

Appendix C

Tritium Inventory

In this appendix several estimates using different assumptions are made of the total tritium inventory in weapons and available for weapons. The first, which is referred to as the "steady-state estimate," assumes that there was no change in the tritium inventory during the late 1970s. In other words, the amount produced equalled the amount lost through radioactive decay during this period. The tritium in the U.S. stockpile is produced at the Savannah River Plant. The second inventory estimate made assumes that the routine atmospheric releases of tritium from the tritium recovery operations at SRP are proportional to the amount of tritium processed (i.e., produced).

In an attempt to place upper and lower bounds on the tritium inventory estimate two additional estimates are also made using tritium release data from SRP.

Steady-State Estimate

The tritium production rate from FY 1977-FY 1980 is estimated to have averaged 2.2 ± 0.7 kg per year.¹ DOE statements² indicate that this was designed to offset losses due to radioactive decay. Thus a determination of the steady state tritium inventory in that period is found by setting the production rate equal to the rate of radioactive decay.³ Setting the production rate $P = 2.2 \pm 0.7$ kg per year yields a steady state tritium inventory $I = 40 \pm 13$ kg. The tritium production rate in FY 1981 is estimated to have been 2.6 kg and in FY 1982-84 averaged 10.6 kg per year (see Savannah River Production, Chapter Three). Thus, allowing for radioactive decay, the tritium inventory at the end of FY 1984 based on the steady state assumption is estimated to be 63 ± 20 kg.

Estimates Based on Atmospheric Releases of Tritium

The SRP production reactors have been producing tritium in quantity since 1956. A second estimate of tritium production at SRP is made by analyzing the tritium losses from the lithium target processing facility (the 200-H separations area). Tritium is recovered from Li-Al targets by heating the irradiated targets to high temperatures to drive out the tritium gas.

The combined atmospheric releases of tritium from the F and H separations areas at Savannah River through the year 1983 are presented in column 2 of Table C.1 and Figure C.1. These are routine releases, mainly from tritium processing in the 200-H area. An examination of these data indicates that the tritium releases during 1965-70 and 1974-81 were relatively low, and there were few if any dedicated tritium production runs during these years. Also, the tritium releases per megawatt-day of production during these periods are comparable, suggesting that the tritium release fraction from the separations area has remained relatively constant over the lifetime of the facility—at least through 1981.

It is assumed that in the years 1960-63 a single reactor was dedicated to tritium production and there was no incidental production of tritium in control rods, as occurred later on. Using the average thermal output for SRP reactors (see Table 3.2), the tritium production in this period was 7.92 ± 2.53 kg annually. The uncertainty is derived from including the possibility of tritium production in control rods, at a rate of 0.0008 g/Mwd of thermal output. Based on these assumptions, the annual tritium production is estimated in Column 3 of Table C.1. The total tritium production (uncorrected for radioactive decay) through 1984 is about 179 kg. Tritium has a half-life of 12.33 years; consequently, 5.5 percent of the existing inventory is lost each year through radioactive decay. As shown in the table, this quantity would have decayed by the end of 1984 to 79 ± 25 kg.

As seen from Table C.1 this method predicts that all reactors were dedicated to tritium production in 1958—that is, an estimated 25.7 kg of tritium was produced in 1958 compared to a maximum production of 26.2 kg, based on a thermal energy production of 2.1 million Mwd.⁴

Bounding Estimates

In an attempt to bound the estimates of tritium production a low estimate is made by assuming that there were no dedicated tritium runs prior to FY 1982. Here it is assumed that the production rate per reactor has remained at a constant of 0.002 g/Mwd through 1981,

1. This is accountants from about equal rates of production in control rods (0.001 g/Mwd) and in blankets and dischargeable targets during plutonium production operations.

2. There is a constant supply (of tritium) produced for reactor weapons in the stockpile. The tritium also decays. The quantity that you have in the stockpile has to have makeup to keep a constant quantity. Duane C. Sewell, ASDE in HASC, FY 1980 DOE, p. 30.

3. The vital role of tritium in the U.S. nuclear stockpile demands a minimum of (deleted) reactors be on line and available to meet steady state tritium makeup needs. Duane C. Sewell, ASOP in HASC, FY 1981 DOE, p. 133.

Continued production and processing of tritium is necessary just to maintain the supply need for the stockpile. Long Range Nuclear Weapon Planning Analysis or the Final Report of the DDALDOE Long Range Reservoir Planning Group, 15 July 1980, p. 66.

4. Setting $\frac{dI}{dt} = P - \lambda I = \left[P - \frac{0.0008}{T_{1/2}} \right] - 0$ where P is the rate of production, I is the inventory, λ is the radioactive decay constant, and $T_{1/2}$ is the radioactive half-life $T_{1/2} = 12.33$ years for tritium.

Table C 1
**Tritium Release and
 Estimated Tritium Production at SRP**

Estimates of Tritium Production and Inventory

Calendar Year	Routine Release to Atmosphere from F and H Separations Areas (10 ³ curies) ^a	Constant Release Fraction		Low		High	
		Annual Production (kg)	Inventory (kg)	Annual Production (kg)	Inventory (kg)	Annual Production (kg)	Inventory (kg)
1955	20	0.2	0.2	1.00	1.0	0.50	0.5
1956	420	4.9	4.9	2.45	3.3	7.35	7.6
1957	1120	12.8	17.1	3.65	6.7	15.51	22.3
1958	2250	25.7	41.2	4.20	10.4	28.35	48.6
1959	820	9.4	48.0	5.80	15.5	10.15	55.8
1960	645	7.4	52.6	6.25	20.7	10.94	53.4
1961	654	7.5	57.0	6.45	25.8	11.29	70.9
1962	736	8.4	62.0	6.35	30.6	11.11	77.9
1963	736	8.4	66.8	6.30	35.0	11.02	84.3
1964	963	11.0	73.9	6.45	39.4	12.18	91.6
1965	311	3.6	73.3	4.25	41.4	2.13	88.6
1966	301	3.4	72.6	4.40	43.4	2.20	85.9
1967	308	3.5	72.1	5.20	46.1	2.80	83.7
1968	411	4.7	72.7	4.95	48.4	4.95	84.0
1969	272	3.1	71.8	3.50	49.1	3.50	82.8
1970	246	2.8	70.6	3.00	49.4	3.00	81.2
1971	379	4.3	70.9	2.85	49.4	2.85	79.5
1972	530	6.1	73.0	3.50	50.1	10.21	85.1
1973	312	3.6	72.4	3.77	51.1	3.77	84.1
1974	189 ^b	2.2	70.6	3.82	52.0	3.82	83.2
1975	143 ^b	1.6	68.3	2.82	51.9	2.82	81.4
1976	125	1.4	68.0	4.05	53.0	4.05	80.9
1977	192	2.2	64.5	2.62	52.6	2.62	79.0
1978	182	2.2	63.1	2.42	52.1	2.42	77.0
1979	180	2.1	61.7	2.38	51.6	2.38	75.2
1980	200	2.3	60.5	2.90	51.6	2.90	73.9
1981	231	2.6	59.8	2.76	51.4	2.76	72.5
1982	257	10.8	67.0	10.79	59.1	10.79	79.1
1983	407	10.2	73.2	10.21	65.8	10.21	84.7
1984	-	10.2	79.2	10.21	72.2	10.21	90.0
Total Production		178.6		139.3		208.6	

^a Sources: C. Ashley, C.C. Ziegler, Releases of Radioactivity at the Savannah River Plant, 1954 through 1978, DPSPU 75-25-1, February 1980, p. 102. For 1979 the total atmospheric release from E, I, Duport, Environmental Monitoring in the Vicinity of the Savannah River Plant, Annual Report for 1979, DPSPU 80-31-1 was diminished by 160,000 curies, approximately the average release from reactors and the 400-D laboratory for years 1977 and 1978. For 1980 the total atmospheric release estimated from Radioactive Waste Management at the Savannah River

Plant, National Research Council, Washington, D.C., 1981, Fig. 7, p. 2 was diminished by 160,000 curies. Releases for 1981-83 from Savannah River Plant, Technical Reports DPSP 83-1-1, DPSP 83-1-1, and DPSP 84-1-1, cited in letter from Ernest Chaput, DOE, Savannah River Operations Office, to Thomas G. Cochran, 13 September 1984.

^b Excludes accidental releases: 470,000 curies released 2 May 1974; 182,000 curies released 31 December 1975.

with one half of the tritium produced in control rods, and the other half produced in blankets and dischargeable targets inside driver assemblies.⁴ The total production under this assumption would be 139 ± 46 kg through 1984. Decayed to the end of 1984, this would be about 72

± 24 kg. This surely underestimates the actual production since dedicated tritium production runs very likely were made in the 1950s to meet thermonuclear program needs. Also, it is known that there have been other tri-

⁴ This comparison assumes tritium produced in FY 1958 is produced in calendar 1958. Maximum tritium production = $(0.072) \text{ g/Mwd}$, where 0 g Pu (equivalent) per Mwd, and $1/72 \text{ g T} = 1 \text{ g Pu}$ (equivalent). This assumes no production in control rods.

⁵ During plutonium production runs prior to 1968 SRP reactors were fueled with uniform cores of natural uranium. It is unlikely, therefore, that dischargeable lithium targets were utilized during plutonium runs prior to 1968.

tium campaigns prior to 1980. One is reported to have occurred in 1972 and another probably occurred in 1963-64, when routine atmospheric releases peaked.

A high estimate of tritium production is found by first estimating the number of reactors dedicated to tritium production from the quantity of tritium released annually, and then calculating tritium production from the combined annual thermal output of the Savannah River reactors (from Table 3.2).

Here, it has been assumed that no reactors were dedicated to tritium production during the periods of low tritium release (1955, 1965-71, and 1973-81); one reactor was dedicated to tritium production during 1959-64, 1972, and 1982-84; two reactors in 1956; three in 1957, and five in 1958. In all years 0.001 g of tritium is assumed to have been produced per megawatt-day in control rods. Also, in later years, 1968-84, an additional 0.001 g of tri-

tium is assumed to have been produced in blankets and dischargeable targets in those reactors dedicated to plutonium production. As seen by the last two columns in Table C.1, these assumptions give a total production through 1984 of 209 ± 70 kg, and 90 ± 30 kg decayed to the end of 1984.

Summary

Based upon the calculations in this appendix and assuming no significant quantities of tritium produced since 1956 were burned, released, or sold, the best estimate of the tritium inventory at the end of FY 1984 lies in the range of 70 to 80 kg, with an uncertainty of ± 25 kg. Taking into account the loss of 5.5 percent of the inventory each year this inventory is the result of the cumulative production between FY 1955-84 of some 175 kg of tritium, with an uncertainty ± 60 kg.

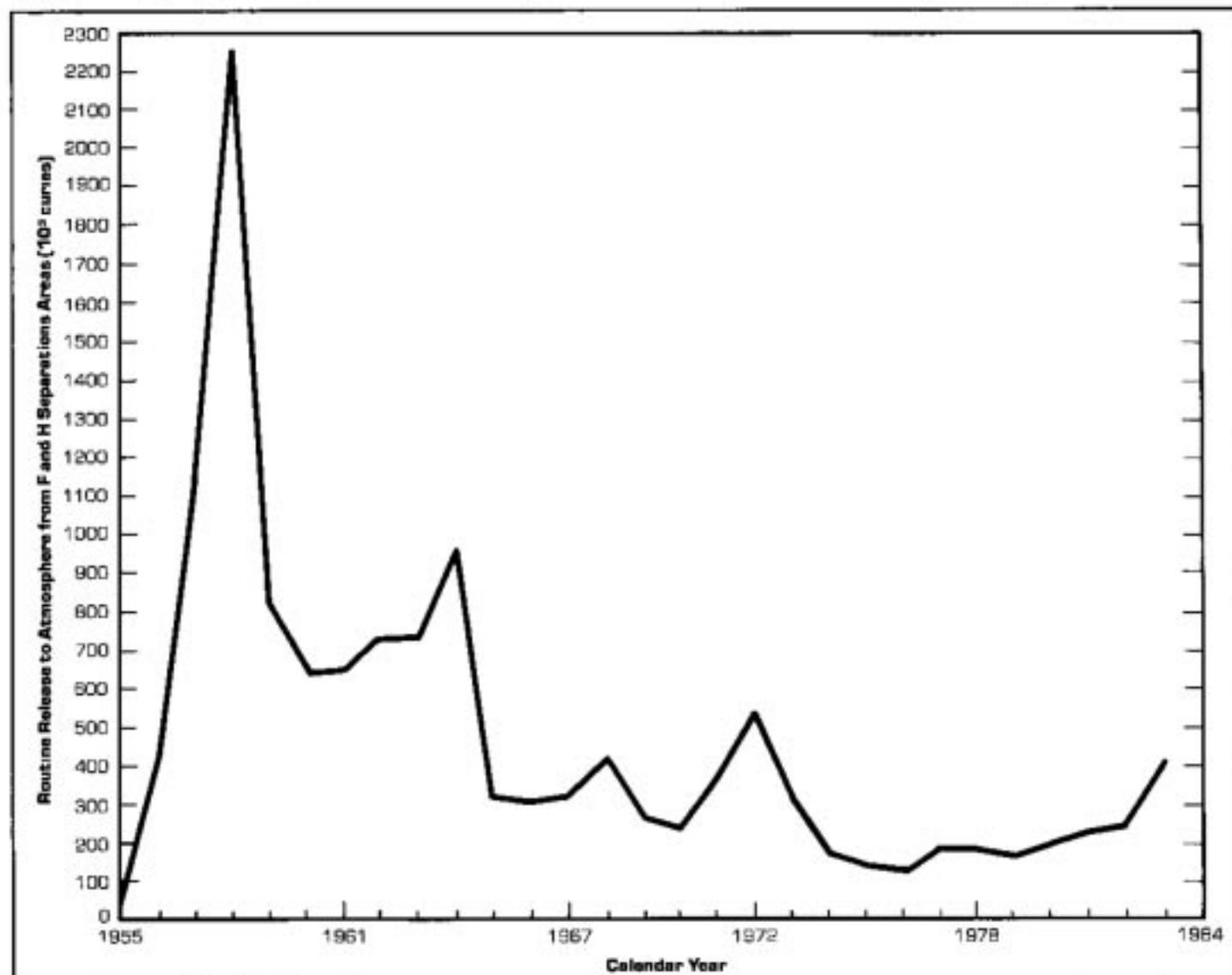


Figure C.1 Releases of tritium to the atmosphere at SRP

Appendix D

Inventory of Highly Enriched Uranium Allocated for Warheads

The highly enriched uranium in the nuclear weapons stockpile, including uranium currently available for new weapons, was produced in the gaseous diffusion plants prior to mid-1964.¹ "Weapon grade" uranium metal, commonly referred to as oralloy,² contains about 93.5 percent U-235. Based on materials balance considerations, the quantity of U-235 available for weapons is limited by AEC purchases of uranium concentrate (U₃O₈) between 1943 and the end of FY 1964 (see Table D 1, column 9, and Figure 3 4) and by the separative work production of the enrichment complex during this period (Table D 1, column 2 and Figure 3 5).

Most of the uranium enriched prior to FY 1965 was for warheads. If all the separative work performed by the enrichment complex prior to FY 1965 had gone into the production of oralloy, about 751 MT would have been produced (see Table D 1, column 6). From this amount it is necessary to subtract the equivalent oralloy production that did not end up in the warheads and the inventory allocated for warheads. The dominant corrections are uranium in process and in working inventory at the enrichment plants at the end of FY 1964, uranium used as fuel through 1964 in U.S. production reactors, naval propulsion reactors, and central station electric power reactors, and uranium used in weapons tests. Smaller amounts of uranium were used through FY 1964 in U.S. research and test reactors and were exported for civilian reactors and under military agreements with the United Kingdom and France.

A check on uranium feed requirements as derived from the reported separative work production is provided by the annual and cumulative uranium concen-

trate purchases (Table D 1, columns 8 and 9). The difference between uranium requirements and purchases provides the inventory of uranium concentrate at the end of FY 1964.³ Table D 1 indicates that there was an apparent stockpile of about 46,800 tons U₃O₈ at the end of FY 1964.⁴ But as will be seen, most of this was used to fuel the production reactors and additional quantities were in process.

Uranium in Process

The uranium in process at the gaseous diffusion plants at the end of FY 1964 is estimated to be no more than 10 percent of the annual separative work production, equivalent to 7.5 MT of oralloy product,⁵ and perhaps as much as several thousand MT equivalent of natural uranium feed.⁶ In addition, a four-month working inventory of enriched UF₆ equivalent to 5.16 million SWU or 25 MT of oralloy product is assumed to have been on hand at the diffusion plants at the end of FY 1964.⁷

Production Reactor Fuel

At Hanford, the amount of U-235 allocated to the production reactors through FY 1964 consisted of the U-235 consumed during that period plus the U-235 tied up in various stages of the fuel cycle.

Through FY 1964 eight Hanford graphite reactors accumulated 41 million Mwd of operation, producing an estimated 35 MT of plutonium (see Table 3 3). The Hanford production reactors were originally fueled with natural uranium passed once through. The plutonium was recovered from the irradiated fuel, but the uranium, containing perhaps 85 percent of the original U-235, was dis-

1. There has been no production of HEU for weapons since 1964. The Enriched Uranium Conversion Facility used to convert UF₆ to UF₄ at the Oak Ridge Y-12 plant received its last material in July 1964. This was processed prior to August or September 1964 at the latest at which time the plant was placed on standby. It is not expected to be restarted by DOE prior to FY 1980. Since this is the only facility for this purpose, DOE (AEC) has lacked the capability to convert highly enriched UF₆ to metal in quantity since mid-1964.

2. Oralloy was the code word used for U-235 or highly enriched uranium metal during the Manhattan Project. The name derives from Oak Ridge Alloy.

3. In 1951 the AEC set a goal of maintaining sufficient stock feed reserves for 20 months; Len Bowen, *A History of the Air Force Atomic Energy Program 1943-1953*, Vol. IV, p. 29. Bowen cites a memorandum from the MLC to the AEC, Supplemental Report on Fissionable Materials Production Plant Expansion Study, 29 September 1951; JCS 1823/73. This would suggest that some 54,000 tons of U₃O₈ should have been in stock feed reserve at the end of FY 1964 when uranium enrichment for weapons ceased.

4. In the calculations for Table D 1 it is assumed that tails accumulated since 1944 were stripped in the years FY 1956 and FY 1957 when the tails assays dropped temporarily to 0.183 and 0.199 percent respectively. This action would have been taken shortly after completion of the Paducah gaseous diffusion plant to increase the feed reserve at a time of rapidly increasing separative work production. At Paducah construction of 4 plants (C-31, C-33, C-35, and C-37) occurred during FY 1951-1955. Paducah was to process great quantities of depleted uranium from the "bottom" of the Oak Ridge cascade; Richard G. Hewlett and Francis Duncan, *A History of the United States Atomic Energy Commission II: Atomic Shield (1947-1952)*, U.S. AEC Report No. WASH-1215, 1972, p. 554.

5. 534 thousand SWU was in process at the end of FY 1960 and 434 thousand SWU at the end of FY 1970 with a production of 6 to 7 MSWU annually; Howard Hahn, DOE private communication with Milton M. Hoenig, September 1983.

6. At the end of FY 1962 there were 960 thousand SWU in process in some 8100 MT of natural uranium equivalent (0.2 percent tails); *Ibid*.

7. AEC planning estimates include a working inventory equivalent to about 4 months' production of enriched uranium for the purpose of meeting fluctuations in demand and of providing a working inventory of various assays. This working inventory is in addition to the plant's in process inventory; GAO Report to the Joint Committee on Atomic Energy of the United States, *Possible Transfer of the Atomic Energy Commission's Gaseous Diffusion Plants to Private Ownership*, 20 May 1969, p. 58, reproduced in JCAE Selected Materials Concerning Private Ownership of the AEC's Gaseous Diffusion Plants, June 1980, p. 333. DOE testified in 1978 that a working inventory of 9.0 MSWU is now required to operate the enrichment complex; NCST, *Fiscal Year 1983 Department of Energy Budget Review (Uranium Enrichment)*, Vol. VI, p. 197.

8. At Hanford the first three fuel separations facilities (T Plant, B Plant, and U Plant) used a hexamethylenephosphate process for extraction of plutonium and uranium was not recovered. Following startup of the REDOX Plant in August 1951, the U Plant was converted to recover the uranium from stored radioactive waste. The B and T plants were shut down in 1952 and 1956, respectively. From 1952 to 1958 the radioactive waste at Hanford was mined from the storage tanks and the U Plant was used for radioactive recovery. ERDA, *FFS Waste Management Operations, Hanford Reservation*, ERDA-1536, December 1975, pp. B 1-10 to 14.

Table D 1
Uranium Enrichment Activities FY 1944-FY 1964
Production of HEU Equivalent

FY	Enrichment ^a Production		Tails ^b Assay Percent	HEU Equivalent ^c Production		Feed ^d Requirements		Uranium ^e Purchases	
	MSWU			MTU		Thousand Short Tons U ₃ O ₈		Thousand Short Tons U ₃ O ₈	
	Annual	Cumulative		Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1944	-	-	-	-	-	-	-	4.81	4.81
1945	0.07	0.07	0.529	0.58	0.58	0.30	0.30	0.50	5.31
1946	0.25	0.32	0.529	1.59	2.17	1.06	1.36	4.10	9.41
1947	0.38	0.70	0.488	2.32	4.49	1.27	2.62	1.68	11.07
1948	0.39	1.09	0.515	2.45	6.94	1.52	4.14	2.01	13.08
1949	0.43	1.52	0.506	2.67	9.61	1.58	5.72	2.24	15.32
1950	0.50	2.02	0.495	3.07	12.68	1.73	7.45	3.06	18.38
1951	0.55	2.57	0.506	3.42	16.10	2.03	9.48	3.89	22.07
1952	1.54	4.11	0.447	9.05	25.15	4.17	13.65	3.86	25.73
1953	2.25	6.36	0.438	13.09	38.24	5.83	19.48	2.89	28.61
1954	4.53	10.89	0.368	24.37	62.61	8.60	28.08	4.69	33.30
1955	8.05	18.94	0.278	38.53	101.14	10.84	38.92	5.94	39.24
1956	13.72	32.66	0.163	35.47	136.61	0.0	38.92	10.43	49.68
1957	14.53	47.19	0.199	52.35	186.96	4.56	43.49	16.16	65.84
1958	14.85	62.04	0.297	73.04	262.00	21.49	64.98	26.37	92.21
1959	15.60	77.64	0.339	81.19	343.19	26.57	91.55	33.33	125.54
1960	16.11	93.75	0.337	83.64	426.83	27.23	118.77	34.58	160.12
1961	16.61	110.36	0.343	86.85	513.68	28.73	147.51	32.26	192.38
1962	16.23	126.59	0.341	94.66	599.34	27.86	175.36	29.36	221.74
1963	15.48	142.07	0.313	77.87	676.21	23.63	199.19	26.98	248.72
1964	15.48	157.55	0.285	74.90	751.11	21.42	220.61	18.68	267.40

a. James H. Hill and Joe W. Parks. *Uranium Enrichment in the United States*. CONF-750324-7, Energy Research and Development Administration. 5 March 1975. Figure 1, p. 13.

b. Tails assays after FY 1964 were: FY 1965, 0.197; FY 1966-71, 0.200; FY 1972-75, 0.300; FY 1976-79, 0.250; FY 1979-80, 0.200.

c. 94 percent U-235. Unit is metric tons of uranium metal (MTU). Enrichment of F kg of feed (assay x_1) produces P kg of product (assay x_2) and T kg of tails (assay x_3) with

$PV_2 = (x_2 - x_3)(F_0 - x_3)$. The number of separative work units (SWU) is $S = (V_1x_1 - V_2x_2) - (V_1x_1 - V_2x_2) - (V_3x_3 - V_4x_4)$ where $V_1x_1 = (1 - 2x_1) \ln(1 - x_1)$.

d. Assume tails stripping in FY 1955-1957. FY 1956: strip tails from FY 1945-FY 1953 requiring 13.72 MSWU and producing 35.5 MT HEU. FY 1957: strip tails from FY 1953-FY 1955 requiring 9.98 MSWU and producing 33.2 MT HEU.

e. See Table 3.15.

carded. In the early 1950s, the AEC began recovering the uranium from the fresh and stored processing waste, and the fuel cycle was closed.⁹ In order to maintain the reactivity of the plants, it became necessary to slightly enrich the fresh fuel.⁹ It is estimated to have taken approximately two years to recycle the spent uranium fuel—that is, two years to irradiate, cool, process, recover, and refabricate the uranium fuel.

Assuming the Hanford reactors used natural uranium feed and the uranium recovered from spent fuel was re-enriched to normal assay (0.711 percent U-235) with enrichment tails assay of 0.32 percent U-235,¹⁰ some 12,000 MTU of natural uranium feed (16,000 short tons U₃O₈ containing 88 MT U-235) were required to

operate the reactors to the end of FY 1964. Out of this, about 49 MT of U-235 were consumed in the eight reactors, and an additional 39 MT of U-235 ended up as enrichment tailings. A further two-year fuel supply would have tied up an additional 7800 MT of natural uranium (10,000 short tons U₃O₈ containing about 55 MT of U-235), since the Hanford reactors produced about 3 MT of plutonium per year, requiring some 1300 MT fresh fuel (9.2 MT U-235) for each metric ton of plutonium.

The five Savannah River heavy water reactors accumulated 24.5 million Mwd of operation through FY 1964, producing an estimated 23.7 MT of plutonium equivalent, including an estimated 90 kg of tritium (6.5 MT Pu equivalent).¹¹ The Savannah River reactors used

9. Hewlett and Duncan. *Atomic Shield*, p. 62.

10. The operating enrichment tails assay at the enrichment complex has been reduced from about 0.529 percent in the 1940s to 0.2 percent currently (Table D 1). From Table D 1, the average tails assay for FY 1944-FY 1964 was 0.32 percent, which was also the average value for the years FY 1950-FY 1964.

11. The plutonium production estimate is taken from Table 1, Appendix C, for the constant release fraction case (column 3).

HEU driver fuel in dedicated tritium runs. They used natural uranium or LEU fuel when producing plutonium until 1968 when HEU driver fuel was introduced.

Some 5600 MT of natural uranium feed (7300 short tons U_3O_8 containing 40 MT U-235) are estimated to have been required for operating the reactors during plutonium production to the end of FY 1964, allowing for enrichment of the recovered uranium in the gaseous diffusion plants. Of this, 22 MT of U-235 in natural or LEU fuel were consumed by the reactors, and an additional 18 MT of U-235 ended up as enrichment tailings. Allocation of a two-year fuel supply for each reactor would tie up an additional 1660 MT of natural uranium (2200 short tons U_3O_8 containing about 11.8 MT U-235), since in the SRP heavy water reactors some 830 MT of (5.9 MT U-235) natural uranium feed is required for each metric ton of plutonium produced.

The production of 90 kg of tritium through FY 1964 would have consumed 8.8 MT of U-235 in HEU driver fuel. Assuming a fuel cycle inventory in the reactors and in fresh and spent fuel of five HEU driver charges (8 MT U-235), the total HEU committed to the tritium production at SRP through FY 1964 contained about 15.6 MT U-235. It is assumed here that no HEU recovered by the Idaho Chemical Processing Plant was used for driver charges prior to FY 1965.

The N-reactor began operating at Hanford on 31 December 1963. The reactor requires about 800 MT of slightly enriched uranium (approximately 1 percent U-235) per year when operating in the weapon-grade plutonium production mode (6 percent Pu-240). It is assumed that by the end of FY 1964 some two years supply of fuel was committed, requiring about 1500 short tons U_3O_8 feed.

In sum, an estimated 18 MT of HEU (17 MT U-235) and some 41,000 short tons U_3O_8 were tied up in production reactor fuel requirements.

Naval Reactors

By the end of 1964, there were sixty-two nuclear powered naval vessels (fifty-eight submarines and four surface ships), driven by seventy-two naval reactors. In addition there were six land-based naval prototype reactors. Through the end of FY 1964, it is estimated that the

Navy had procured 180 reactor cores and performed less than ten refuelings.¹²

An estimated 185 naval reactor cores were processed at the Idaho Chemical Processing Plant by the end of FY 1984¹³ and approximately 8940 kg HEU containing 6974 kg U-235 was recovered.¹⁴ Hence the average naval core processed through FY 1984 yielded 48 kg HEU containing 38 kg U-235. The corresponding average fresh core is estimated to have contained about 90 kg HEU (97.3 percent U-235).¹⁵ Through the end of 1964, the fresh naval cores that were irradiated, discharged, and processed contained an estimated 70 kg HEU (97.3 percent U-235), on the average, assuming that only 40 percent of the original U-235 was destroyed.¹⁶

These data suggest that through FY 1964 some 13 MT of HEU (97.3 percent U-235) was required for fresh naval reactor fuel and less than 0.4 MT of U-235 was recovered from spent fuel.

Domestic Power Reactor Program

Prior to 1967 the Atomic Energy Act provided for Presidential determination as to the quantities of special nuclear materials that were to be available for distribution to licensed users within the United States and to nations having agreements for cooperation with the United States.

In 1954 the AEC undertook several actions designed to accelerate the development of civilian power reactors, including initiating construction of the Shippingport Atomic Power Station. This 68 Mwe pressurized water reactor achieved criticality in December 1957, becoming the first large-scale civilian nuclear power plant built in the United States.¹⁷ Also, in 1954, the AEC began development of several prototype reactors including boiling water, fast breeder, and an experimental sodium graphite reactor.¹⁸ Only four of these small experimental civilian power projects went online between 1956 and 1964.¹⁹

Early in 1955 the AEC launched the Power Demonstration Reactor Program designed to encourage private investment in larger scale nuclear power plants. Under the first two rounds, six power plants were undertaken and came on line between 1960 and 1965.²⁰ This was followed by the AEC's announcement in 1957 of a third round aimed at advanced reactor technologies. Four pro-

12. The procurement of new reactor cores as of the end of 1964 is estimated by extrapolated data for 1969 and 1974. On 5 May 1969 Admiral Kicker testified that the Navy had procured 297 reactor cores and conducted 66 refuelings. SAC FY 1970 DOE Part 4, pp. 3584-86.

On 25 February 1974 Admiral Kicker testified that the Navy had procured 409 reactor cores and conducted 124 refuelings. ICAR NNPP 1974, p. 5.

On 24 April 1979 Admiral Kicker testified that the Navy had procured 586 nuclear cores and performed 166 refuelings. JEC Economics of Defense Policy Part 2, p. 449.

13. This estimate is based on 175 refuelings conducted as of 4 March 1983 (HAC FY 1982 EWDA Part 7, p. 548) and 166 refuelings as of 24 April 1979 (JEC Economics of Defense Policy Part 2, p. 449) and an assumed fifteen months between refueling and chemical processing of the fuel.

14. These estimates are taken from the summary of ICFP reprocessing quantities (Volume III, Table 5) where it has been assumed that 2700 kg of HEU containing 2300 kg U-235 recovered in 1958-59 were SRP production reactor fuels.

15. The average burnup (U-235 fissioned) would be 47 percent and the average amount of U-235 consumed would be 60 percent.

16. As points of reference, in 1959 a highly enriched prototype submarine reactor core containing 40 kg of U-235 was being considered for export to France. ICAR Agreements for Cooperation for Mutual Defense Purposes June-July 1959, p. 51. The core of the first Brit-

ish submarine, the Drednought, contained 40 kg of HEU; John Simpson, *The Independent Nuclear State: The United States, Britain and the Military Atom* (New York: St. Martin's Press, 1983), p. 201.

17. A 60 Mw_e LWBR core replaced Shippingport's PWR core in 1977. The reactor was retired in 1982.

18. Experimental Boiling Water Reactor (EBWR) (boiling water, 100 Mw_e, 4 Mw_e, 1956-57); Experimental Breeder Reactor 2 (EBR-2) (sodium cooled, fast, 62.5 Mw_e, 20 Mw_e, April 1962-present); Sodium Reactor Experiment (SRE) (sodium graphite, 20 Mw_e, 5.7 Mw_e, 1957-64); Boiling Water Reactor Experiment No. 3 (BORAX 3) (boiling water, integral nuclear superheat, 20 Mw_e, 2.6 Mw_e, April 1962-64); Experimental Gas Cooled Reactor (EGCR) (gas cooled, graphite moderated, 64.3 Mw_e, 20 Mw_e, terminated 1960 prior to construction); Experimental Organic Cooled Reactor (EOCR) (organic cooled and moderated, 40 Mw_e, no electrical, terminated 1962 prior to operation).

19. EBWR, EBR-2, SRE, and BORAX-3.

20. Yankee-Rose (PWR, 110 to 175 Mw_e, 1959-present); Enrico Fermi (LMFER, 60.9 Mw_e, 200 Mw_e, 1963-67, retired 1973); Hallam (sodium cooled, graphite moderated, thermal reactor, 75 Mw_e, 245 Mw_e, 1962-64, retired 1964); Elk River (BWR, 22 Mw_e, 30.2 Mw_e, 1962-66, retired 1968); Piquet Power Station (organic-cooled and moderated, 45.3 Mw_e, 13.4 Mw_e, 1963-66, retired 1969); LaCrosse (BWR, 105 Mw_e, 50 Mw_e, 1967-present).

Table D 2
Amount of Highly Enriched Uranium (>90%) Supplied to Experimental Power Reactors through Fiscal Year 1964

Reactor ^a (MWt)	Startup	Shutdown	Enrichment (%)	Yearly U-235 Requirement (kg/yr)	Total U-235 Requirement (kg)	Reprocessor
EWBR (100)	1956	1967	93 ^a	—	30 ^a	Stored at SRP ^a
HWCTR (81)	1962	1964	93?	—	50 ^b	Stored at SRP ^c
VBWR (33)	1957	1963	90	—	35 ^d	INEL ^d
SRE (20)	1957	1964	93	—	150 ^e	Stored at SRP ^f
OMRE (12)	1957	1963	90	—	75 ^g	INEL
MSRE (6)	1965	1969	93	8 ^h	32 ⁱ	?
BORAX 1,2,3,5	1953	1965	90-93	—	50 ^j	INEL ^k but some stored there
EBR-1 (1.4)	1951	1962	90	—	150 ^k	INEL
HRE-1 (1)	1952	1954	93	1 ^h	5	?
HRE-2 (5)	1957	1961	93	5 ^h	25	?
LAPRE 1 (2)	1956	1957	93	—	4 ^l	?
LAPRE 2 (1)	1959	1959	93	—	4 ^l	?
EOCR (40)	terminated in 1962		93	—	55 ^m	INEL
				TOTAL	675	

^a The unabbreviated names of the reactors are listed in DOE Nuclear Reactors Built, Being Built, or Planned, TIC-8200-R annual.

^b Only the second core of the EBWR (inserted in early 1960s) contained HEU; M. T. Simnad, Fuel Element Experience in Nuclear Power Reactors, An AEC Monograph, Gordon and Breach Science Publishers, 1971, p. 345. About 27 kilograms of EBWR spent fuel enriched to 92 percent in uranium-235 are stored at SRP; DOE Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, RW-0008, September 1984.

^c The core contained 27 kilograms of uranium-235 in driver elements; R. R. Burn, Research, Training, Test, and Production Reactor Directory, American Nuclear Society, 1983, p. 777. Two cores were used in this reactor; JCAE, FY 1969 AEC, p. 308.

^d About 32 kilograms of uranium-235 in spent HWCTR spent fuel is stored at SRP; DOE Spent Fuel.

^e The first core used HEU; the reactor was modified in 1960 to low enriched uranium; M. T. Simnad, Fuel Element, p. 349. In the early 1960s about 33 kg of U-235 was recovered from VBWR spent HEU at the Idaho reprocessing facility; AEC Annual Report to Congress, 1964, p. 51.

Source: David Abright, private communication.

^f Only the second core of the SRE reactor contained HEU; M. T. Simnad, Fuel Element, p. 465. The amount is estimated (see footnote f).

^g Spent fuel from the SRE reactor containing 143 kg of U-235 and enriched to 92 percent is stored at SRP; DOE Spent Fuel. It is assumed that this is the entire core.

^h Three cores were fabricated for the OMRE reactor; JCAE, FY 1965 AEC. Each core contained about 25 kg of U-235; M. T. Simnad, Fuel Element, p. 437.

ⁱ This is a rough estimate assuming that for each MWt, one kg of U-235 is required each year.

^j Assumes only one core.

^k It is estimated that BORAX 1 and 2 contained about 15 kg of U-235 and BORAX 3 contained a little less than 15 kg of U-235; JCAE, Accelerating Civilian Reactor Program, 1956, p. 54. BORAX 5 is estimated to have required about 20 kg of U-235, most of which is currently stored at INEL; DOE Spent Fuel.

^l The EBR 1 used three cores each containing about 50 kg of U-235; M. T. Simnad, Fuel Element, p. 516.

^m JCAE, Accelerating Civilian Reactor Program, 1966, pp. 54-57.

ⁿ R. R. Burn, Research, Training, p. 658.

jects in the 15 to 60 Mwe range were undertaken and came on line between 1962 and 1964.²¹

In addition to the AEC and cooperative development programs, seven privately funded reactor projects came on line between 1957 and 1966.²²

The fuel, furnished by the AEC for all of these reactors through FY 1964 is estimated in Tables D 2, D 3, and D 4 to have required about 3 MT of U-235 contained in HEU (greater than 90 percent U-235) plus lower enriched uranium requiring about 4000 short tons U₃O₈ feed and 1.7 million kg SWU. These fuel requirements are equivalent to 12.6 MT HEU (93.5 percent U-235) plus 2000 short tons U₃O₈.²³

Research and Test Reactors

Through 1964 there were nine AEC-owned civilian, and ten AEC-licensed, research and test reactors with rated power levels greater than five Mw_e (see Tables D 5 and D 6). All of these reactors operated using HEU. The fuel requirement through FY 1964 for these together with the smaller reactors (1 to 5 Mw_e) is estimated in the tables to be 2.8 MT of U-235, equivalent to 3 MT of HEU (93.5 percent U-235).

There were eight other safety research and test reactors prior to 1965, operating either under transient power conditions or at power levels below one Mw_e. The fuel requirements for all of these were too small to have con-

21. Pathfinder (BWR, 190 Mw_e, 38.5 Mw_e, 1963-67); Canibus-Vigilante Tube Reactor (PWR, 17 Mw_e, 1963-67); Peach Bottom (EPWR, 113 Mw_e, 40 Mw_e, 1969-1974, retired 1974); Big Rock Point (BWR, 249 Mw_e, 48-75 Mw_e, 1962-present).

22. Vallecitos BWR (23 Mw_e, 5 Mw_e, 1967-62); Dresden 1 (PWR, 790 Mw_e, 184 to 320 Mw_e, 1958-78, retired 1964); Sastot (PWR, 23.5 Mw_e, 3 Mw_e, 1962-72); Indian Point 1 (PWR, 615 Mw_e, 190 Mw_e, nuclear supplied), 265 Mw_e, 1962-74, retired 1980; Humboldt Bay (BWR, 242 Mw_e, 40 to 65 Mw_e, 1962-76, retired 1983); ESADA Vallecitos Superheat Reactor; 15 Mw_e, 1963-67).

23. The 4000 short tons U₃O₈ and 1.7 million kg SWU could have been utilized to produce 8.7 MT HEU (93.5 percent U-235) from 2000 short tons U₃O₈ operating the enrichment plant at 0.32 percent tails assay with 2000 short tons U₃O₈ left unenriched.

Table D 3
**Amount of Highly Enriched Uranium (>90% U-235) Supplied to
 Civilian Power Reactors Through Fiscal Year 1964**

Reactor	Power (MWt)	Startup	Shut Down	Enrichment (%)	Uranium-235 Requirement Through 1964 (kg)	Total U-235 Requirement (kg)	Reprocessor
Shippingport	236	1957	1982	92	680 ^a	1020 ^a	INEL ²⁶
Indian Point 1	615	1962	1980	93	1100 ^b	1100	West Valley ^c
Elk River	58	1962	1968	93	344 ^b	344 ^b	Italy, but large amount stored at SRP ^d
Pathfinder	190	1963	1967	93	50 ^d	100 ^d	INEL ^e
Peach Bottom	115	1966	1974	93	220 ^f	440 ^f	Stored at INEL ^g
TOTAL					2,390	3,000	

- a. The first core used four seeds containing 345 kg of U-235 and the second core used two seeds each containing 350 kg of U-235; M T Simnad, *Fuel Element Experience in Nuclear Power Reactors*, An AEC Monograph, Gordon and Breach Science Publishers, 1971, p. 211 and F. Duncan and J. M. Holl, *Shippingport: The Nation's First Atomic Power Station*, History Division Department of Energy, undated, available in HASL NNPP-1983. The second seed of the second core was not fabricated before the end of FY 1964; Duncan, *op. cit.* The seeds from the first core were most likely reprocessed at INEL. It is unclear what happened to the seeds in the second core, although it can be expected that they will (or have been) reprocessed at INEL.
- b. Only the first core of Indian Point 1 used HEU fuel; M T Simnad, *Fuel Element*, pp. 286-289.
- c. Almost all of the spent HEU fuel was reprocessed at West Valley in 1968; G. Rochlin, et al., *West Valley: Remnant of the AEC*, *Bulletin of the Atomic Scientists* January 1979; table 2.
- d. Two cores were fabricated for the Pathfinder reactor, although the second core was not fabricated until a few years after FY 1964; JCAE, FY 1965 AEC; JCAE, FY 1967 AEC. Each core contained 50 kg of U-235; M T Simnad, *Fuel Element*, pp. 405-6.

- e. Not all of the HEU fuel from the Pathfinder reactor has been reprocessed. About 50 kg of slightly irradiated fuel is currently stored at INEL; DOE, *Spent Fuel*, RW-006, September 1984.
- f. Two cores were fabricated for the Peach Bottom reactor; H L. Bray and H G. Olson, *Fort St. Vrain Experience*, *Nuclear Energy* 22, 2 (April 1983): 120. Each core contained about 220 kg of U-235; M T Simnad, *Fuel Element*, p. 115. Because the second core was inserted after 1968, it is assumed that only one core was fabricated by the end of FY 64; *Operating History of U.S. Nuclear Power Reactors*, Appendix 4, JCAE, FY 1970 AEC, Part 2, p. 1561.
- g. At the end of 1983 Peach Bottom spent fuel containing about 330 kg of HEU, of which about 220 kg is U-235, is stored at INEL; DOE, *Spent Fuel*.
- h. One core was inserted into the Elk River reactor and another was being fabricated in March 1964; JCAE, FY 1965 AEC, p. 781. Each core contained 172 kg of U-235; M T Simnad, *Fuel Element*, p. 378.
- i. At the end of 1983 about 190 kg of 83 percent enriched uranium spent fuel from the Elk River reactor were stored at SRP; DOE, *Spent Fuel*. In the 1970s a small amount of Elk River fuel was reprocessed at the ITREC facility in Italy; S. Cao et al., *Italian Experience with Pilot Reprocessing Plants*, IAEA-CN-36/004, May 1977.

Source: David Albright, private communication.

tributed significantly to the estimate of or alloy production made here.

Rocket Propulsion Reactors

Under Project Rover, a joint NASA-AEC program to develop a nuclear propulsion reactor for space travel, there were seven nuclear rocket reactor experiments conducted between 1960 and 1965. These reactors had power levels ranging between 100 Mw_t and 1070 Mw_t. The combined power of all seven was 4820 Mw_t. Two additional experiments were conducted after 1965 (1400 Mw_t (1967) and 4200 Mw_t (1968)). DOE ultimately recovered 2,819 MT U-235 at the ICPP from fuel used in Project Rover.²⁴

Exports for Foreign Civilian Reactors

Through 1964 the United States exported 1.9 MT of HEU to foreign research reactors, containing 1.6 MT of U-235.²⁵ During this same period only 97 kg of uranium

containing 80 kg U-235 were returned to the United States.²⁶

Consumption in Nuclear Weapons Tests²⁷

The United States conducted 374 nuclear tests through 1964 plus three joint U.S.-UK tests (see Appendix B). These tests correspond to about 1.4 percent of the current nuclear weapons stockpile of about 26,000 warheads. Thus the total HEU expended in tests conducted prior to the end of 1964 was about 10 MT (about 20 kg HEU per warhead).

Weapon Grade Uranium Inventory in 1964

The inventory of weapon grade uranium (93.5% U-235) at the end of FY 1964, when or alloy production ceased, can now be estimated by subtracting the uranium used in other activities from the purchases before FY 1965. According to Table D 7 a stockpile of some 657 MT (93.5 percent U-235) was available for weapons at the

24. ICPP, private communication to David Albright, 1986. See also *Nuclear Fuel* (27 August 1984): 13. Earlier it was reported that there were 2800 kg of unprocessed Rover fuel; SASG, FY 1979 DOE, p. 46.

25. Donald P. Hodel, Secretary of Energy, *Yearly Export Totals and Summary of Totals: Exports of Low Enriched Uranium, High Enriched Uranium, Uranium-233, Plutonium and Heavy Water*, January 1, 1954 Through February 28, 1983. Enclosures 1 and 2 in a letter to Representative Richard Ottinger, 10 May 1983.

26. DOE, NMMSS Report U.S. Origin Impacts, (computer printout) enclosure in letter from Robert A. O'Brien, Jr. to Thomas B. Cochran, 13 December 1984.

27. Perhaps a dozen nuclear weapons were lost to accidents. See *U.S. Nuclear Weapons Accidents: Danger in Our Midst*, *The Defense Monitor*, Volume X, Number 5, 1981.

Table D 4
**LEU-Fueled Power Reactors: Domestic Separative Work
 Requirements (SWU) Through Fiscal Year 1964**

Reactor ^a	Fuel Charge ^b (kg Uranium)	Enrichment ^b (%)	Number of Cores Produced ^c	Total (kg SWU)	Feed (MTU)
Indian Pt 1	20,000	3.4	1	79,960	158
Yankee-Rowe	20,800	3.4	2	166,320	328
	20,900	4.0	3	317,310	588
Big Rock Pt	11,700	3.2	3 ^e	127,860	259
Dresden 1	51,500	2.0	2	162,120	442
Humboldt Bay	13,840	2.6	1	36,040	78
	13,840	2.2	0.5 ^d	13,425	34
La Crosse	8,600	3.63	1	37,940	73
Bonus Boiler	2,810	2.4	1	6,380	15
Superheater	1,790	3.25	1	6,680	13
Halleim	29,200	3.6	1	127,230	245
	29,200	4.9	1	197,400	342
Piqua	6,550	1.8	1	9,610	26
Carolina-Virginia Tube Reactor	3,280	1.75	2	8,120	24
Pathfinder Boiler	6,560	2.2	1	12,740	32
EBR-2	350	49.0	2	68,840	88
Fermi	2,000	25.6	2	195,410	258
EBWR	5,800	1.44	1	4,440	16
EVESR	2,200 ^g	5.4 ^h	2 ^f	34,040	59
EBOR	160 ^g	62.5 ^h	1	20,430	26
EGCR	9,860 ^g	2.55 ^h	1	24,840	56
Saxton	1,270	5.7	1.5	15,780	26
SRE	3,000	2.8	1	8,630	19
	3,000	5.2	1	21,980	37
VBWR	800	3.0	1	2,630	6
NS Savannah	?	?	1	?	?
			TOTAL	1,706,365	3,247

a. The unabbreviated names of the reactors are contained in DOE Nuclear Reactors Built, Being Built, or Planned. DOE/TIC-9200-annual.

b. Unless otherwise noted the source is M. T. Gimard, Fuel Element Experience in Nuclear Power Reactors, an AEC Monograph. Gordon and Breach Science Publishers, 1971.

c. Unless otherwise noted, the number of cores whose uranium was enriched prior to the end of FY 1964 is based on AEC tables listing power reactor fuel elements fabricated through various years that are in the hearings of the JCAE authorizing AEC legislation or reporting on the development of the atomic energy industry.

d. Partial inserts of the core.

e. R. R. Burn, Research, Training, Test, and Production Reactor Directory. American Nuclear Society 1963, p. 649.

f. Appendix 4, Operating History of U.S. Nuclear Power Program. In JCAE FY 1970 AEC Part 2.

g. R. R. Burn, Research, Training, p. 987.

h. AEC, Costs of Nuclear Power. TID-8531, January 1961.

Source: David Albright, private communication.

end of FY 1964.

This estimate, 657 MT, is judged to have an error of about 10 percent and should be taken as an upper limit on or alloy production. It is consistent with a previous report that "more than half a million kilograms (500 MT) of weapon-grade uranium were produced in the United States since 1945."²⁸

Removals 1964-90

Since FY 1964, the inventory of HEU available for weapons has been further reduced by fuel requirements

of the Savannah River production reactors, fuel needs for research and test reactors, uranium exports to Britain and France for military purposes, and nuclear tests.

Presently highly enriched uranium metal is provided from the current DOE inventory at the Y-12 plant for nuclear weapons components and for fuels for the Savannah River production reactors, and DOE research and test reactors. It is assumed this has been the practice ever since the AEC placed its Enriched Uranium Conversion Facility (for conversion of UF_6 to UF_4) on standby in early FY 1965 and will continue until 1988-90 when the facility is scheduled to be reactivated.

28. John McPhee, *The Curve of Burning Energy* (New York: Farrar, Straus & Giroux, 1974), p. 21.

Table D 5
**Amount of HEU (>90%) Required in DOE Civilian Research
 and Test Reactors (>1 Mwt)**

Reactor* (Mwt)	Startup	Shutdown	Enrichment (%)	Yearly U-235 Requirement (kg/yr) ^b	U-235 Requirement Through 1964 (kg)	Total U-235 Requirement Through 1984 (kg)	Reprocessor
ATR (250/125) ^c	1967	—	93	175 0 ^d	—	3900 ^d	INEL
HFIR (100)	1965	—	93	140 0 ^e	—	2800	SRP
HFBR (40)	1965	1982	93	40 0 ^f	—	720	SRP and INEL ^g
(60)	1962	—	93	59 0	—	120	SRP and INEL ^g
ORR (30)	1959	—	93	18 0	130	490	SRP and INEL ^h
OWR (8)	1956	—	93	5 4	49	160	INEL
BMRR (3)	1959	—	90-93	0 2	1	5	?
BSR (2)	1950	—	93	0 5	8	18	SRP and INEL
TSR-2 (1)	1960	—	93	0 2	1	5	SRP and INEL
ETR (175)	1957	1972 ⁱ	93	180 0 ^j	1440	2700	INEL
MTR (40)	1952	1970	93	40 0 ^f	520	720	INEL
ALRR (5)	1965	1977	93	5 0 ^f	—	60	SRP
CP-5 (5)	1954	1979	93	5 0 ^f	55	125	Some at SRP
SER (5)	1961	1970	93	5 0 ^f	20	45	INEL
Retired Reactors (1 to 5 Mwt)					70	120	INEL and SRP ^g
				TOTAL	2,294	11,988	

* The unabbreviated names of the reactors are listed in U.S. Department of Energy Nuclear Reactors Built, Being Built, or Planned, DOE/TIC-6200-R47, August 1993.
 a Unless otherwise noted the source of this data is letter to K. L. Masters, DOE, from J. E. Moses, Argonne National Laboratory, Subject: RERTR Program Reactor Summary—September 1982, 22 September 1982.
 b The ATR only ran at 250 MWt in 1967. In 1968 it ran at about 220 MWt and after that the power was reduced gradually to about 120 or 130 MWt by 1975 (INEL personal communication, May 1984).
 c Each year the ATR requires about 150 to 175 new fuel elements, each containing 1.075 kg of U-235 (INEL, personal communication, May 1984). If the average power of the ATR is 125 MWt, about 1.3 to 1.5 kg U-235 is required per MWt per year.
 d Using the information in footnotes b and c and assuming a linear decrease in power from 1968 until 1975, the ATR has required about 3900 kg of U-235 through 1984.
 e HFBR staff, Oak Ridge, Tennessee, personal communication, May 1984. An independent estimate was derived from the average amount of spent fuel sent to SRP for reprocessing. From 1978 through 1984 the average amount of HEU returned was 120 kg of HEU. The average burnup of the U-235 in the fuel was 30 percent (R. R. Dum, Research, Training, Test and Production Reactor Directory, American Nuclear Society, 1983). This burnup corresponds to the spent fuel having an enrichment of about 95 percent U-235 or containing on average about 100 kg of U-235. Since about 30 percent of the original U-235 is burned up (either it is fissioned or converted into U-236), the annual need for fresh U-235 for HFBR is about 140 kg of U-235.
 f This is a rough estimate of the amount of U-235 required yearly, based on assuming that one kilogram of uranium-235 is needed each year per MWt for the HFBR (Moses, RERTR Program).
 g Due to a ban on shipments of spent fuel through New York City, no fuel was shipped off-site from 1975 until 1985. The spent fuel from this reactor is being sent to INEL. Once the current backlog of spent fuel is sent to INEL, it will probably be sent to SRP. Previous to 1975 or 1977 the spent fuel was most likely sent to SRP.
 h Starting in 1982 ORR spent fuel was sent to INEL for reprocessing. During 1985 or early 1986 shipments to SRP should resume. From 1978 through 1991 ORR sent on average 15 kg of spent HEU per year to SRP for reprocessing.
 i In 1972 ETR was shutdown to install a sodium loop for fast breeder reactor research. After 1972 until the reactor was shutdown in 1982 it used very little HEU fuel. The ETR may be restarted and will require about 180 kg of U-235 per year.
 j INEL, personal communication, May 1985.

Source: David Albright, private communication.

The SRP reactors, as noted previously, were converted to HEU driver fuel for plutonium production in 1968. No dedicated tritium runs occurred between 1965 and 1972. From FY 1969 through FY 1984 the SRP production reactors operated 25.5 million Mwd; an additional 13.5 million Mwd are projected to accumulate between FY 1985 and FY 1990. Of the total 39 million Mwd, an estimated 7 million Mwd is generated in reactors dedicated to tritium production and "high flux" operation and the remaining 32 million Mwd is in reactors producing plutonium, where the power distribution is about 75 percent in the highly enriched drivers and 25

percent in the depleted uranium targets. Consequently, highly enriched driver fuel contributes some 31 million Mwd of operation between FY 1965 and FY 1990, consuming an estimated 38 MT U-235 (41 MT weapon-grade HEU equivalent).

An additional 19 MT U-235 (20 MT weapon grade HEU equivalent) are probably tied up in the fuel cycle (in and out of reactor inventories). However, this must be reduced by 8 MT, the amount of U-235 assumed to be in the fuel cycle pipeline in FY 1964.²⁹

A considerable portion of the HEU needed to fuel the SRP production reactors since FY 1964 has come from

²⁹ Assume a three-year pipeline. An SRP reactor charge contains up to 1.6 MT of U-235 and some 2.6 MT of HEU was scheduled for recovery in FY 1980; NRC, FY 1980 DOE, p. 752.

Table D 6
**Amount of HEU (<90%) Required in NRC (or AEC)-Licensed
 Reactors (<1 Mwt)**

Reactor ^a (Mwt)	Startup	Shutdown	Enrichment (%)	Yearly U-235 Requirement (kg/yr) ^b	U-235 Requirement Through 1964 (kg)	Total U-235 Requirement Through 1984 (kg)	Reprocessor ^c
NBSR (20)	1967	—	93	13 0	—	230	SRP
MURR (5)	1966	1974	93	9 0 ^e	—	90	?
(10)	1974	—	93	19 0	—	190	SRP
MITR (5)	1956	—	93	5 4	38	146	SRP or INEL
UCNR (5)	1961	—	93	5 4	22	130	SRP
GTRR (5)	1964	—	93	1 9	2	40	SRP?
FNR (2)	1957	—	93	3 3	26	80 ^d	SRP
RINSC (2)	1964	—	93	2 5	3	53	SRP
UVAR (2)	1960	—	93	1 3	7	33	SRP
ULR (1)	1974	—	93	0 2	—	2	not applicable
NASA-TR (60)	1963	1974	93	30 0 ^e	60	330	INEL and SRP ^f
WTR (60)	1959	1962	93	—	80 ^g	80 ^g	INEL
GETR (30)	1958	1966	93	30 0 ^h	210	270	INEL
(50)	1966	1977	93	50 0 ^h	—	550	INEL
BAWTR (6)	1964	1971	93	6 0 ^h	6	42	?
Retired Reactors (1 to 5 Mwt)				—	50	150	INEL ⁱ and SRP
TOTAL					504	2406	

- * The unabbreviated names of the reactors are listed in DOE, *Nuclear Reactors Built, Being Built, or Planned* DOE/TIC-8200-R47 August 1983.
- a Unless otherwise noted the source is letter to K. L. Matern DOE from J. E. Meeks Argonne National Laboratory Subject: REPTR Program Reactor Summary—September 1982 22 September 1982.
- b Unless otherwise noted the source is R. R. Burn Research, Training, Test, and Production Reactor Directory American Nuclear Society 1983.
- c Scaled.
- d The Ford reactor converted to low enriched uranium fuel in the early 1980s.
- e This estimate of the yearly requirements of uranium-235 for the NASA-TR is derived from the average annual amount of uranium-235 recovered from its spent fuel at

Source: David Albright, private communication.

SRP and INEL and the enrichment of the recovered HEU (Annual Report to Congress of the Atomic Energy Commission for the years 1964, 1965, and 1967 and Major Activities in the Atomic Energy Programs January-December 1966 January 1967).

- f Annual Report op cit After 1967 it is assumed that half of the U-235 was recovered at SRP and half at INEL.
- g Annual Report to Congress of the Atomic Energy Commission for 1964 p. 61.
- h Rough estimate based on assuming 1 kg U-235 per year per Mwt (Meeks REPTR Program 1).
- i Some of the spent fuel from the IRL reactor was reprocessed at INEL (Annual Report op cit 1964 1966).

uranium recovered from naval (and research) reactor spent fuel, primarily in Idaho. Through FY 1984 28.8 MT of uranium containing 22.8 MT U-235 were recovered at ICPP, and perhaps as much as 25 MT U-235 (27 MT weapon grade HEU equivalent) will be recovered through 1987. An additional 4 MT HEU will be recovered at SRP from research reactor fuel. This suggests that possibly a total of some 21 MT of U-235 will be withdrawn from the HEU inventory to meet SRP reactor driver fuel requirements between FY 1965 and FY 1990.

About 15 to 20 MT of uranium from the HEU stockpile will be needed to supply domestic and foreign research and test reactors between FY 1965 and FY 1990 (see Table D 7).

The United States has supplied approximately 9 (or 5) MT³⁰ of HEU to the United Kingdom for submarine reactors and weapons under the U.S./UK Defense Agreement signed in 1958. If the HEU was supplied in metal form it would have come from pre-1964 production HEU stocks. If it was supplied as UF₆, it could have been from HEU enriched after 1964. In addition, the United States committed itself in May 1959 to supply France with up to 0.44 MT of enriched uranium "for use in the development and operation of a land-based prototype submarine nuclear propulsion plant"³¹. Up to 0.3 MT was to be enriched to 90 percent in the isotope U-235, with the remainder enriched up to 20 percent.³²

Finally, some additional 370 nuclear tests (includ-

30 Nine MT is based on the assumption that the U.S./UK treaty arrangement called for the exchange of 1.76 kg HEU for each kg of plutonium; 5 MT assumes an exchange ratio of one.

31 ICAE, *Agreements for Cooperation for Mutual Defense Purposes*, June/July 1959, pp. 12-72, 73.

32 U.S. Department of State memorandum to the American Embassy Paris, 7 May 1959.

Table D 7
Estimate of U.S. Stockpile of Weapon-Grade Uranium (1984)

Activity	HEU (93.5% U-235) Equivalent (MTU)	U ₃ O ₈ (thousands short tons)
Through FY 1964		
Uranium Purchases (FY 1943-FY 1964)		266.6
Enrichment Plant Production (FY 1943-mid-FY 1964)	751.1	-220.6
In Process	-7.5	-
Working inventory	-26.0	
Production Reactors	-18.0	-41.0
Naval Reactors	-13.0	
Domestic Power Reactor Program	-12.6	-3.0
Research and Test Reactors	-3.0	
Rocket Propulsion Reactors	-3.0	
Exports for Foreign Civilian Reactors	-1.6	
Weapons Tests	-10.0	
Subtotal - End FY 1964	approx 657.0	approx 2.0
FY 1965-90		
SRP Driver Fuel Consumed in Reactors	-41.0	
Additional Fuel Cycle Inventory	-12.0	
U-235 Recovered at ICPP & SRP	27.0	
SRP Subtotal	-26.0	
Domestic and Foreign Research and Test Reactors	-15.0 to -20.0	
Weapons Tests	-10.0	
Exports Under Military Agreements	-0.4 to -3.4	
Subtotal (FY 1965-90)	-51.4 to -65.4	
Available for Weapons	592 to 605	

ing 14 joint U.S./UK tests) were announced during the 1965 through FY 1984 period, requiring an estimated 10 MT of HEU.

In sum, the additional drawdowns of the HEU stockpile through FY 1990 total some 51 to 65 MT weapon-grade HEU (93.5 percent U-235) equivalent, as indicated in Table D 7, leaving the estimated HEU inventory avail-

able for weapons at the end of FY 1984 at about 600 MT.

This 600 MT estimate is an upper limit on the HEU inventory available for weapons. There are surely additional inventories and drawdowns which have not been taken into account. The authors believe a better estimate of the HEU inventory reserved for weapons is 500 MT.



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Glossary of Terms

Actinides	The series of heavy radioactive metallic elements of increasing atomic number from actinium (89) through hahnium (105)		
Advanced Gas Centrifuge (AGC)	High speed, high-efficiency gas centrifuge for enriching uranium hexafluoride	ATMX	The designation assigned to a special railcar used to transport nuclear weapons. Only series 500 and 600 ATMX cars are nuclear weapons transporting railcars.
Advanced Isotope Separation (AIS)	Processes under development for enriching uranium, including Molecular Laser Isotope Separation (MLIS), Atomic Vapor Laser Isotope Separation (AVLIS), the Plasma Separation Process (PSP), and the Advanced Gas Centrifuge (AGC)	Atomic bomb	An explosive device whose energy comes from the fissioning of uranium or plutonium. A fission bomb, as distinguished from a hydrogen bomb.
Airburst	The explosion of a nuclear weapon in the air at height greater than the maximum radius of the fireball.	Atomic demolition munition (ADM)	Nuclear device designed to be detonated on or below the surface, or under water, to block, deny, and/or canalize enemy forces.
Alpha particle	A positively charged particle, made up of two neutrons and two protons, emitted by certain radioactive nuclei. The nucleus of He-4 atom.	Atomic number	The number of protons in an atomic nucleus.
Anti-submarine warfare (ASW)	Methods of warfare utilizing specialized sensors, data processing techniques, weapons platforms, and weapons intended to search for, identify, and destroy submarines.	Atomic weight	The mass of an atom expressed in atomic mass units (amu), usually relative to carbon-12, which is defined to have a mass of 12 amu. Approximately, the sum of the number of neutrons and protons in the nucleus.
Anti-ballistic missile (ABM)	A defense missile used to intercept and destroy an attacking strategic ballistic missile.	Ballistic missile	A missile that follows a ballistic trajectory, relying only on gravity and aerodynamic drag when its thrust is terminated.
Aqueous phase	In solvent extraction, the water-containing layer, as differentiated from the organic phase.	Ballistic missile defense (BMD)	A defensive system designed to destroy incoming ballistic missiles or their warheads. Usually conceived as structured in several different layers that attack missiles in any of their trajectory phases: boost phase, post-boost phase, midcourse phase, and terminal (or reentry) phase.
Arming	As applied to weapons and ammunition, the changing from a safe condition to a state of readiness for initiation.	Beryllium	Element with atomic number 4 and atomic weights between 6 and 11. Used in nuclear weapons as a neutron reflector and a neutron source.
Arms control	The process of limiting or reducing arms to lessen the risk of conflict and to reduce the consequences of a conflict should it occur.		
Arms control agreement verification	The collection, processing, and reporting of data indicating testing or employment of proscribed		

Beta particle	An electron or positron emitted by an atomic nucleus during radioactive decay		
Blanket	A layer of assemblies containing fertile material, such as uranium-238 or thorium-232, surrounding the core of a nuclear reactor, for the purpose of absorbing escaping neutrons	Control rods	Rods of neutron absorbing material that are inserted into the core of a nuclear reactor to control its operation
Blast	The pressure pulse (shock wave) in air initiated by the expansion of the hot gases produced by an explosion	Conversion ratio	The ratio of the number of atoms of new fissile materials produced in a reactor to the number of atoms of fissile material consumed This ratio is usually less than unity
Blast yield	That portion of the total energy of a nuclear explosion that is manifested as a blast (or shock) wave	Crater	The pit, depression, or cavity formed in the surface of the earth by a surface or underground explosion Crater formation can occur by vaporization of the surface material, by the scouring effect of air blast, by throwout of disturbed material, or by subsidence In general, changes from one process to the next occur with increasing depth of burst The apparent crater is the depression which is seen after the burst; it is smaller than the true crater, which is covered with a layer of loose earth, rock, etcetera In a deep underground burst when there is no rupture of the surface, the resulting cavity (a sealed pocket of smoke and gas) is called a camouflet
Boosted fission weapon	A nuclear weapon in which neutrons produced by thermonuclear reactions serve to enhance the fission process The thermonuclear energy represents only a small fraction of the total explosion energy		
Burnup	The percentage of fuel atoms fissioned during operation of a nuclear reactor Also, the energy produced by a nuclear reactor, usually expressed as Mwd per MT of fuel		
Byproduct material	Any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the production or utilization of special nuclear material	Critical facility	A research facility that contains nuclear material and can sustain a chain reaction but produces no power and requires no cooling Its core is designed for great flexibility and uses fuel that can be repositioned and varied to investigate different reactor concepts and core configurations
Chain reaction	A series of reactions in fissionable material in which neutrons that are the product of fission reactions induce subsequent fissions	Critical mass	The least mass of fissionable material that will allow a self-sustaining nuclear chain reactor The critical mass depends on the type of fissionable isotope, its chemical form, geometrical arrangement, and density
Cladding	The material forming the outer layer of a nuclear fuel element May be aluminum, steel, or Zircalloy, an alloy of zirconium		
Command disable system	A system incorporating command and control features that destroys a weapon's ability to achieve a significant nuclear yield		
Component	Any operational, experimental, or research-related part, subsec-		

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Critical nuclear weapons design information (CNWDI)	That TOP SECRET Restricted Data or SECRET Restricted Data revealing the theory of operation or design of the components of a thermonuclear or implosion-type fission bomb, warhead, demolition munition, or test device. Specially excluded is information concerning arming, fuzing, and firing systems; limited life components; and total contained quantity of fissionable, fusionable, and high explosive materials by type. Among these excluded items are the components which Service personnel set, maintain, operate, test or replace.	Deuterium	A hydrogen isotope (atomic weight 2) with one proton and one neutron in the nucleus. Represented by letter D or by H-2. Used as a thermonuclear fuel constituent and as a neutron moderator (in the form of heavy water) in nuclear reactors.
Cruise missile	A low-flying, air-breathing, guided missile that, like an aircraft, relies on propulsion to balance drag and aerodynamic lift to balance gravity.	Disablement	The rendering of a nuclear weapon incapable of achieving a nuclear yield for some specified period of time. Not included in disablement are the prevention of the recovery of active nuclear material and preventing the obtainment of classified design information.
Cryogenic	Relating to the production of very low temperatures.	Electromagnetic pulse (EMP)	A sharp pulse of radio-frequency (long wavelength) electromagnetic radiation produced when a nuclear explosion occurs in an unsymmetrical environment, especially at or near the earth's surface or at high altitudes. It is caused by Compton-recoil electrons and by photoelectrons. The intense electric and magnetic fields can damage unprotected electrical and electronic equipment over a large area.
Curie (Ci)	A unit of radioactivity; the activity of a quantity of any radioactive nuclide undergoing 37 thousand million disintegrations per second.	Electron-volt	A unit of energy. 22.5 billion trillion electron-volts equal one kilowatt-hour.
Custody	1 As defined in the AEC-DOD Stockpile Agreement, custody is the responsibility for the control of transfer and movement of, and access to, weapons and components. Custody also includes the maintenance of accountability for weapons and components. 2 As used within the individual Military Services, custody is the guardianship and safekeeping of nuclear weapons and their components and of source and special nuclear material. Custody may or may not include accountability.	Enhanced radiation weapon	A nuclear explosive device designed to maximize nuclear radiation effects and reduce blast and thermal effects.
Depleted uranium	Uranium having a concentration of U-235 smaller than found in nature (0.711 percent).	Enrichment	Increasing the concentration of one isotope of an element relative to the other isotopes. For example, uranium-235 relative to uranium-238 or plutonium-239 relative to plutonium-240.
Detonator	A device containing a sensitive explosive intended to produce a detonation wave for detonating a high explosive element.	Feed material	A nuclear material introduced at the start of a process or operation (e.g., uranium hexafluoride (UF ₆) as the feed to an enrichment process or uranium metal as the feed to a fuel fabrication process).
		Fertile isotope	An isotope that is converted into a fissile isotope, either directly or after a brief decay process, by absorbing a neutron. For example,

	fertile U-238 captures a neutron to form U-239, which subsequently decays to fissile Pu-239		
Fireball	The luminous sphere of hot gases produced by a nuclear explosion	Fission yield	monly known as atomic bomb The amount of energy released by fission in a thermonuclear (fusion) explosion as distinct from that released by fusion
Firing system	The system of components in a nuclear weapon that converts (if necessary), stores, and releases electrical energy to detonate the weapon when commanded by the fuzing system	Formerly Restricted Data (FRD)	Information removed from the Restricted Data category upon a joint determination by the Department of Energy (or antecedent agencies) and Department of Defense that such information relates primarily to the military utilization of atomic weapons and that such information can be adequately safeguarded as classified defense information (Section 142d, Atomic Energy Act of 1954, as amended)
Fissile material	An isotope that readily fissions after absorbing a slow neutron, emitting 2 to 3 neutrons Fissile materials are U-235, U-233, Pu-239, and Pu-241	Fuel cycle	The set of chemical and physical operations needed to prepare nuclear material for use in reactors and to dispose of or recycle the material after its removal from the reactor
Fission	The splitting of the nucleus of a heavy atom following absorption of a neutron into two lighter nuclei, accompanied by the release of neutrons, X-rays, gamma rays, and kinetic energy of the fission products	Fuel element	A rod, tube, or other form into which nuclear fuel is fabricated for use in a reactor
Fissionable material	A material that will undergo nuclear fission Includes fissile materials, but also isotopes such as U-238 that are fissioned only by fast neutrons	Fuel fabrication plant	A facility where the nuclear material (e.g., enriched or natural uranium) is fabricated into fuel elements for a reactor
Fission products	The product nuclei resulting from the fission of a heavy nucleus (e.g., uranium-235 or plutonium-239) These are distinguished from the <i>direct fission products</i> or <i>fission fragments</i> that are formed by the actual splitting of the heavy-element nucleus The fission fragments are radioactive and decay into daughter products The complex mixture of fission products thus formed contains about 200 different isotopes of over thirty elements	Fuel processing plant	A plant where irradiated fuel elements are dissolved, waste materials removed, and reusable materials are recovered
Fission weapon	A nuclear warhead whose material is uranium or plutonium that is brought to a critical mass under pressure from a chemical explosive detonation to create an explosion that produces blast, thermal radiation, and nuclear radiation The complete fission of one pound of fissionable material would have a yield equivalent to 8000 tons of TNT Com-	Fusion	The process in which two light nuclei atoms, especially isotopes of hydrogen, combine to form a heavier nucleus with the release of a substantial amount of energy Extremely high temperatures, resulting in highly energetic, fast-moving nuclei, are required to initiate fusion reactions
		Fusion weapon	Nuclear warhead containing fusion materials (e.g., deuterium and tritium) that are brought to critical density and temperature conditions by use of a primary fission reaction (thermonuclear) in order to initiate and sustain a rapid fusion process, which in turn creates an explosion that

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	produces blast, thermal radiation, and nuclear radiation. Commonly known as hydrogen bomb or thermonuclear weapon		um, with atomic numbers of 90 and above
Fuze	A union of one or more subassemblies or major components that, when combined with other major assemblies as required (such as bomb, power supply, etc.), is capable either in itself or in conjunction with a firing set of controlling the electrical or mechanical arming and firing of a weapon	Heavy water	Water containing significantly more than the natural proportion (1 part in 6500) of deuterium atoms (as D ₂ O) to ordinary hydrogen atoms (as H ₂ O)
Fuzing system	The system of components in a nuclear weapon that determines the time and place to detonate the weapon	Heavy water reactor	A nuclear reactor that uses heavy water as moderator and/or coolant
Gamma ray	High-energy electromagnetic radiation emitted by nuclei during nuclear reactions or radioactive decay	Helium	Element (symbol He) with atomic number 2 and atomic weights between 3 and 8
Gaseous diffusion	An isotope separation process used for enriching uranium in uranium-235 based on the fact that the lighter isotopes of a gas diffuse through a porous barrier at a greater rate than the heavier isotopes	Highly enriched uranium (HEU)	Uranium that is enriched in U-235 to above 20 percent, usually 90 percent or greater
Gas centrifuge	A rotating cylinder that can be used for enrichment of uranium hexafluoride gas. The heavier uranium isotope U-238 tends to concentrate at the walls of the rotating centrifuge, leaving uranium enriched in U-235 near the center	High-level waste (HLW)	The highly radioactive waste containing fission products that is discharged from a nuclear fuel processing plant
Gun-type weapon	A device in which two or more pieces of fissionable material, each less than a critical mass, are brought together very rapidly so as to form a supercritical mass that can explode as the result of a rapidly expanding fission chain	Homogenous core	A reactor core composed of only one type of fuel assembly
Half-life	The time in which one half of a quantity of identical radioactive atoms decays	Igloo	An earth-covered structure of concrete and/or steel designed for the storage of ammunition and explosives
Heavy metal	The fuel materials, including uranium, plutonium and thori-	Implosion weapon	A weapon in which a quantity of fissionable material, less than a critical mass at ordinary pressure, has its volume suddenly reduced by compression (a step accomplished by using chemical explosives) so that it becomes supercritical, producing a nuclear explosion
		Inertial confinement fusion (ICF)	A concept for attaining the density and temperature condition that will produce nuclear fusion by use of lasers or particle beams to compress and heat small pellets of fusion fuel. The energy released is in the form of fast neutrons, X-rays, charged particles, and debris
		Initial operational capability (IOC)	The date when the first combat missile unit is equipped and trained, and logistic support established to permit performance of combat missions in the field. An initial operational capability date is associated with each new missile system as a target date for delivery of combat equipment,

	repair parts, maintenance equipment, and publications, plus supply of trained personnel		
Intercontinental ballistic missile (ICBM)	A land-based rocket-propelled vehicle capable of delivering a warhead over intercontinental distances. Once rocket propulsion is terminated an ICBM travels on a ballistic trajectory.		<i>Joint test assembly, rebuild</i> Weapons randomly selected from War Reserve stockpile in which the nuclear explosive package is removed and instrumentation substituted prior to evaluation.
Intermediate-range ballistic missile (IRBM)	A ballistic missile, with a range capability from about 1500 to 3000 nautical miles.	Joint test subassembly (JTS)	The instrumented package substituted for the nuclear explosive package.
Ion exchange	Chemical methods of recovering products or removing impurities from solutions involving the exchange of ions between the solution and an insoluble resin. Used in uranium milling to recover uranium from acid leach liquors and in fuel processing for final product decontamination and the separation of certain fission products from high level waste. For the separation of metals, ion exchange is preferable over solvent extraction for small quantities or low concentrations.	Kiloton (Kt)	The energy of a nuclear explosion that is equivalent to the explosion of 1000 tons of trinitrotoluene (TNT) high explosive.
		Laser	A device that produces a coherent, intense, and collimated beam of electromagnetic radiation of well-determined wavelength, through a physical process known as stimulated emission.
		Laser isotope separation (LIS)	An enrichment process in which desired isotopes are separated by differentially exciting a vapor or gas with a finely tuned laser. Used to separate U-235 from U-238 and Pu-240 and Pu-244 from Pu-239.
Irradiation	Exposure to neutrons in a nuclear reactor. More generally, exposure to any source of radiation.	Light-water reactor	A nuclear reactor that uses ordinary water as moderator and coolant.
Isotopes	Atoms of the same chemical element having different numbers of neutrons in their nucleus. An isotope is specified by its atomic number and a symbol denoting the chemical element (e.g., U-235 for uranium with 235 neutrons and protons).	Liquid-metal fast breeder reactor	A nuclear reactor that uses a liquid metal (e.g., sodium) for cooling, operates with high-energy (fast) neutrons, and produces more fissionable material than it consumes.
Joint test assembly (JTA)	Warheads and bombs employed in test projects. JTAs are non-nuclear test configurations with appropriate instrumentation installed.	Lithium	Element with atomic number 3 and atomic weight between 5 and 9. As thermonuclear fuel constituent, it is usually compounded with deuterium.
	<i>Joint test assembly, pre-build</i> Instrumented warheads on bombs assembled alongside war reserve weapons. The nuclear explosive package is excluded, with instrumentation substituted that will allow subsystem evaluation at a later time during weapon evaluation.	Low-enriched uranium	Uranium enriched in U-235 to less than 20 percent, usually 2 to 4 percent.
		Mean free path	The average path distance a particle (neutron or photon) travels before undergoing a specified reaction (with a nucleus or electron) in matter.

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Megaton (Mt)	A measure of the explosive yield of a nuclear weapon equivalent to one million tons of trinitrotoluene (TNT) high explosive. Equal approximately to one thousand million calories or 4.2 thousand million joules.		dies out and the reactor is "sub-critical"; for k greater than unity the reaction grows and is "super-critical."
Megawatt thermal (Mwt)	A measure of the rate of heat production (power output) in a nuclear reactor equal to one million watts.	National Security Information	A category of information classified under Executive Order 12356, "National Security Information."
Megawatt-day (Mwd)	A measure of thermal energy production in a nuclear reactor. One Mwd is equal to 86.4 thousand million joules.	Natural uranium	Uranium as found in nature, containing about 0.711 percent of U-235, 99.3 percent of U-238, and a trace of U-234.
Military characteristics	Those characteristics of equipment upon which depend its ability to perform desired military functions. Military characteristics include physical and operational characteristics but not technical characteristics.	Neutron flux	A measure of the intensity of neutron radiation equal to the product of neutron density and velocity. Expressed as the number of neutrons per square centimeter per second.
"Mod" designator number	Modifications made to the major assembly design of a weapon system. Mod-0 is the first version of a weapon design, with subsequent modifications of the weapon design numbered consecutively.	Neutron generator	A high-voltage vacuum tube used in contemporary nuclear weapons to furnish neutrons at a precise instant to begin fission reactions in fissile cores.
Moderator	A material (e.g., water, heavy water, or graphite) in the core of a nuclear reactor that slows neutrons by elastic collision, thus increasing their chance of absorption by a fissile nucleus.	Nuclear component	A part of a nuclear weapon that contains fissionable or fusionable material.
Metric Ton (MT)	1000 kilograms, or 2205 pounds.	Nuclear device	Nuclear fission or fission and fusion materials, together with the arming, fuzing, firing, chemical explosive, canister, and diagnostic measurement equipment, that have not reached the development status of an operational weapon.
Multiple independently targetable reentry vehicle (MIRV)	Multiple reentry vehicles carried by a ballistic missile, each of which can be directed to a separate and arbitrarily located target.	Nuclear radiation	Particle and electromagnetic radiation emitted from atomic nuclei in various nuclear processes. The important nuclear radiations, from the weapons effects standpoint, are alpha and beta particles, gamma rays, and neutrons. X-rays are not nuclear radiations since they do not originate in atomic nuclei.
Multiplication Factor (k)	A quantity that describes the degree to which a chain reacting system can sustain operation. k is equal to the ratio of the number of neutrons in a given generation to the number in the preceding generation. When k is equal to unity, the fission chain reaction is self-sustaining and the reactor is "critical"; for k less than unity, the chain reaction	Nuclear reactor	A device in which a controlled, self-sustaining nuclear reaction can be maintained with provisions for cooling to remove generated heat. Types include power reactors, research and test reactors, and production reactors.
		Nuclear waste	The radioactive by-products formed by fission and other nu-

	clear processes in a reactor Separated from spent fuel in a processing plant	Pipeline	Refers to the quantity of an item required in the supply system to maintain an uninterrupted replacement flow
Nuclear weapon	A device that releases nuclear energy in an explosive matter as the result of nuclear reactions involving the fission or fusion of atomic nuclei, or both	Pit	The components of a warhead located within the inner boundary of the high explosive assembly but not including safing materials
Nuclear weapons effects	Effects associated with the explosion of a nuclear weapon, including blast, heat, X-rays, prompt nuclear radiation, and electromagnetic pulse	Plutonium	A heavy, man-made, radioactive metallic element (symbol Pu) The most important isotopes are Pu-238 and Pu-239
Nuclear winter	Global effects of nuclear war resulting in the lowering of land surface temperatures to near freezing or below due to the spread of massive amounts of smoke from fires and dust through the atmosphere screening out the sun's energy	Plutonium-239	A fissile isotope produced by neutron capture in uranium-238 It is used in the core of nuclear weapons
One-point detonation	A detonation of high explosive which is initiated at a single point This type of detonation may be intentionally initiated in certain self-destruct systems	Plutonium-240	An isotope of plutonium, produced in reactors by neutron capture in Pu-239 Because of its high rate of spontaneous fission, its presence increases the chance of preinitiation and affects the design and operation of nuclear explosive devices
One-point safe	The probability that the detonation of the high explosive of a nuclear weapon by initiation at any one point has a chance of no greater than one in a million of producing a nuclear yield in excess of 4-pounds TNT equivalent It is a term to describe the degree of safety in a nuclear weapon	Preinitiation	The initiation of the fission chain reaction in the active material of a nuclear weapon at any time earlier than at which either the designed or the maximum compression or degree of assembly is attained
Oralloy	Abbreviation for Oak Ridge Alloy Highly enriched uranium metal, typically 93.5 percent U-235, used in nuclear weapons	Primary	The fission trigger or first stage of a multistage thermonuclear weapon or device
Organic phase	In solvent extraction processes (e.g., PUREX) for fuel processing, the solvent (organic) containing layer, as differentiated from the aqueous phase	Production	The conversion of raw materials into products and/or components through a series of manufacturing processes It includes functions of production engineering, controlling, quality assurance, and the determination of resources requirements
Permissive action link (PAL)	A device included in or attached to a nuclear weapon system to preclude arming and/or launching until the insertion of a prescribed discrete code or combination	Production reactor	A nuclear reactor that is designed primarily for the production of plutonium, tritium, and other isotopes by neutron irradiation of selected target materials

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PUREX	Abbreviation for Plutonium U[R]anium E[X]traction. A solvent extraction process commonly used in fuel processing that individually separates the uranium, neptunium, and plutonium from the accompanying fission products contained in the irradiated fuel.	Research and development (R&D) phases	sion products and from each other The phases through which R&D effort passes in its evolution from initial inception to mature technology are: (1) basic research, (2) applied research, (3) exploratory development, (4) advanced development, and (5) engineering development.
Quality assurance (QA)	A continuing program of test and evaluation to determine whether weapons material is of satisfactory quality, to determine the degree of conformance to design intent, and to determine the status of functional stockpile readiness through the use of periodic inspection reports and other checks.	Research reactor	A nuclear reactor that is designed primarily for training and research.
Radioactivity	The spontaneous disintegration of an unstable atomic nucleus resulting in the emission of either alpha or beta particles, gamma rays, or neutrons.	Resonance capture	An inelastic nuclear collision that occurs because of the strong tendency for a nucleus to capture incident particles or photons of electromagnetic radiation having particular (resonant) energies.
Reactor core	The central portion of a nuclear reactor containing the fuel elements.	Restricted Data (RD)	All data (information) concerning: (a) design, manufacture, or utilization of atomic weapons; (b) the production of special nuclear material; or (c) the use of special nuclear material in the production of energy, but shall not include data declassified or removed from the restricted data category pursuant to Section 142 of the Atomic Energy Act (Section 11w, Atomic Energy Act of 1954, as amended).
Reclama	A request to duly constituted authority to reconsider its decision or its proposed action.	Safing	As applied to weapons and ammunition, the changing from a state of readiness for initiation to a safe condition.
Recycle	The reuse of unburned uranium and plutonium in fresh fuel after separation from fission products in spent fuel at a reprocessing plant.	Salt cake	The damp solid formed when the liquid fraction of the high-level waste is removed through the use of an evaporation crystallizer.
Reentry vehicle (RV)	That portion of a ballistic missile which carries the nuclear warhead. It is called a reentry vehicle because it reenters the earth's atmosphere in the terminal portion of the missile trajectory.	Scrap	Rejected nuclear material removed from the process stream. Often requires separation from contaminants or chemical treatment to return the material to a state acceptable for subsequent processing.
Reflector	A layer of material immediately surrounding a reactor core which scatters back or deflects into the core many neutrons that would otherwise escape. Also, in nuclear warheads. Common reflector materials are graphite, beryllium, and natural uranium.	Separative work	A measure of the effort required in an enrichment plant or unit to separate uranium of a given U-235 content into two fractions, one having a higher percentage and one having a lower percent-
Reprocessing	The chemical treatment of spent reactor fuel to separate the plutonium and uranium from the fis-		

	age of U-235 The unit of separative work is the kilogram separative work unit (kg SWU)		related physical environments involved in the delivery of a nuclear weapon from the stockpile to the target It may also define the logistical flow involved in moving nuclear weapons to and from the stockpile for quality assurance testing, modification and retrofit, and the recycling of limited life components
Solvent extraction	Chemical methods of recovering metals based on their preferential solubility in solvents immiscible in water Used in uranium milling to separate uranium from leach liquor and in fuel processing to separate plutonium and uranium from fission products		
Source material	As defined under the Atomic Energy Act, ores containing uranium or thorium	Strategic forces	Nuclear weapons and delivery systems designed for nuclear attack against strategic targets or for active defense against such an attack Bombers, missile systems, and strategic interceptors
Special isotope separation (SIS) plant	DOE facility using the atomic vapor laser isotope separation (AVLIS) process (or molecular laser isotope separation (MLIS) process) to enrich plutonium in the isotope Pu-239		Commonly refers to offensive weapons in the United States and Soviet Union that can deliver a nuclear strike on each other or a third party
Special nuclear material (SNM)	As defined under the Atomic Energy Act, plutonium, uranium-233, and uranium enriched in the isotope U-233 or the isotope U-235 SNM does not include source material such as natural uranium or thorium	Stripping	In uranium enrichment, the process of enriching the tails of an enrichment plant or previous enrichment stage In the PUREX solvent extraction process, the transfer of product from the organic phase back into the aqueous phase
Spent fuel	Fuel elements that have been removed from the reactor because they contain too little fissile material and too high a concentration of radioactive fission products They are highly radioactive	Subcritical	An assembly containing an insufficient quantity of fissile fuel to sustain a fission reaction
		Submarine-launched ballistic missile (SLBM)	A ballistic missile carried in and capable of being launched from a submarine
Stimulated emission	Physical process by which an excited molecule is induced by incident radiation to emit radiation at an identical frequency and in phase with the incident radiation	Tactical nuclear weapons	Nuclear capable devices assigned to support the conduct of battles and deployed close to likely areas of military engagement
Stockpile	Nuclear storage Also, the total number of nuclear weapons which a nation maintains in storage at all locations and potentially available for deployment	Tails	The depleted stream of an enrichment plant or stage after the enriched product is removed Expressed as percent of U-235 content Also, applies to the depleted stream from uranium milling
Stockpile to target sequence	1 The order of events involved in removing a nuclear weapon from storage, and assembling, testing, transporting, and delivering it on the target 2 A document that defines the logistical and employment concepts and	Tamper	A heavy, dense material surrounding the fissionable material in an atomic weapon, for the purpose of holding the supercritical assembly together longer by its

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	inertia, and also for the purpose of reflecting neutrons, thus increasing the fission rate of the active material	Uranium-233	A fissile isotope bred by neutron capture in thorium-232. It is similar in weapons use to Pu-239.
Target	Material irradiated with neutrons in a production reactor in order to produce plutonium-239, tritium, uranium-236, plutonium-238, or other desired isotopes	Uranium-235	The only naturally occurring fissile isotope. Natural uranium has 0.7 percent of U-235. Reactors use natural or enriched uranium as fuel. Weapons use uranium enriched to about 93.5 percent U-235.
Thermal neutrons	Low-energy, low-speed neutrons in thermal equilibrium with their surroundings. Frequently, neutrons with speed of 2200 m/s	Uranium-238	A fertile isotope from which Pu-239 can be bred. It comprises 99.3 percent of natural uranium.
Thermal reactor	A reactor in which the fission chain reaction is sustained by low-energy (thermal) neutrons which have been moderated to thermal energy in order to increase reaction probabilities.	Uranium hexafluoride	A volatile compound of uranium and fluorine that is a white crystalline solid at room temperature and atmospheric pressure but vaporizes upon heating, at 56.6 degrees C. Feedstock in gaseous diffusion, gas centrifuge, and other enrichment processes.
Thermonuclear weapon	A nuclear weapon (also referred to as hydrogen weapon) in which the main contribution to the explosive energy results from fusion of light nuclei, such as deuterium and tritium. The high temperatures required for such fusion reactions are obtained by means of an initial fission explosion.	Uranium milling	The process by which uranium ore containing only a very small percentage of uranium oxide (U_3O_8) is converted into material containing a high percentage (80 percent) of U_3O_8 , often referred to as yellowcake.
Thorium-232	A naturally occurring isotope from which the fissile isotope U-233 can be bred by neutron capture.	Uranium ore concentrate	U_3O_8 , often referred to as yellowcake.
Transuranic (TRU) elements	Elements with atomic number greater than uranium (atomic number 92). They include neptunium, plutonium, americium, and curium.	Vitrification	The solidification process in which high level waste is melted with a frit to form a glass.
Tritium	An isotope of hydrogen, with an atomic number 1, atomic weight of 3, and a nucleus composed of one proton and two neutrons. Tritium decays by beta decay, with a half-life of 12.3 years. It can be produced by lithium-6 bombardment in nuclear reactors or in the fusion fuel of thermonuclear weapons. Represented by T or H-3.	Warhead	That part of a missile, projectile, torpedo, rocket, or other munition which contains either the nuclear or the thermonuclear system, high explosive system, chemical or biological agents, or inert materials, intended to inflict damage.
		War reserve (nuclear)	Nuclear weapons materiel stockpiled in the custody of the Department of Energy or transferred to the custody of the Department of Defense and intended for employment in the event of war.
		Weapons grade (or weapon-grade)	Nuclear material considered most suitable for a nuclear weapon. Uranium enriched to about 93% U-235 (Oralloy) or plutonium with greater than about 93%.

	Pu-239 Weapons can be fabricated from lower grade material
Wooden bomb	A concept which pictures a weapon as being completely reliable and having an infinite shelf life while at the same time requiring no special handling, storage, or surveillance
X-rays	Intermediate energy electromagnetic radiation, typically emitted during atomic transitions, having wavelength shorter than 10 billionths of a meter Differentiated from more energetic and shorter wavelength gamma rays, which originate in the nucleus
X-ray laser	A laser producing a beam of coherent x-rays A device driven by a nuclear explosion to produce a burst of coherent X-ray radiation before the device is vaporized by the fireball
Yellowcake	The product of the uranium milling process, containing about 80 percent U_3O_8 Loosely, U_3O_8 itself
Yield	The energy released in a nuclear explosion, expressed usually as the number of tons of TNT releasing the same amount of energy The total yield is manifested as nuclear radiation, thermal radiation, and blast energy, the actual distribution being dependent upon the medium in which the explosion occurs, the type of weapon, and the time after detonation
Yield-to-weight ratio	The ratio of the yield to the mass of a nuclear warhead Expressed as Kt per kg or Mt per kg
Yield-to-volume ratio	The ratio of the yield to the volume of a nuclear warhead

Glossary of Abbreviations and Acronyms

A		ASD	Aeronautical Systems Division
AASM	Advanced Air-Surface Missile System	ASDP	Assistant Secretary for Defense Programs
AAU	Argonne Associated Universities	ASN (R,E & S)	Assistant Secretary of the Navy (Research, Engineering, and Systems)
ABM	Anti-Ballistic Missile	ASROC	Anti-Submarine Rocket
ADM	Atomic Demolition Munition	ASTD (AE)	Assistant to the Secretary of Defense (Atomic Energy)
AEC	Atomic Energy Commission	ASW	Anti-Submarine Warfare
AF	Air Force	ATB	Advanced Technology Bomber ("Stealth")
AFB	Air Force Base	ATF-1	Advanced Toroidal Facility-1
AFGL	Air Force Geophysics Laboratory	AVLIS	Atomic Vapor Laser Isotope Separation
AFS	Air Force Station	AWST	Aviation Week and Space Technology (magazine)
AFSC	Air Force Systems Command	B	
AFRRI	Armed Forces Radiobiology Research Institute	B	Bomb
AFWL	Air Force Weapons Laboratory	BCSR	Boeing Computer Services, Richland, Inc
AGC	Advanced Gas Centrifuge	Be	Beryllium
AIS	Advanced Isotope Separation	BeO	Beryllium Oxide
Al	Aluminum	BMD	Ballistic Missile Defense
ALO	Albuquerque Operations Office	BNL	Brookhaven National Laboratory
Am	Americium	BOAR	Bureau of Ordnance Atomic Rocket
AMAC	Aircraft Monitor and Control	BPET	Breeder Processing Engineering Test
AMC	Army Materiel Command	BWIP	Basalt Waste Isolation Project
AMCCOM	Army armament Munitions and Chemical Command	BWR	Boiling Water Reactor
AMU	Atomic Mass Unit	C	
ANCA	Army Nuclear and Chemical Agency	CARL	Comparative Animal Research Laboratory
ANL	Argonne National Laboratory		
Ar	Argon		
ARES	Advanced Research EMP Simulator		
ARHCO	Atlantic Richfield Hanford Company		
ARSTAF	Army S[TAF]f		

Glossary of Abbreviations and Acronyms

CCD	Counter[C]urrent Decantation	DNA	Defense Nuclear Agency
Cf	Californium	DOD	Department of Defense
CFMO	Central Scrap Management Office	DOE	Department of Energy
CFX	Californium Multiplier	DPS	Decision Package Sets
CG	Consolidated Guidance	DRAAG	Design Review And Acceptance Group
CGN	Nuclear powered cruiser	DRP	Defense Review Panel
Ci	Curie	DSARC	Defense Systems Acquisition Review Council
Cm	Curium	DSCS	Defense Satellite Communications System
CND	Campaign for Nuclear Disarmament	D-T	Deuterium-Tritium
CNO	Chief of Naval Operations	DU	Depleted Uranium
CO ₂	Carbon Dioxide	DWPF	Defense Waste Processing Facility
COE	Chief Of Engineers		
CPDF	Centrifuge Plant Demonstration Facility	E	
CSA	Chief of Staff of the Army	EBR	Experimental Breeder Reactor
CUP	Cascade Upgrade Program	EBT-B	Elmo Bumpy Torus-B
CVN	Nuclear-powered aircraft carrier	ECF	Expended Core Facility
CY	Calendar Year	EG&G	(Formerly) Edgerton, Gerneshausen, and Grier, Inc
D		EMP	Electro[M]agnetic Pulse
D	Deuterium	EMPSAC	EMP Simulator for Aircraft
D ₂ O	Deuterium Oxide ("heavy water")	ENICO	Exxon Nuclear Idaho C[O]mpany
		EOD	Explosive Ordnance Disposal
DARCOM	Army Material Development And Readiness C[OM]mand	EPA	Environmental Protection Agency
DARPA	Defense Advanced Research Projects Agency	ER	Enhanced Radiation
DCNO	Deputy Chief of Naval Operations	ERAB	Energy Research Advisory Board
		ERDA	Energy Research and Development Administration
DCP	Development Concept Paper	ESD	Electronic Systems Division
DCSLOG	Deputy Chief of Staff for L[OG]istics	ETR	Eastern Test Range
DCSOPS	Deputy Chief of Staff for Operations and Plans; or in the Air Force Deputy Chief of Staff, Operations, Plans and Readiness	eV	Electron Volt
		EWD	Energy and Water Development
DCSRDA	Deputy Chief of Staff, Research, Development, and Acquisition	EWDA	Energy and Water Development Appropriation Subcommittee
DEIS	Draft Environmental Impact Statement	F	
		F	Fuel-grade; or Fluorine
DG	Defense Guidance	FBM	Fleet Ballistic Missile

Glossary of Abbreviations and Acronyms

FCDNA	Field Command Defense Nuclear Agency	HEHF	Hanford Environmental Health Foundation
FEIS	Final Environmental Impact Statement	HEU	Highly Enriched Uranium
FEMA	Federal Emergency Management Agency	HLOS	Horizontal Line Of Sight
FFTF	Fast Flux Test Facility	HLW	High Level Waste
FMEF	Fuels and Materials Examination Facility	HP	Horse[Power]
FMPC	Feed Materials Production Center	HPD	Horizontal Polarized Dipole
FPU	First Production Unit	HQ	Head[Quarters]
FRD	Formerly Restricted Data	HQMC	Head[Quarters], Marine Corps
FTE	Full-Time Equivalents	HSTC	House Science and Technology Committee
FY	Fiscal Year	HTGR	High Temperature Gas Reactor
G		HTRE	Heat Transfer Reactor Experiment
g	Gram	HUMINT	H[uman] I[n]telligence
GAO	General Accounting Office	HWR	Heavy Water Reactor
GCEP	Gas Centrifuge Enrichment Plant	I	
GDP	Gaseous Diffusion Plant	ICBM	Intercontinental Ballistic Missile
GE	General Electric Company	ICPP	Idaho Chemical Processing Plant
GLCM	Ground-Launched Cruise Missile	ID	Inside Diameter
GOCO	Government Owned-Contractor Operated	IFPF	Idaho Fuels Processing Facility (Now ICPP)
GS	Dual-Temperature Water-Hydrogen Sulfide Exchange	IG	Inspector General
GSA	General Services Administration	IHE	Insensitive High Explosive
H		INC	Insertable Nuclear Component
H	Hydrogen	INEL	Idaho National Engineering Laboratory
H ₂ O	Hydrogen Oxide ("Water")	INFCE	International Nuclear Fuel Cycle Evaluation
HAC	House Appropriations Committee (see Chapter One, footnote 9)	IOC	Initial Operational Capability
HASC	House Armed Services Committee (see Chapter One, footnote 9)	IPNS	Intense Pulsed Neutron Source
HEAF	High Explosive Application Facility	IRBM	Intermediate-Range Ballistic Missile
He	Helium	ISPM	International Solar Polar Mission
HE	High Explosive	ISX-B	Impurity Studies Experiment-B
HEDL	Hanford Engineering Development Laboratory	J	
		JAIEG	Joint Atomic Information Exchange Group
		JAJ	J A Jones Construction Service Company

Glossary of Abbreviations and Acronyms

JCAE	Joint Committee on Atomic Energy	LMFBR	Liquid Metal Fast Breeder Reactor
JCS	Joint Chiefs of Staff	LoADS	Low Altitude Defense System
JEC	Joint Economic Committee	LSI	Large Scale Integrated
JLRSA	Joint Long-Range Strategic Appraisal	LWBR	Light Water Breeder Reactor
JNACC	Joint Nuclear Accident Coordinating Center	M	
JPAM	Joint Program Assessment Memorandum	M	Meter; million (10 ⁶)
JSAM	Joint Strategic Assessment Memorandum	MC	Military Characteristics
JSCP	Joint Strategic Capability Plan	MED	Manhattan Engineer District
JSPD	Joint Strategic Planning Document	MENS	Mission Element Needs Statement
JSPS	Joint Strategic Planning System	MeV	Million Electron Volts
JTA	Joint Test Assembly	MFTF-B	Mirror Fusion Test Facility-B
JTCAMS	Joint Tactical Missile System	MIR	Major Impact Report
K		MIRV	Multiple Independently targetable Reentry Vehicle
K	Kilo- (1000)	Mk	Mark
KEH	Kaiser Engineers Hanford Company	MLC	Military Liaison Committee
Kg	Kilogram	MLIS	Molecular Laser Isotope Separation
KJ	Kilo[J]oule	MM	Minute[M]an
KMR	Kwajalein Missile Range	MMP	Materials Management Plan
Kt	Kilotons	MRS	Monitored Retrieval Storage
Kwh	Kilowatt-hour	MSWU	Million Separative Work Units
L		Mt	Megaton
LAMPF	Los Alamos Meson Physics Facility (Now Clinton P Anderson Meson Physics Facility)	MT	Metric Ton
LANL	Los Alamos National Laboratory	MTU	Metric Ton Uranium
LBL	Lawrence Berkeley Laboratory	Mw	Megawatt
LCTF	Large Coil Test Facility	Mwd	Megawatt-day
Li	Lithium	Mw _e	Megawatt (electric)
Lithco	Lithium Corporation of America	Mw _t	Megawatt (thermal)
LIS	Laser Isotope Separation	N	
LLNL	Lawrence Livermore National Laboratory	N	Neutron
LLW	Low Level Waste	NASAP	Nonproliferation Alternative Systems Assessment Program
		NATO	North Atlantic Treaty Organization
		NAVMAT	N[AV]al M[AT]erial
		NBC	Nuclear Biological and Chemical

Glossary of Abbreviations and Acronyms

NDB	Nuclear Depth Bomb	OD	Outside Diameter
NDEW	Nuclear-Driven Directed Energy Weapons	ODCSOPS	Office of the Deputy Chief of Staff for Operation[S] and Plans
NDRC	National Defense Research Council	OJCS	Office of the Joint Chiefs of Staff
NDT	Non[D]estructive Testing	OMA	Office of Military Application
NERP	(Oak Ridge) National Environmental Research Park	OMB	Office of Management and Budget
NFS	Nuclear Fuel Services	ONEST	Overseas Nuclear Emergency Search Team
nm	Nanometer (10 ⁻⁹ meter)	ORAU	Oak Ridge Associated Universities
NMC	Naval Material Command	ORGDC	Oak Ridge Gaseous Diffusion Complex
NMMSS	Nuclear Materials Management and Safeguard[S]	ORGDP	Oak Ridge Gaseous Diffusion Plant
NNPP	Naval Nuclear Propulsion Program	ORNL	Oak Ridge National Laboratory
Np	Neptunium	OSD	Office of the Secretary of Defense
NPR	New Production Reactor	OSRD	Office of Scientific Research and Development
NR	Nuclear powered Research submarine	OUSDRE	Office of the Under Secretary of Defense for Research and Engineering
NRC	Nuclear Regulatory Commission		
NRDC	Natural Resources Defense Council, Inc	P	
NRL	Naval Research Laboratory	PAL	Permissive Action Link
NSC	National Security Council	PBFA	Particle Beam Fusion Accelerator
NSDD	National Security Decision Directive	PD	Presidential Directive
NSDM	National Security Decision Memorandum	PDM	Program Decision Memorandum
NTRS	National Reactor Testing Station (Now INEL)	PFM	Process Facility Modification
NTS	Nevada Test Site	PHOTINT	P[HO]tographic I[NT]elligence
NUMEC	Nuclear Materials Equipment Corporation	PNL	Pacific Northwest Laboratory
NVO	Nevada Operations Office	POG	Program Officers Group
NWCF	New Waste Calcining Facility	PPBS	Planning, Programming, and Budgeting System
NWDG	Nuclear Weapons Development Guidance	PSP	Plasma Separation Process
NWEF	Naval Weapons Evaluation Facility	PSR	Proton Storage Rin
NWSM	Nuclear Weapons Stockpile Memorandum	Pu	Plutonium
		PuLIS	Plutonium Laser Isotope Separation
O		PUREX	Plutonium U[R]anium E[X]traction
O	Oxygen	PWR	Pressurized Water Reactor

Glossary of Abbreviations and Acronyms

R		SOW	Stand[O]ff Weapon
R	Republican	SR	Savannah River
R&D	Research and Development	SRAM	Short-Range Attack Missile
RBOF	Receiving Basin for Offsite Fuel	SRL	Savannah River Laboratory
RD&T	Research, Development and Testing	SRO	Savannah River Operations office
RDT&E	Research, Development, Testing and Evaluation	SRP	Savannah River Plant
REEC	Reynolds Electrical and Engineering Company	SSBN	Nuclear-powered ballistic missile submarine
RHO	Rockwell Hanford Operations	SSN	Nuclear-powered attack submarine
RMI	Reactive Metals, Inc	STL	Simulation Technology Laboratory
RRR	Reduced-Residual-Radioactivity	STS	Stockpile-to-Target Sequence
RTG	Thermoelectric Generator	SUBROC	S[UB]marine R[OC]ket
RV	Reentry Vehicle	SWU	Separative Work Unit
S		T	
S	Second	T	Tritium; Tera- (10^{12})
SAC	Strategic Air Command; or Senate Appropriations Committee (see Chapter One, footnote 9)	TAN	Test Area North
SADM	Special Atomic Demolition Munition	TASM	Tactical Air-to-Surface Missile, or Tomahawk Anti-Ship Missile
SAF	Secure Automated Fabrication	TBP	Tri[B]utyl Phosphate
SAGA	Studies, Analysis and Gaming Agency	TFTR	Tokamak Fusion Test Reactor
SAMTO	Space And Missile Test Organization	TRADOC	T[RA]ining And D[O]ctrine Command
SASC	Senate Armed Services Committee (see Chapter One, footnote 9)	TREAT	Transient Reactor Test Facility
SECDEF	S[EC]retary of D[EF]ense	TRU	T[R]ans[U]ranic waste
SEU	Slightly Enriched Uranium	TTR	Tonopah Test Range
SICBM	Small ICBM	Tw	Terawatt (10^{12} watts)
SIGINT	S[IG]nals I[NT]elligence	U	
SIS	Special Isotope Separation	U	Uranium
SLBM	Submarine-Launched Ballistic Missile	UCCND	Union Carbide Corporation, Nuclear Division
SNL	Sandia National Laboratories	UF ₄	Uranium tetra[F]luoride
SNLA	Sandia National Laboratories at Albuquerque	UF ₆	Uranium hexa[F]luoride
SNLL	Sandia National Laboratories at Livermore	UO ₂	Uranium Dioxide
SNM	Special Nuclear Material	UO ₃	Uranium Trioxide
		U ₃ O ₈	Uranium Oxide ("yellowcake")
		UK	United Kingdom
		UNH	Uranyl Nitrate Hexahydrate, UO ₂ (NO ₃) ₂ 6H ₂ O

Glossary of Abbreviations and Acronyms

UNI	United Nuclear Industries, Inc	WCF	Waste Calcining Facility
U S	United States	WEC	Westinghouse Electric Corporation
USACDA	United States Arms Control and Disarmament Agency	WHC	Westinghouse Hanford Company
USD(P)	Under Secretary of Defense, Policy	WIPP	Waste Isolation Pilot Plant
USDRE	Under Secretary of Defense for Research and Engineering	WPPSS	Washington Public Power Supply System
U S S R	Union of Soviet Socialist Republics	WSCR	Weapon Design and Cost Report
V		WTR	Western Test Range
VLA	Vertical-Launch ASROC	Y	
VLSI	Very Large Scale Integrated	Yr	Year
VPD	Vertical Polarized Dipole	Z	
W		ZPPR	Zero Power Plutonium Reactor
W	Warhead, or Weapon-grade	ZPR	Zero Power Reactor

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