accurate data on the processing waste streams may become available, allowing refinement of the calculations and fewer assumptions. Additional data and corrections are welcomed and will aid in the revision and re-issue of this document.

7.0 SOURCES

The following sources provided valuable advice, comments, and information during the research of this document:

- PFP (Z Plant) engineers and operators who provided information on PFP waste, how its plutonium content was measured, and the manner the waste was discarded.
- Tank farm engineers and operators who helped to follow the PFP waste stream from Z Plant to tank farms through the 242-T Evaporator, and into the TX Tank Farm.
- Evaporator and tank farm operators and engineers who explained how the 242-T Evaporator handled the PFP waste, how and where it was sent in the tank farms, and what happened with it when the evaporator was not operating.
- Engineers who aided with information on PFP waste sent to the cribs, and why the PFP waste was eventually diverted to tank farms.
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- Older and retired Hanford workers who worked at Hanford in some of the earlier years or are knowledgeable in areas of Hanford waste who gave insights into the waste management practices through the years at Hanford.

In addition to the resources above, the following documents were consulted:

- *Analysis of the History of 241-C Farm* (Agnew 1993)
- *PUREX Flowsheet - Reprocessing N Reactor Fuels* (Allen 1985)
- *A History of the 200 Area Tank Farms* (Anderson 1990)
- *A History of Major Hanford Facilities and Processes Involving Radioactive Material* (Ballinger 1991)
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