SECTION 6
REMOVALS

The total quantity of HEU removed from the U.S. inventory for the period between 1945 and September 30, 1996, was **324.6** MTU containing <deleted>. For the purpose of this report, removal categories include the following: b(5)

- Refeed at the enrichment plants
- Nuclear tests and wartime detonations
- Fission and transmutations
- Normal operating losses
- Transfers to foreign countries
- Down blending HEU to LEU
- Inventory differences

It is important to note that the **324.6** MTU removed from the U.S. inventory does not include uranium associated with inventory differences. Data on inventory differences is available only in terms of uranium-235.

REFEED AT THE ENRICHMENT PLANTS

A total of **194.6** MTU containing **114.2** MTU-235 was removed from the HEU inventory and refed into the enrichment processes (**Table 6-1**). Refeed is the reintroduction of HEU, which had been previously produced as a finished product, back into the enrichment process. **Tables 6-2, 6-3**, and **6-4** provide data on HEU removed from the inventory and refed at the Y-12 Plant calutrons, and at the Oak Ridge and the Portsmouth Gaseous Diffusion Plants. Quantities of HEU are presented by year in percent uranium-235 ranges (i.e., 20 to <70 percent).

Refeed at Enrichment Plants

Location	*MTU*
Y-12 Plant Calutrons	4.4
Oak Ridge Gaseous Diffusion Plant	18.6
Portsmouth Gaseous Diffusion Plant	171.6
Total	194.6

For the purposes of the overall material balance, refeed is treated as a removal so as to prevent double counting of HEU produced. This is particularly evident when more than one production site is involved in the enrichment process. For example, HEU produced from the Oak Ridge Gaseous Diffusion Plant between 1945 and 1946 was refed to the Y-12 Plant calutrons to produce 90 percent HEU. Also, in some instances, HEU produced at the Oak Ridge Gaseous Diffusion Plant was later refed at the Portsmouth Gaseous Diffusion Plant.

In the past, HEU was refed into the enrichment process to produce either a higher assay product or to adjust an existing batch of HEU that did not meet the requirements of a specific isotopic specification. For example, 40 percent uranium-235 may have been refed into the cascade and enriched to produce 93 percent material. If this were done, the resulting quantity of 93 percent material would be less than the initial amount of the lower assay refed material. Each kilogram of 93 percent material produced by this means would require approximately 2.33 kilograms of 40 percent material.

Today, HEU is primarily refed to reduce the HEU inventory by down blending HEU to LEU for fuel in commercial nuclear reactors. For example, if 90 percent uranium-235 is available and no longer needed, but LEU at 3 percent is in demand, the 90 percent material can be refed into the cascade to produce 3 percent material. In this case, 30 kilograms of 3 percent material can be produced from 1 kilogram of 90 percent material as feed.

Table 6-1 Total HEU Refed at the Enrichment Plants

Location	Percent U-235[a]								Totals[a]	
	20 to <70%		70 to <90%		90 to <96%		≥96%			
	U	U-235	U	U-235	U	U-235	U	U-235	U	U-235
Y-12 Plant Calutrons	4,418	1,233	--	--	--	--	--	--	4,418	1,233
Oak Ridge Gaseous Diffusion Plant	13,486	5,241	3,308	2,635	1,834	1,714	--	--	18,628	9,590
Portsmouth Gaseous Diffusion Plant	106,230	42,686	8,994	7,121	25,996	24,090	30,331	29,504	171,551	103,401
Total	**124,134**	**49,160**	**12,302**	**9,756**	**27,830**	**25,804**	**30,331**	**29,504**	**194,597**	**114,224**

[a] Quantities are in kilograms.

Table 6-2 HEU Refed at the Y-12 Plant Calutrons

Year	Percent U-235[a]								Totals[a]	
	20 to <70%		70 to <90%		90 to <96%		≥96%			
	U	U-235	U	U-235	U	U-235	U	U-235	U	U-235
1946[b]	4,371	1,218	--	--	--	--	--	--	4,371	1,218
1947	47	15	--	--	--	--	--	--	47	15
Total	**4,418**	**1,233**	**--**	**--**	**--**	**--**	**--**	**--**	**4,418**	**1,233**

[a] Quantities are in kilograms.

[b] Includes HEU cumulative production through 1946.

Table 6-3 HEU Refed at the Oak Ridge Gaseous Diffusion Plant

Year	Percent U-235[a]								Totals[a]	
	20 to <70%		70 to <90%		90 to <96%		≥96%			
	U	U-235	U	U-235	U	U-235	U	U-235	U	U-235
1947	30	9	--	--	1	1	--	--	31	10
1948	18	6	--	--	--	--	--	--	18	6
1949	83	35	68	50	6	6	--	--	157	92
1950	542	217	4	3	--	--	--	--	546	220
1951	9	3	--	--	--	--	--	--	9	3
1952	52	17	11	8	4	3	--	--	67	29
1953	8	3	1	1	1	--	--	--	10	4
1954	19	7	--	--	27	25	--	--	46	32
1955	47	13	5	4	229	214	--	--	281	231
1956	6,404	2,496	2,928	2,328	83	77	--	--	9,415	4,901
1957	14	4	10	9	18	17	--	--	42	30
1958	32	11	3	2	90	84	--	--	125	97
1959	134	45	1	1	65	61	--	--	200	107
1960	178	53	4	3	833	783	--	--	1,015	839
1961	816	266	200	165	249	232	--	--	1,265	663
1962	322	96	--	--	144	135	--	--	467	231
1963	2,318	923	32	23	57	53	--	--	2,408	999
1964	2,297	1,004	42	36	25	23	--	--	2,364	1,064
1965	165	34	--	--	--	--	--	--	165	34
Total	**13,486**	**5,241**	**3,308**	**2,635**	**1,834**	**1,714**	**--**	**--**	**18,628**	**9,590**

[a] Quantities are in kilograms.

Table 6-4 HEU Refed at the Portsmouth Gaseous Diffusion Plant

Year	Percent U-235[a]								Totals[a]	
	20 to <70%		70 to <90%		90 to <96%		≥96%			
	U	U-235	U	U-235	U	U-235	U	U-235	U	U-235
1956	31	15	30	24	3	2	--	--	64	42
1957	71	32	--	--	1	1	--	--	73	34
1958	135	50	8	6	2	2	--	--	145	58
1959	172	46	3	2	1	1	--	--	176	50
1960	63	15	--	--	2	2	--	--	66	17
1961	100	34	10	8	--	--	--	--	110	42
1962	373	201	--	--	--	--	--	--	374	201
1963	286	135	--	--	--	--	--	--	286	135
1964	223	104	57	50	32	29	911	885	1,223	1,068
1965	6,914	3,102	881	727	865	795	--	--	8,660	4,624
1966	266	91	619	526	1,276	1,173	--	--	2,160	1,790
1967	153	76	21	15	42	39	--	--	215	130
1968	76	30	12	10	48	45	510	498	646	583
1969	2,367	799	998	852	9,662	8,949	2,625	2,549	15,651	13,150
1970	4,108	1,695	1,017	866	1,956	1,807	1,385	1,344	8,466	5,712
1971	2,210	910	922	702	1,691	1,586	715	698	5,537	3,896
1972	20,181	7,657	400	306	1,694	1,566	883	861	23,159	10,390
1973	23,145	8,750	220	179	1,282	1,178	15	15	24,662	10,122
1974	9,569	4,193	1,427	1,028	1,315	1,215	967	941	13,277	7,376
1975	8,847	4,284	435	344	1,500	1,392	1,511	1,467	12,294	7,487
1976	13,169	5,404	1,383	995	2,672	2,490	999	970	18,223	9,859
1977	7,048	2,635	32	28	736	683	2,968	2,889	10,785	6,235
1978	821	325	14	12	167	157	2,697	2,624	3,700	3,119
1979	1,353	507	213	190	254	236	423	410	2,243	1,343
1980	2	1	--	--	280	258	--	--	281	259
1981	1,135	416	90	73	--	--	2,852	2,776	4,077	3,266
1982	3,370	1,165	4	3	5	5	2,191	2,133	5,571	3,306
1983	6	2	--	--	21	20	142	138	169	160
1984	--	--	12	10	23	22	109	106	144	138
1985	20	6	--	--	42	39	34	33	96	78
1986	--	--	--	--	16	15	611	595	628	610
1987	--	--	--	--	--	--	1,756	1,709	1,756	1,709
1988	--	--	--	--	--	--	483	470	483	470
1989	--	--	--	--	--	--	2,405	2,340	2,405	2,340
1990	--	--	--	--	--	--	2,111	2,053	2,111	2,053
1991	--	--	--	--	--	--	849	826	849	826
1992	--	--	--	--	--	--	--	--	--	--
1993	--	--	--	--	--	--	41	40	41	40
1994	--	--	--	--	--	--	--	--	--	--
1995	15	6	13	10	273	255	55	53	356	325
1996	--	--	173	152	133	126	84	81	390	359
Total	**106,230**	**42,686**	**8,994**	**7,121**	**25,996**	**24,090**	**30,331**	**29,504**	**171,551**	**103,401**

[a] Quantities are in kilograms.

Nuclear Tests and Wartime Detonations

HEU was expended in 1,054 U.S. nuclear tests and one wartime detonation from 1945 through 1992. No nuclear weapons tests have been conducted by the U.S. since 1992. It is important to note that not all of these nuclear tests included the expenditure of HEU, and some comprise multiple detonations.

Figure 6-1 provides an annual account of the nuclear tests conducted by the United States. For national security reasons, the HEU expended is combined with the amount of HEU consumed in naval reactors. This data (**31.9** MTU-235) is listed in Table 4-1 of this report under "Removals" as "Nuclear Test and Wartime Detonations, and Naval Reactor Use."

U.S. Nuclear Tests and Wartime Detonations

✓ The U.S. conducted a total of **1,054** nuclear weapons tests and peaceful nuclear explosions beginning in July 16, 1945, with the first U.S. nuclear weapon test, code named "Trinity." Of the **1,054** tests conducted, **1,030** were conducted solely by the U.S. and **24** were conducted jointly with the United Kingdom.

✓ In August 1945, the U.S. detonated **two** nuclear weapons over Japan in World War II. The first bomb, "Little Boy," was dropped on Hiroshima on August 6, 1945 and was a uranium gun-type weapon. The second, "Fat Man," was dropped on Nagasaki on August 9,1945 and was an implosion-type weapon with a plutonium pit. These nuclear weapons were intended to end World War II as quickly as possible.

Purpose of U.S. Nuclear Tests

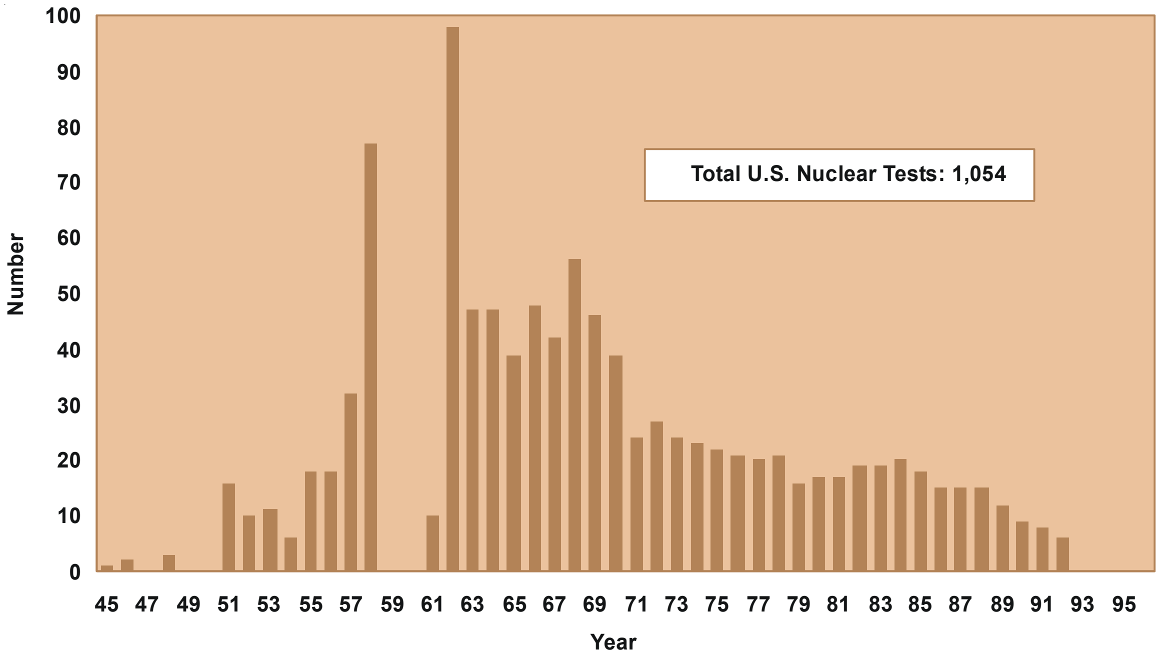
The United States performed its nuclear tests for several reasons. The following paragraphs define the seven different purposes for these detonations.

- Joint U.S.-United Kingdom (U.K.) - The U.S. conducted 24 joint nuclear tests with the U.K. at the Nevada Test Site between 1962 and 1991. These nuclear tests were in accordance with the cooperative agreement in effect between the two countries since August 4, 1958.
- Plowshare - During the 1960s and 1970s, the U.S. Government investigated the application of nuclear explosives for peaceful purposes, such as large-scale earth moving projects. This effort was called Project Plowshare. A total of 35 nuclear detonations were conducted as part of Project Plowshare between 1961 and 1973. Most Plowshare detonations were at the Nevada Test Site; however, some experiments were also conducted at Carlsbad and Farmington, New Mexico; and Grande Valley and Rifle, Colorado.
- Safety Experiments - Eighty-eight safety experiments were designed to confirm that a nuclear explosion would not occur in case of an accidental detonation of the explosive associated with the device.
- Storage and Transportation - Four tests were performed at Nellis Air Force Base, Nevada, in 1963 to study distribution of nuclear materials during accidents in several transportation and storage configurations.
- Vela Uniform - This was a DoD program to improve the United States' ability to detect, identify, and locate nuclear explosions from a great distance. The Vela Uniform tests that

began in 1963 with the Shoal detonation in Fallon, Nevada, continued through 1971. In addition, six other Vela Uniform tests were conducted: one at Amchitka, Alaska; two at Hattiesburg, Mississippi; and three at the Nevada Test Site.

- Weapons Effects - One hundred detonations were conducted to evaluate the military effects of a nuclear detonation on various targets, such as structures, equipment, and other weapons.
- Weapons Related - Eight hundred ninety-one detonations were weapons-related tests to prove that a weapon would function as designed or to advance weapon design.

Figure 6-1 Total Nuclear Tests Conducted by the U.S.



Notes:

1 From November 1958 to August 1961, the U.S. did not conduct any nuclear weapons tests as part of a moratorium on testing, which was also observed by the United Kingdom and the former Soviet Union.

2 On August 5, 1963, the U.S. and the former Soviet Union signed the Limited Test Ban Treaty, which effectively banned testing of nuclear weapons in the atmosphere, the oceans, and space.

3 On October 2, 1992, the U.S. entered into another unilateral moratorium on nuclear weapons testing. This moratorium was extended through September 1996.

4 In September 1996, President Clinton signed the Comprehensive Test Ban Treaty, which prohibited all nuclear testing.

Nuclear Testing Sites

The U.S. Government conducted its nuclear tests primarily in the United States and the South Pacific Ocean. **Figure 6-2** provides the number of nuclear tests by location. The following paragraphs summarize activities at the nuclear test sites.

- Alaska - Three nuclear tests were conducted on Amchitka Island, Alaska: Long Shot on October 19, 1965, Milrow on October 2, 1969, and Cannikin on November 6, 1971.

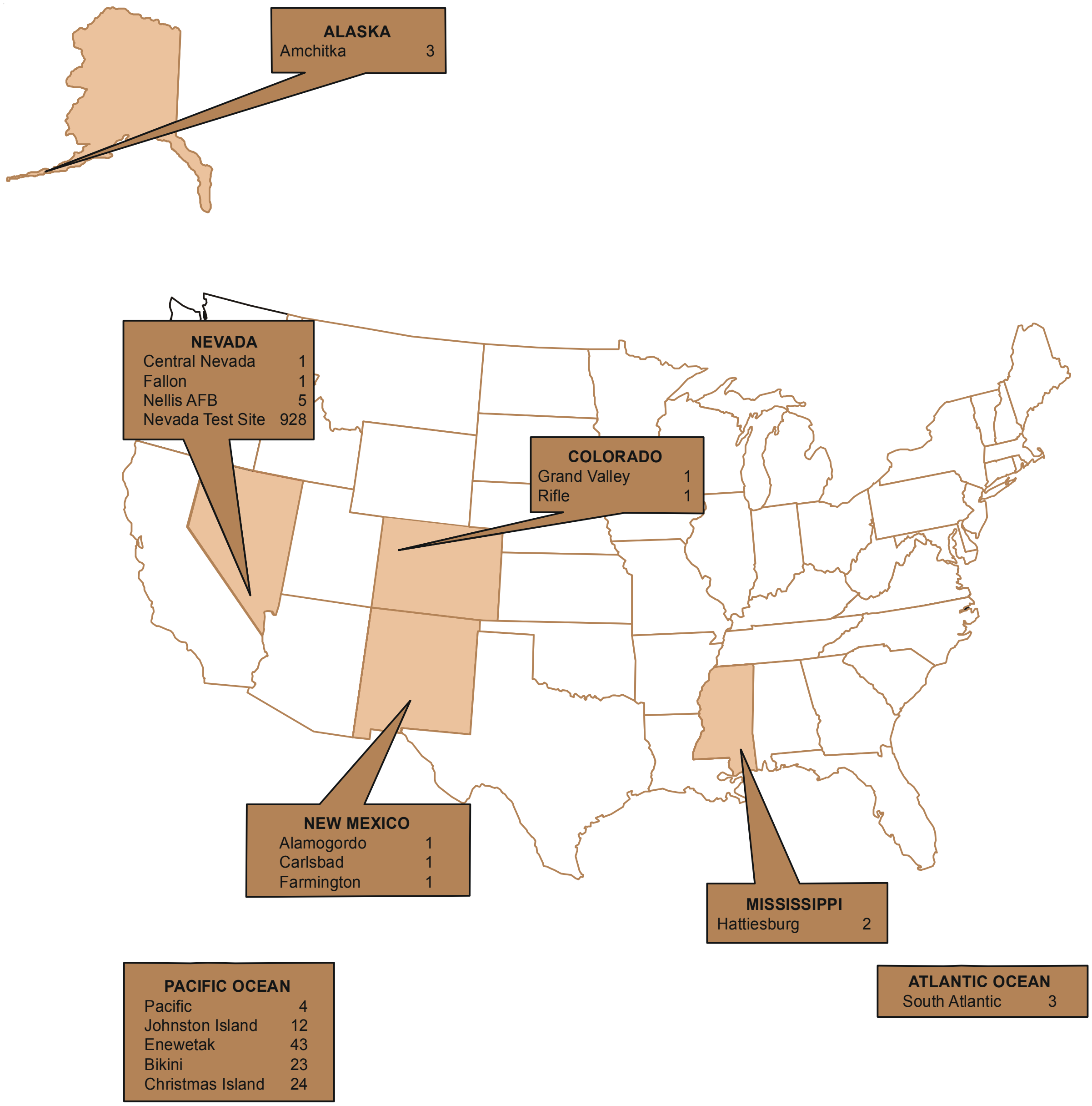
Long Shot was for nonweapons purposes (part of the Vela Uniform program) while Cannikin and Milrow were weapons-related tests. The area is now managed as the Amchitka Island Test Site.

- Colorado - Two nuclear tests were conducted in Colorado, one each at Grand Valley and Rifle. Both tests were part of Project Plowshare. Shot Rulison was conducted in Grand Valley on September 10, 1969, and Rio Blanco in Rifle on May 17, 1973.
- Mississippi - Two nuclear tests were conducted in Hattiesburg, Mississippi, both of which were part of Vela Uniform. Shot Salmon was conducted on October 22, 1964, and Sterling on December 3, 1966.
- Nevada - Nevada Test Site (NTS) was established in 1951 and was originally known as the Nevada Proving Grounds. A test site in the continental United States reduced the costs and logistical delays involved in testing in the South Pacific. The site also allowed the Army to conduct land-based troop maneuvers to simulate atomic warfare. There have been 928 nuclear tests at NTS since 1951. The first nuclear test, called Able, occurred January 27, 1951, and was an air-dropped air burst. The last test, called Divider, was on September 23, 1992. Most of the tests at NTS were weapons related.
- Nevada -- Other Sites - Shot Shoal, a Vela Uniform test, was detonated in Fallon, Nevada, in 1963. Nuclear test Faultless, a weapons-related seismic calibration test, was detonated in central Nevada on January 19, 1968. A total of five shots were conducted at Nellis Air Force Base, Nevada. The first shot was a safety experiment in 1957 followed by four storage and transportation shots in 1963.
- New Mexico - The first United States nuclear weapon test, code named Trinity by the Manhattan Engineer District, occurred on July 16, 1945, in Alamogordo, New Mexico. The Trinity test site was the Jornada del Muerto region in the northwest corner of the Alamogordo Bombing Range in southern New Mexico. Today, the site is part of the White Sands Missile Range. Additionally, two nuclear tests were conducted at Carlsbad and Farmington, New Mexico as part of Project Plowshare on September 10, 1961, and December 12, 1967, respectively.
- Pacific - A total of 106 nuclear tests were conducted in the Pacific from 1946 through 1962. Bikini Atoll and Enewetak Atoll in the South Pacific were the sites of weapons testing following the end of World War II, beginning with Operation Crossroads at Bikini Atoll in June and July of 1946. After a two-year hiatus, testing in the Pacific resumed in 1948. The primary Pacific test site was the Enewetak Proving Ground, although significant thermonuclear testing was conducted near and on some of the islands of Bikini. The Enewetak Proving Ground was placed on standby after Operation Hardtack I in 1958 and officially abandoned in 1960. Other nuclear weapons tests were conducted in the Pacific Ocean, including Johnston Island and Christmas Island. The last test, called Tightrope, was conducted in the Johnston Island area on November 4, 1962.
- Atlantic - The United States also conducted nuclear weapons tests in the Atlantic Ocean. Operation Argus included three high-altitude tests in the South Atlantic in 1958.

Workers at the Nevada Test Site prepare for an underground nuclear test by lowering a diagnostic/ weapons canister into hole.

Additional information on nuclear tests is available in the DOE report, *United States Nuclear Tests, July 1945 through December 1992* (DOE 1994b).

Figure 6-2 U.S. Nuclear Tests By Location



Purpose	Alaska	Nevada	Colorado	New Mexico	Mississippi	Atlantic	Pacific
Joint U.S.-U.K.		●					
Plowshare		●	●	●			
Safety Experiment		●					●
Storage-Transportation		●					
Vela Uniform	●	●			●		
Weapons Effects		●					●
Weapons Related	●	●		●		●	●

On July 24, 1946, the Baker shot was conducted at Bikini Atoll in the Pacific Ocean. This underwater nuclear test was the third conducted by the U.S., and its purpose was to study weapons effects.

The Sedan Crater was formed when a 104 kiloton thermonuclear device buried 635 feet underground was fired at the Nevada Test Site on July 6, 1962. This test was part of the Plowshare Program.

Fission and Transmutations

Fission and Transmutations	
Location	MTU
Savannah River Site	46.1
Other Government and Commercial	4.4
Total	50.5

A total of **50.5** MTU and **56.2** MTU-235 were removed from the HEU inventory from fission and transmutations (**Table 6-5**). Fission and transmutation removals account for HEU consumed by nuclear irradiation during reactor operation. It is important to note that the total quantity of uranium-235 consumed is larger than that of total uranium. The reason for this is that in HEU reactors, some of the uranium-235 is converted into uranium-236 by transmutation.

The largest consumers of HEU in this category were the Savannah River Site production reactors and the Naval Nuclear Propulsion Program (NNPP) reactors.

Nuclear Materials Production

The five Savannah River Site reactors, code named R, P, L, K and C, consumed large quantities of HEU in the production of plutonium, tritium, and other isotopes. The Savannah River Site reactors were the largest consumers of HEU, accounting for approximately 91 percent (**46.1** MTU) of the overall total from 1955 through 1996. Prior to 1968, these reactors used natural uranium for plutonium production and HEU for making tritium. In 1968, they were converted to use HEU as fuel for both plutonium and tritium production.

Naval Nuclear Propulsion Program

The Naval Nuclear Propulsion Program reactors consumed large quantities of HEU as fuel for the production of nuclear power for submarines, surface ships, and training platforms. In total, the Navy had built over 200 nuclear-powered ships. Of these, 96 nuclear-powered submarines, 4 surface ships, 8 aircraft carriers, and 4 training platforms were still in operation in 1996. For national security reasons, the amount of HEU for fission and transmutation for naval reactors is included with the amount of HEU expended in nuclear tests and wartime detonations. This data is listed in Table 4-1 of this report under “Removals” as “Nuclear Tests, Wartime Detonations, and Naval Reactor Use.”

In support of the NNPP, the DOE constructed and operated nine training platforms of new design nuclear propulsion plants for basic research and development work on advanced reactor plants and long-life cores. These reactors were located in Idaho, New York, and Connecticut. Of these nine platforms, only two are still in operation, both located in New York.

Other Government and Commercial Reactors

Other government and commercial reactors used HEU for the production of power, research and development activities, and the production of isotopes. These reactors accounted for approximately 6 percent (**4.4** MTU) of the overall total through 1996. Some examples of these reactors are as follows:

- Production of Power - The Army Nuclear Power Program developed specialized nuclear power reactors, which were operated by military services in some of the most remote areas of the world. These reactors largely eliminated the need for supplying large amounts of fossil fuel. During the life of the program (1954-1977), the Army designed, constructed, and deactivated nine nuclear power program facilities. Appendix D provides more information on the Naval Nuclear Propulsion and Army Nuclear Power Programs.

  An example of a commercial reactor that utilized HEU for the production of power was the Fort St. Vrain Nuclear Generating Station in Platteville, Colorado. Fort St. Vrain first produced power in December 1976 with a capacity of 342 megawatts and used HEU enriched to about 93.15 percent uranium-235. In August 1989, Fort St. Vrain was shut down.

- Research and Development - Research and development was primarily conducted at the Idaho National Engineering and Environmental Laboratory (INEEL). Over 52 research and test reactors at INEEL have been used through the years to develop, demonstrate, and improve reactor systems, fuel and target designs, and overall safety. Some of the more notable reactors at INEEL that have used HEU include the Advanced Test Reactor, Engineering Test Reactor, Experimental Breeder Reactor II, and Materials Testing Reactor.

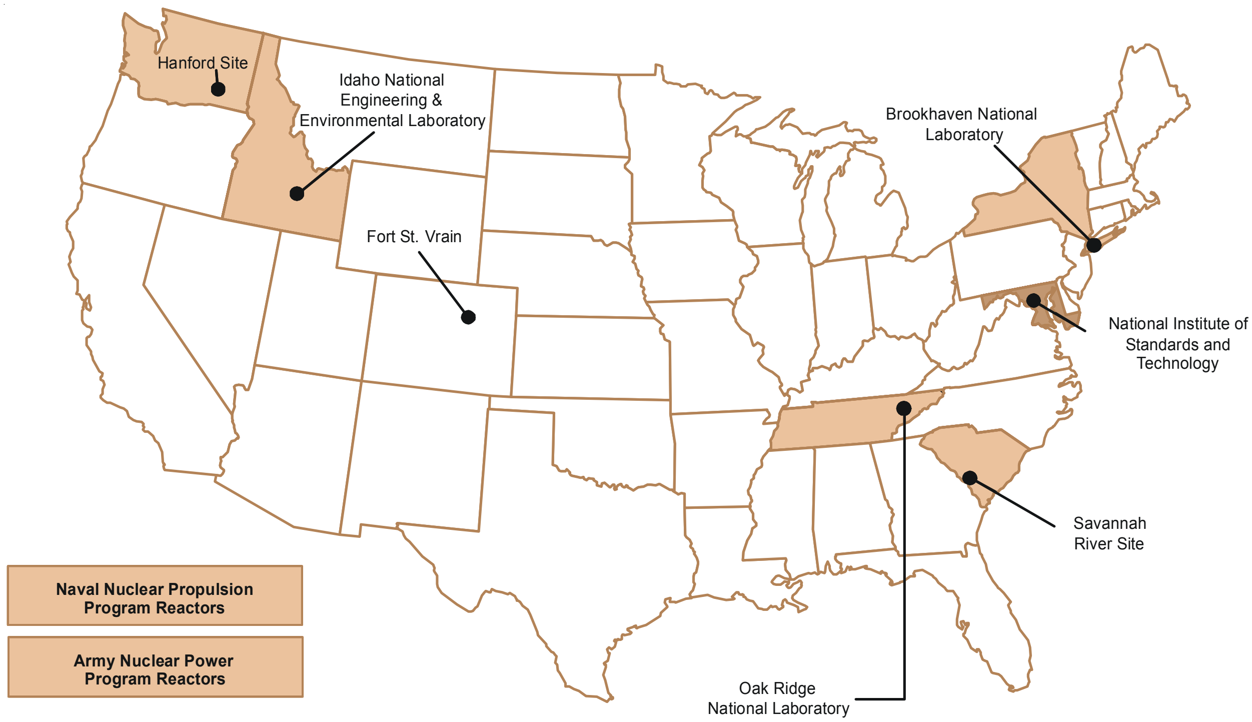
  Research and development was also conducted at other locations. For example, the National Institute of Standards and Technology (NIST) research reactor in Gaithersburg, Maryland, focuses on the establishment of measurements and standards. The NIST reactor uses HEU to provide a neutron source for industry researchers and scientists. The High Flux Beam Reactor at the Brookhaven National Laboratory used HEU for studies in chemistry, physics, materials science, medicine, and biology.

- Production of Isotopes - The High Flux Isotope Reactor at the Oak Ridge National Laboratory uses HEU for the production of isotopes. These isotopes are used in cancer radiotherapy, mineral exploration, and neutron radiography.

After the spent nuclear fuel has been irradiated and removed from a reactor, it is either sent away for reprocessing or storage. Spent nuclear fuel has been reprocessed or stored primarily at the Idaho Chemical Processing Plant or the Savannah River Site. Appendix C provides a complete listing of the location of all spent HEU fuel in the U.S.

The U.S. Navy submarines, surface ships, and training platforms have consumed large quantities of HEU as fuel for the production of power. Shown is the bow view of a 688 class nuclear-powered fast attack submarine.

Table 6-5 Cumulative HEU Fission and Transmutations



Site	kg U	kg U-235
Savannah River Site Reactors (R, P, L, K and C)	46,149	50,996
Idaho National Engineering and Environmental Laboratory	1,553	1,915
Oak Ridge National Laboratory	1,059	1,247
Brookhaven National Laboratory	292	353
Other Reactors	1,476	1,714
Total	**50,529**	**56,225**

Notes:

1 Idaho National Engineering and Environmental Laboratory reactors include the Advanced Test Reactor, Engineering Test Reactor, Experimental Breeder Reactor II, and Materials Test Reactor.

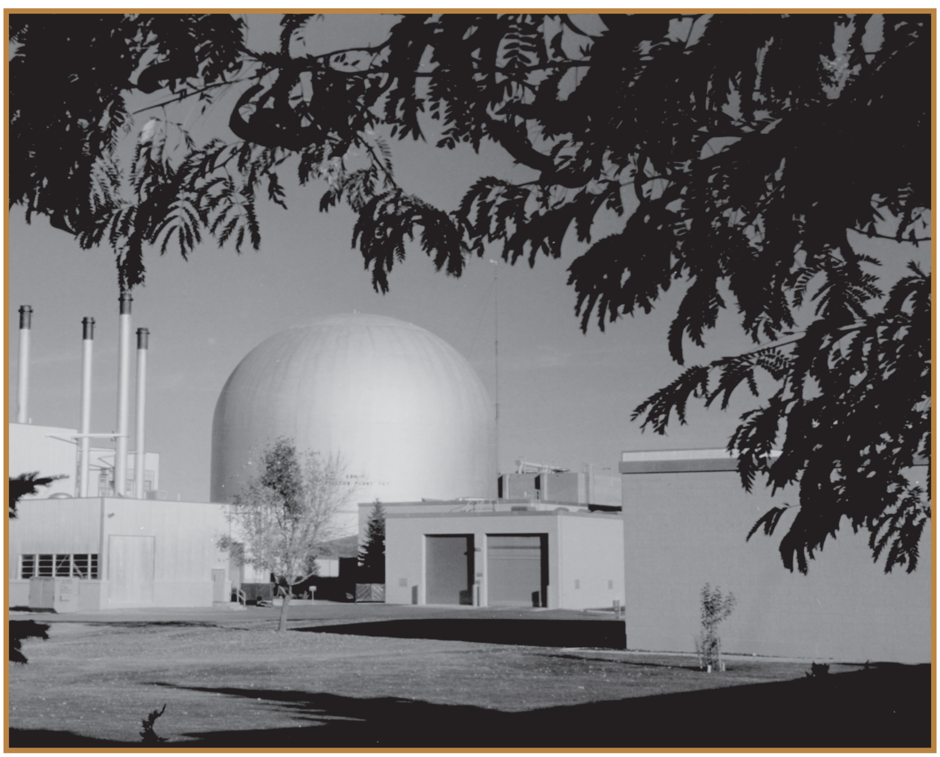
2 Oak Ridge National Laboratory reactors include the High Flux Isotope Reactor.

3 Brookhaven National Laboratory reactors include the High Flux Beam Reactor.

4 Other reactors include the Army Nuclear Power Program reactors, the Fort St. Vrain reactor, the National Institute of Standards and Technology research reactor, and the Hanford production reactors.

5 Naval Nuclear Propulsion Program reactors are not included for national security reasons.

The Savannah River Site reactors were the largest consumers of HEU for the production of nuclear materials. The SRS P-reactor operated from 1954 to 1988.



Other government and commercial reactors used HEU for the production of power; research and development activities; and the production of isotopes. The Experimental Breeder Reactor-II at the Idaho National Engineering and Environmental Laboratory was designed to demonstrate the feasibility of using sodium-cooled fast breeders for central station power plants.

Normal Operating Losses

Normal Operating Losses

Location	*MTU*
Total DOE Sites	3.2
Total Commercial Sites	2.9
Total	**6.1**

A total of **6.1** MTU containing **4.9** MTU-235 was removed from the HEU inventory as normal operating losses from 1945 through 1996 **(Table 6-6)**. Normal operating losses (also referred to as measured discards) are part of the waste inventory. HEU is declared a normal operating loss when it is determined to be technically or economically unrecoverable. It should be noted that quantities of HEU in spent fuel and HEU expended in weapons testing activities are not considered normal operating losses and are therefore not included in the above stated numbers.

Each process in the production or utilization of HEU generates normal operating losses that are as varied as the processes that produced them. Each of these normal operating losses differs in physical characteristics and chemical properties. Normal operating losses can be categorized as follows:

- **Irradiated Material** - This category of normal operating losses includes highly radioactive solutions from the reprocessing of spent HEU fuel. These normal operating losses were generated primarily at the Idaho Chemical Processing Plant and the Savannah River Site. Most of these solutions are stored in large underground tanks and are part of the high-level waste inventory.
- **Unirradiated Solids** - This category of normal operating losses occurs from the production and processing of unirradiated HEU. While these normal operating losses have a wide range of characteristics, most contain small amounts of radioactivity in large volumes of material. Examples include rags, protective clothing, contaminated equipment, waste resulting from decontamination and decommissioning, construction debris, filters, and scrap metal. Most unirradiated solids have been buried near the earth's surface and are part of the low-level waste inventory.
- **Unirradiated Liquids** - This category of normal operating losses occurs primarily from the chemical processing of unirradiated HEU that generate liquid waste streams. These normal operating losses contain small concentrations of uranium with small amounts of radioactivity. Most are generated from the chemical reprocessing of unirradiated reactor fuels. Additionally, small quantities are generated from site cleanup. Historically, these liquids were held in ponds for solar evaporation.

Department of Energy Sites

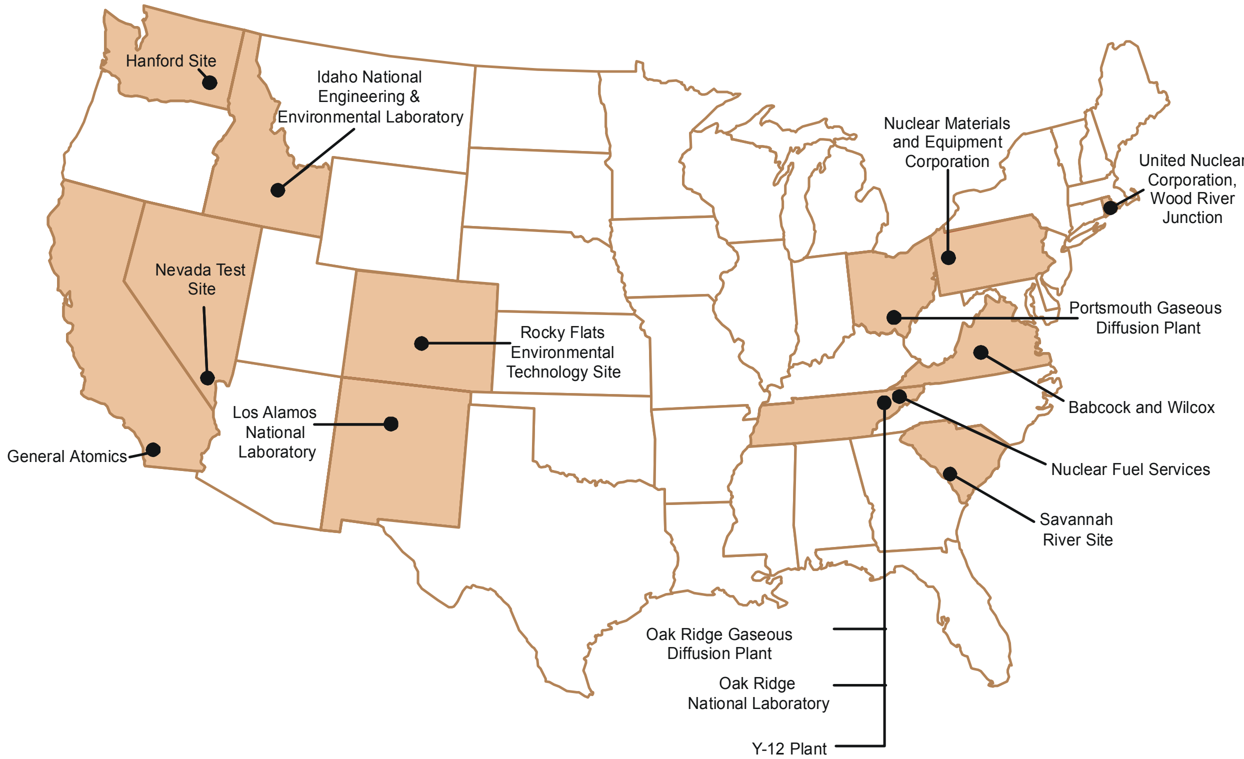
DOE sites removed a total of **3.2** MTU containing **2.4** MTU-235 as normal operating losses. The sites with the largest quantities of HEU removed as normal operating losses are the Y-12 Plant (**1.4** MTU), the Savannah River Site (**0.5** MTU), and the Idaho National Engineering and Environmental Laboratory (**0.2** MTU). These three sites account for approximately 65 percent of all of the Department's HEU normal operating losses.

Commercial Sites

Commercial sites removed a total of **2.9** MTU containing **2.5** MTU-235 as normal operating losses. The sites with the largest quantities of HEU removed as normal operating losses are Babcock and Wilcox, General Atomics, Nuclear Fuel Services, Nuclear Materials and Equipment Corporation, and United Nuclear Corporation. Waste from these sites was shipped to five commercial disposal sites: Sheffield, Illinois; Morehead, Kentucky; Beatty, Nevada; Barnwell, South Carolina; and Grantsville, Utah. The inventories at these five sites came primarily from normal operating losses at commercial facilities that fabricated reactor fuel or reprocessed unirradiated enriched uranium for the Department.

For more information on the DOE's waste inventory as it relates to environmental, safety and health across its sites, refer to the DOE Office of Environmental Management report, *Closing the Circle on the Splitting of the Atom* (DOE 1995b).

Table 6-6 Cumulative HEU Normal Operating Losses



Site	kg U	kg U-235
Hanford Site	111	76
Idaho National Engineering & Environmental Laboratory	215	142
Los Alamos National Laboratory	196	166
Nevada Test Site	123	115
Oak Ridge Gaseous Diffusion Plant	13	6
Oak Ridge National Laboratory	48	35
Portsmouth Gaseous Diffusion Plant	189	92
Rocky Flats Environmental Technology Site	161	150
Savannah River Site	528	382
Y-12 Plant	1,395	1,148
Other DOE Sites	182	102
Commercial Sites[a]	2,954	2,514
Total	**6,115**	**4,928**

[a] The majority of this quantity is from Babcock and Wilcox, General Atomics, Nuclear Fuel Services, Nuclear Materials and Equipment Corporation, and United Nuclear Corporation.

Oak Ridge National Laboratory personnel deal with a wide assortment of wastes, including hazardous chemicals and radioactive materials.

The Oak Ridge Y-12 Plant removed the largest quantities of HEU as normal operating losses. The S-3 Ponds at Y-12 were built in 1951 as a disposal site for liquid wastes. Today, a parking lot is located where the four ponds shown once stood.

HEU Transfers to Foreign Countries

b(5) From 1957 through 1996, the U.S. transferred **<deleted>**
b(5) containing **<deleted>** to foreign countries under two
types of Agreements for Cooperation: (1) peaceful uses
of atomic energy, and (2) mutual defense purposes.
b(5) Authorization for these U.S. international activities is
b(5) permitted by Section 54 of the Atomic Energy Act, as
amended.

Transfers to Foreign Countries

Agreement Type	***MTU***
Peaceful Uses of Atomic Energy	25.6
Mutual Defense Purposes	**<deleted>**
Total	**<deleted>**

Peaceful Uses of Atomic Energy

A total of **25.6** MTU containing **18.6** MTU-235 was exported from the U.S. to various countries for peaceful uses of atomic energy. In accordance with these agreements, the U.S. transferred HEU to foreign countries for use in research applications, including research materials testing, experimental reactors, and reactor experiments. Almost all of this material was exported to Euratom countries, Canada, and Japan. **Figure 6-3** provides the annual quantities of U.S. HEU exported to foreign countries for peaceful uses of atomic energy between 1957 and 1994. No HEU was exported during 1995 and 1996. **Tables 6-7** and **6-8** provide the location and quantities of U.S.-origin HEU exported to Euratom and non-Euratom countries.

The first comprehensive report on HEU exported by the U.S. under international Agreements for Cooperation for the Peaceful Uses of Atomic Energy was published by the NRC in January 1993. The NRC report, *The United States Nuclear Regulatory Commission's Report to Congress on the Disposition of Highly Enriched Uranium Previously Exported from the United States* (NRC 1993), was prepared in response to Section 903(b) of the Energy Policy Act of 1992. This report updates information in the 1993 NRC report through September 1996.

The U.S. entered into many international agreements for the sale or lease of enriched uranium for civil use. These agreements established guidelines and procedures for the use of the material supplied. For example, material supplied for civil use would not be diverted for military use. The majority of the enriched uranium supplied to foreign countries was for use in experimental and research reactors. The enriched uranium was shipped in accordance with applicable agreements.

The export quantities shown in Tables 6-7 and 6-8 reflect the amount of HEU exported from the U.S. to a foreign country of first destination. First destination does not necessarily mean that the receiving country was the ultimate destination for the HEU, only that it was the first foreign receipt for the material. For example, HEU sent to France for fabrication into reactor fuel for a reactor in Switzerland is counted as a delivery to France, not to Switzerland. Therefore, U.S. HEU exports minus imports do not necessarily equal inventories for individual countries. Examples of this are as follows:

- While most U.S. exports of HEU were unirradiated, most imports of HEU were irradiated. A substantial amount of the uranium-235 in HEU is converted to fission products and some of the uranium-238 is converted to plutonium isotopes during irradiation. For example, if the U.S. sent 100 kg of HEU to a foreign research reactor (FRR) and ten years later the FRR sent 60 kg of irradiated HEU back to the U.S., the actual inventory at the FRR might be zero. A direct comparison of the amounts exported and imported would imply an inventory of 40 kg. This is not the case. The amounts of HEU fissioned and transmuted must be accounted for if inventories are to be calculated.
- Some HEU becomes LEU once discharged from a reactor. This is particularly true of HEU at the lower enrichment range. As the fuel is irradiated, the uranium-235 fissions faster than the uranium-238 experiences neutron capture and converts to plutonium isotopes. The net result is irradiated fuel that contains less than 20 percent uranium-235, which is defined as LEU.
- Retransfers of U.S.-origin HEU from one foreign country to another are not accounted for in this report. The U.S. relies on the IAEA to apply international safeguards on U.S.-origin HEU retransferred from one foreign country to another.
- Other processes that could have been applied to HEU exported by the U.S. are blending and reenrichment. For example, HEU could have been blended with LEU in a foreign country to produce a larger quantity of HEU at a lower assay. This could result in a net production of HEU outside of the U.S. On the other hand, HEU could have been fed to a foreign enrichment facility to increase its assay, resulting in a net loss of HEU.
- Some non-U.S.-origin HEU may have been delivered to the U.S. as spent fuel. Note that this material would not be traceable to an original delivery from the U.S.

Figure 6-3 HEU Exported to Foreign Countries for Peaceful Uses of Atomic Energy

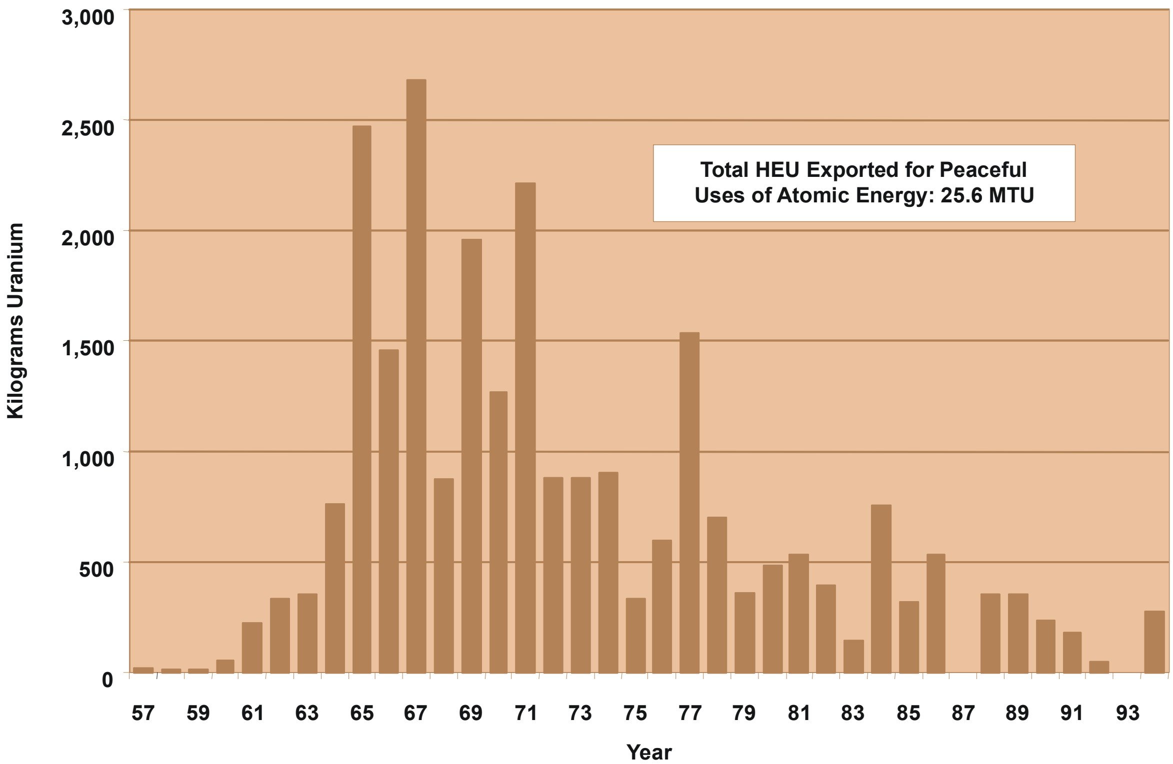


Table 6-7 U.S. HEU Exported to Euratom Countries for Peaceful Uses of Atomic Energy

Country	Percent U-235[a]				Total[a]	
	20 to <90%		≥90%			
	U	U-235	U	U-235	U	U-235
Austria	8	7			8	7
Belgium	162	137	25	23	187	160
Denmark	21	19	5	5	26	24
France	3,018	1,481	4,647	4,330	7,665	5,811
Germany	6,842	3,434	4,431	4,113	11,273	7,547
Greece			7	6	7	6
Italy	301	258	51	48	352	306
Netherlands	49	44	15	13	64	57
Portugal			8	7	8	7
Spain	9	8			9	8
Sweden	137	123	11	10	148	133
United Kingdom[b]	51	37	1,303	1,213	1,354	1,250
Total	**10,598**	**5,548**	**10,503**	**9,768**	**21,101**	**15,316**

[a] Quantities are in kilograms.

[b] The quantity of HEU exported by the U.S. to the U.K. under the Mutual Defense Agreement is not included in this table. In addition, the <deleted> NRC report to Congress (NRC <deleted>) overstated exports under b(5)
Peaceful Use Agreements by <deleted> uranium. The <deleted> were actually exported as part of the b(5)
U.S.-U.K. Mutual Defense Agreement.

Table 6-8 U.S. HEU Exported to Non-Euratom Countries for Peaceful Uses of Atomic Energy

Country	Percent U-235[a]				Total[a]	
	20 to <90%		>90%			
	U	U-235	U	U-235	U	U-235
Argentina	27	24	31	28	58	52
Australia	10	9			10	9
Brazil			8	7	8	7
Canada	43	29	2,144	1,997	2,187	2,026
Colombia	2	2	1	1	3	3
Iran			6	5	6	5
Israel	10	9	9	8	19	17
Japan	1,523	507	531	493	2,054	1,000
Mexico	11	8			11	8
Pakistan	6	5			6	5
Philippines			3	3	3	3
Romania			39	37	39	37
Slovenia	5	3			5	3
South Africa	8	7	25	23	33	30
South Korea	25	18			25	18
Switzerland	7	6	2	2	9	8
Taiwan			10	9	10	9
Thailand	5	5			5	5
Turkey	5	5			5	5
Other			1	1	1	1
Total	**1,687**	**637**	**2,810**	**2,614**	**4,497**	**3,251**

[a] Quantities are in kilograms.

Pictured are the Japanese research reactors JRR-1, JRR-2, and JRR-3.

Mutual Defense Agreements

From <deleted> through <deleted>, under this Agreement for Cooperation, the U.S. transferred b(5)
a total of <deleted> containing <deleted> to the U.K. Of that total amount, 7.5 MTU and 6.7 b(5)
kilograms of tritium were transferred to the U.K. in exchange for 5.4 metric tons of plutonium (5,366 kg). Additional details on these transfers remain classified for national security reasons.

This agreement, as amended, provided for the exchange of information covering the design and use of atomic weapons and other military applications of atomic energy, and for the sale to the U.K. of a nuclear submarine propulsion plant and fuel. The purpose of the agreement was for improving the U.K.'s state of training, operational readiness, and atomic weapon design, development and fabrication capability.

Down Blending

Through September 30, 1996, a total of **3.5** MTU containing approximately **1.5** MTU-235 was removed from the U.S. HEU inventory through the down blending of HEU to LEU. Down blending occurred primarily at the Oak Ridge Y-12 Plant, the Oak Ridge Gaseous Diffusion Plant, and the Portsmouth Gaseous Diffusion Plant. It is important to note that these values may be somewhat understated since data for fiscal year 1977 and all fiscal years prior to 1976 were not available for the Oak Ridge Y-12 Plant.

HEU Down Blending

- ✓ **Total Down Blending – 3.5** MTU (3,475 kilograms) containing **1.5** MTU-235 (1,471 kilograms).
- ✓ **Primary Down Blending Sites** – Oak Ridge Y-12 Plant, Oak Ridge Gaseous Diffusion Plant, and Portsmouth Gaseous Diffusion Plant.
- ✓ **Example:** If 1 kilogram of HEU at a 20 percent enrichment is mixed with 1 kilogram of LEU at a 10 percent enrichment, the resultant mixture will contain 2 kilograms of LEU at an enrichment of 15 percent. This decreases the HEU inventory while increasing the LEU inventory by 1 kilogram.

For the purpose of this report, down blending occurs when HEU is mixed with either depleted, natural, or LEU to form a new product that is not HEU (less than 20 percent uranium-235). The resulting product will, of course, be the average of all of the materials mixed.

HEU is down blended to produce LEU for use in research and development activities, and to reduce weapons-usable fissile material.

Research and Development Activities

In the U.S., most HEU down blending occurred primarily to produce LEU as fuel in research reactors. Many research reactors in the U.S. and elsewhere currently use LEU enriched to approximately 19.75 percent uranium-235. To supply these reactors with the necessary fuel, the U.S. down blended HEU to produce LEU. Down blending has been performed primarily at the Y-12 Plant.

Reduction of Weapons-Usable Fissile Material

The end of the Cold War concluded the nuclear materials production and arms race between the United States and the former Soviet Union. As a result, significant quantities of weapons-usable fissile materials are no longer needed for defense purposes. These surplus fissile materials could pose a danger to national and international security in the form of potential proliferation of nuclear weapons and potential environmental, safety, and health consequences if they are not properly safeguarded and managed.

Consequently, in August, 1996, the Department issued a Record of Decision (ROD) for the Disposition of Surplus Highly Enriched Uranium Final Environmental Impact Statement, which declared that surplus HEU would be made non-weapons-usable by downblending it to LEU for commercial use as reactor fuel to the extent practical. This ROD supports the U.S. nuclear weapons nonproliferation policy by reducing global stockpiles of surplus HEU and recovers the economic value of the materials to the extent feasible. As part of this program, the DOE initially transferred 13 metric tons of U.S. surplus HEU to the USEC for downblending.

Another example of down blending HEU for the reduction of weapons-usable fissile material is the HEU obtained by the U.S. from the former Soviet Republic of Kazakhstan in 1994. The U.S. intends to down blend all **652** kilograms of this HEU containing **581** kilograms of uranium-235. The down blending of this material was performed at a BWX Technologies facility in Lynchburg, Virginia.

Down blending occurred primarily at the Oak Ridge Y-12 Plant and at other sites, including the Oak Ridge Gaseous Diffusion Plant and Portsmouth Gaseous Diffusion Plant. Pictured is an aerial view of the Oak Ridge Y-12 Plant.

INVENTORY DIFFERENCES

Inventory Differences

Location	MTU-235
Department of Energy Sites	1.6
Commercial Sites	1.6
Total	**3.2**

The cumulative HEU inventory difference from 1945 through September 1996 is **3.2** MTU-235. Data on uranium is not provided since inventory difference information is available only in terms of uranium-235. Data on inventory differences are presented in **Tables 6-9** and **6-10** as a cumulative number for each of the major DOE and commercial sites from the beginning of operations through September 30, 1996. Inventory difference information released at the June 27, 1994, Openness Press Conference for DOE facilities has been updated through September 1996. In addition, for the first time, Table 6-10 presents a consolidated view of the cumulative HEU inventory differences at commercial sites.

Inventory differences are the differences between the quantity of nuclear material on hand at a facility, according to the facilities accounting records system, and the quantity measured during a physical inventory. Prior to 1978, the DOE used the term material unaccounted for (MUF) but, along with the NRC, changed the term to inventory difference to clarify the intent and understanding of this terminology. While the term changed, the mathematical calculation remained the same. Today, both the DOE and NRC use the term inventory difference while the IAEA uses the term MUF.

Inventory differences are not unique to the nuclear industry. In fact, a number of other industries whose final product requires chemical or physical processing also experience inventory differences. The fundamental reasons for inventory differences in these industries is the same as in the nuclear industry. As shown in **Figure 6-4,** inventory differences result from reconciling book inventories with physical inventories, after adjustments for transactions, removals, decays, corrections, transmutation, and production. The total inventory difference for any time period is the sum of many smaller differences. Each inventory difference is investigated to assign its cause and to help assure that no loss, diversion, theft or environmental contamination occurred. Inventory differences arise for one or more reasons:

- A fundamental reason for inventory differences is that repeated measurements do not always give the same result. Measurement technology is not perfect, nor will it ever be. Biases in measurement systems often result in inventory differences over time.
- Similarly, failure to measure even minute quantities of nuclear material discharged as waste will also systematically accumulate over time and prevent inventory differences from averaging out to zero. The quantity of nuclear material in waste also has a very large uncertainty because it cannot be measured or estimated accurately. Since the waste quantity is removed from the inventory, any understatement of this quantity will

reflect an inventory difference representing a decrease in the inventory. While retrieval of this material for remeasurement may be possible, it would require a significant amount of effort and cost.

- Additionally, the quantity of material in facility and equipment holdup cannot be measured or estimated very accurately. Holdup is defined as material that has adhered to gloveboxes, ducts, and processing equipment over the years. The book inventory may not reflect all of the holdup material. Any understatement of the quantity of nuclear material in holdup will reflect an inventory difference representing a decrease in the inventory. More accurate values for material in holdup are obtained during the final decontamination of process buildings and equipment.

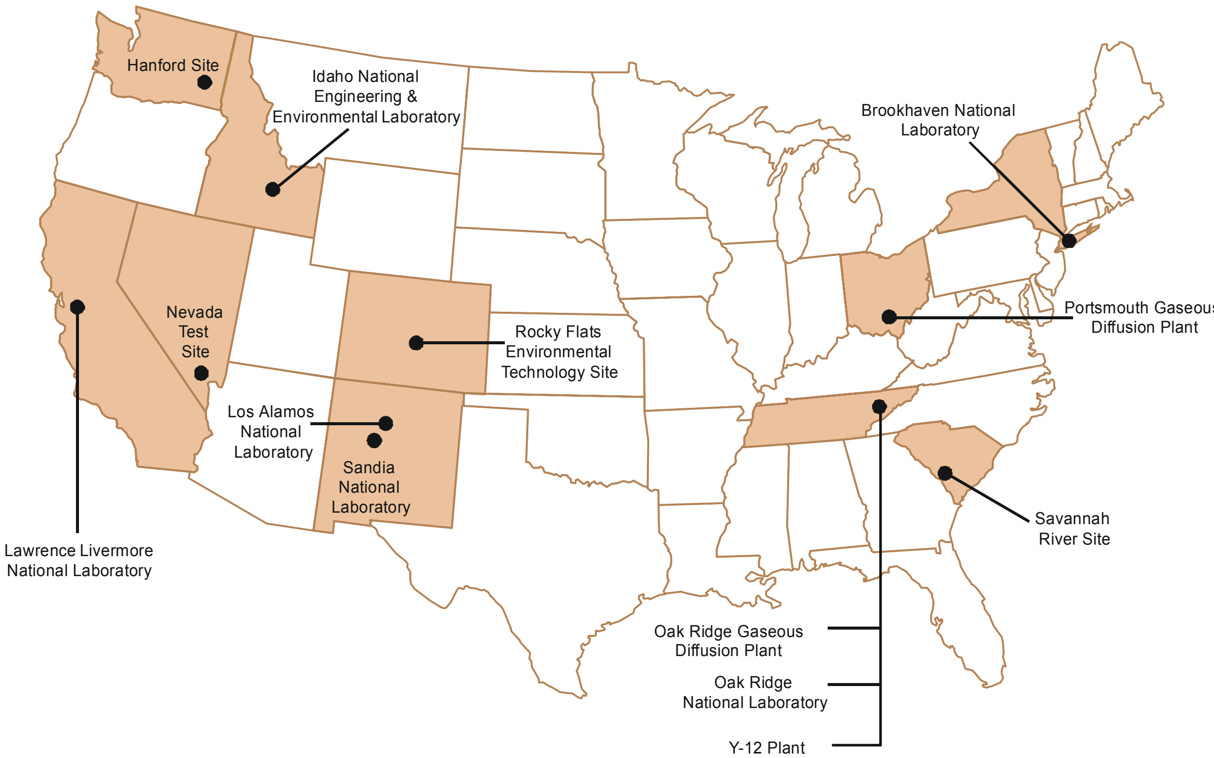
As part of the inventory difference evaluation, other security events are reviewed to ensure that inventory differences are not linked to breaches of physical security or insider acts. If there is no evidence of security breaches, then inventory differences are less likely to be caused by malevolent acts, since integrated security and safeguards provide defense-in-depth.

In addition to detecting losses, analysis of inventory differences provides valuable information on the effectiveness of material control measures, process controls and material management procedures. Personnel at U.S. facilities analyze and explain, to the best of their capability, all significant inventory differences (i.e., those outside strict statistical control limits) as well as missing items. If necessary, an operation may be shut down until any inventory differences are resolved.

Cascade inventory differences at gaseous diffusion plants are not included in this report. Even though the highest product assay produced in the cascades has been over 97 percent uranium-235, the total quantity of 20 percent or greater enriched in the cascades is only a small fraction of the cascade inventory. As a result, the average annual in-process assay in the cascades has ranged from about 0.7 to about 5.0 percent uranium-235. The cascade inventory difference includes all enrichments. There is no practical way of determining precisely how much is attributed to the small amount of uranium in the cascade that is 20 percent or greater because the cascades operate as a single system. Therefore, inventory differences for the cascades are not included in the HEU total, but they are reported separately.

For a thorough discussion of inventory differences by fiscal year and facility, refer to the *Report on Strategic Special Nuclear Material Inventory Differences* (ERDA 1977), and the periodic updates published by the DOE and NRC. As reflected in **Figure 6-5,** the unavailability of highly precise and accurate measurement capabilities and less rigorous accounting practices prior to the mid-1970s, all of which have largely been overcome today, have significantly contributed to the differences observed during this period.

Table 6-9 Cumulative HEU Inventory Differences at Department of Energy Sites (1945 thru September 30, 1996)



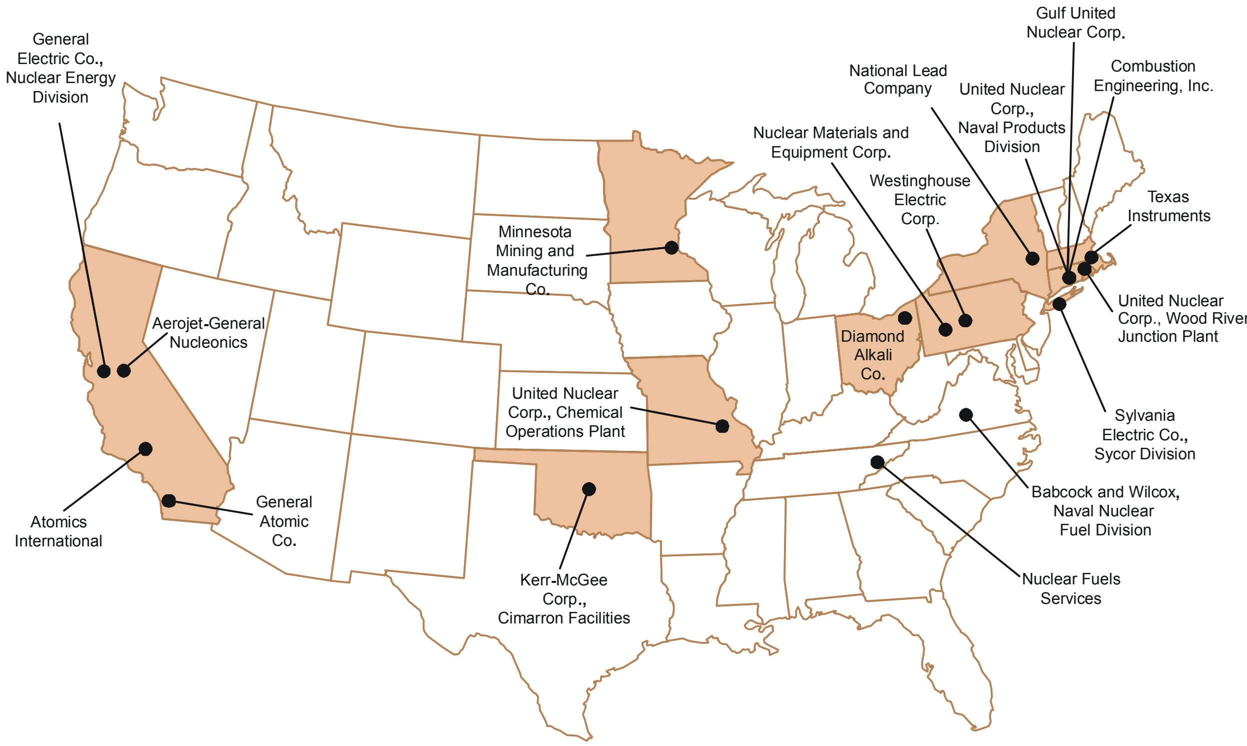
Site	kg U-235
Brookhaven National Laboratory	-4
Hanford Site	11
Idaho National Engineering and Environmental Laboratory	-11
Lawrence Livermore National Laboratory	1
Los Alamos National Laboratory	116
Oak Ridge Gaseous Diffusion Plant	113
Oak Ridge National Laboratory	6
Nevada Test Site	17
Portsmouth Gaseous Diffusion Plant	353
Rocky Flats Environmental Technology Site	308
Sandia National Laboratory	1
Savannah River Site	-422
Y-12 Plant	1,017
Other DOE Sites	105
Total	**1,611**

Notes:

1 A positive inventory difference means an apparent loss of material. A negative inventory difference means an apparent gain of material.

2 Quantities are rounded to the nearest kilogram.

Table 6-10 Cumulative HEU Inventory Differences at Commercial Sites (1952 thru September 30, 1996)



Site	kg U-235		
	Before 1968	After 1968	Total
Nuclear Materials and Equipment Corporation, Apollo	269	76	345
Nuclear Fuels Services	155	170	325
Babcock and Wilcox, Naval Nuclear Fuel Division	69	94	163
Texas Instruments	135	-1	134
United Nuclear Corporation, Chemical Operations Plant	61	44	105
General Atomic Company	41	17	57
Kerr-McGee Corporation, Cimarron Facilities	22	29	51
United Nuclear Corporation, Naval Products Division	26	22	48
United Nuclear Corporation, Wood River Junction Plant	19	26	45
Atomics International	9	29	38
Combustion Engineering, Inc.	32	0	32
National Lead Company	22	2	25
Westinghouse Electric Corporation	24	0	24
Sylvania Electric Products, Sycor Division	22	0	22
General Electric Company, Nuclear Energy Division	18	0	18
Gulf United Nuclear Corporation	0	18	18
Aerojet-General Nucleonics	3	14	16
Minnesota Mining and Manufacturing Company	16	0	16
Diamond Alkali Company	13	0	13
Other Commercial Facilities	41	8	49
Total	**995**	**549**	**1,544**

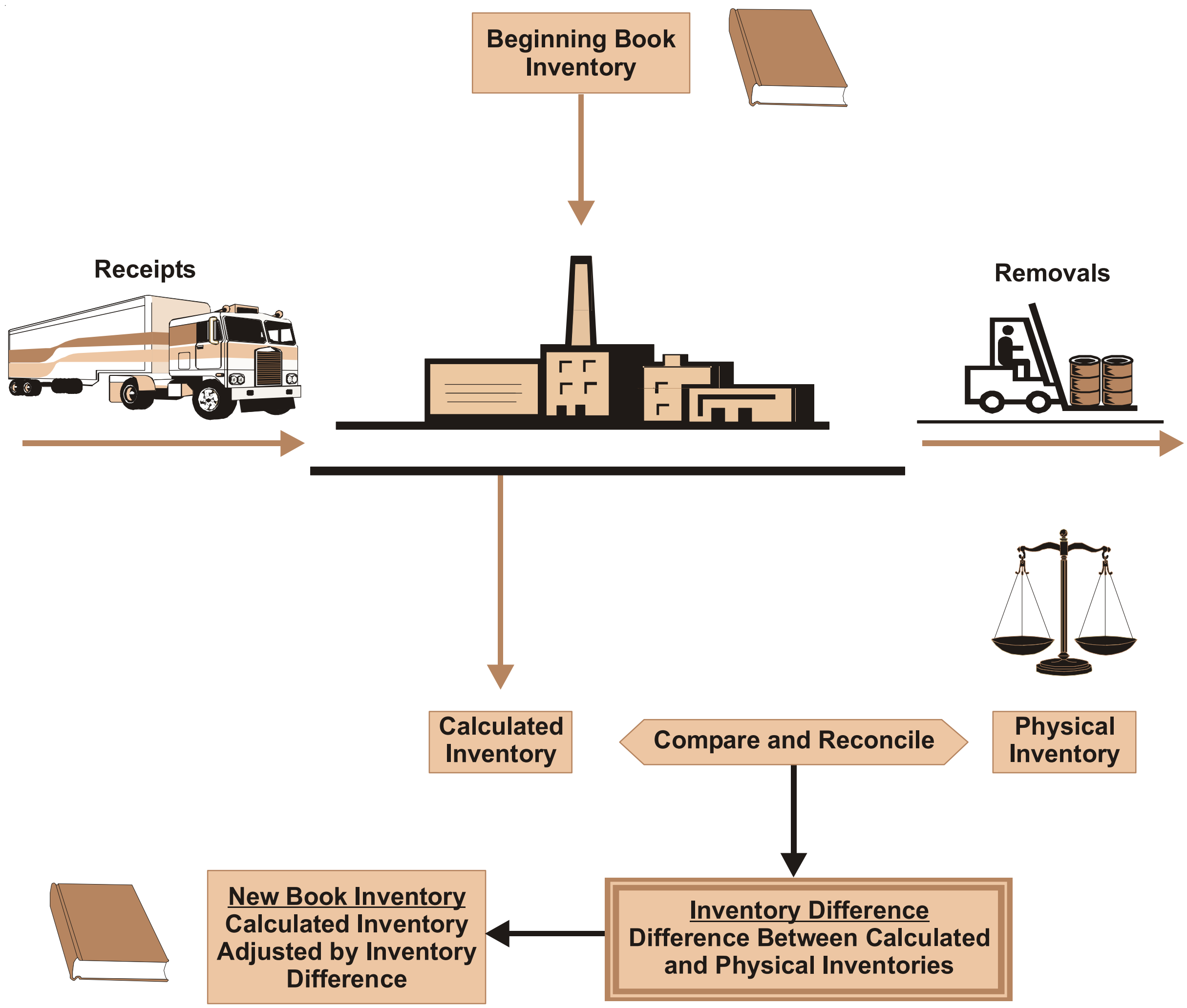
Notes:

1 Data before 1968 reflects the quantities in ERDA 77-68, Report on Strategic Special Nuclear Material Inventory Differences, August 1977.

2 Data after 1968 reflects the quantities in the NUREG-350 and 430 series of reports through June 30, 1996 (NRC 1998).

3 A positive inventory difference means an apparent loss of material. A negative inventory difference means an apparent gain of material.

Figure 6-4 Flow Diagram of the Calculations of Inventory Differences

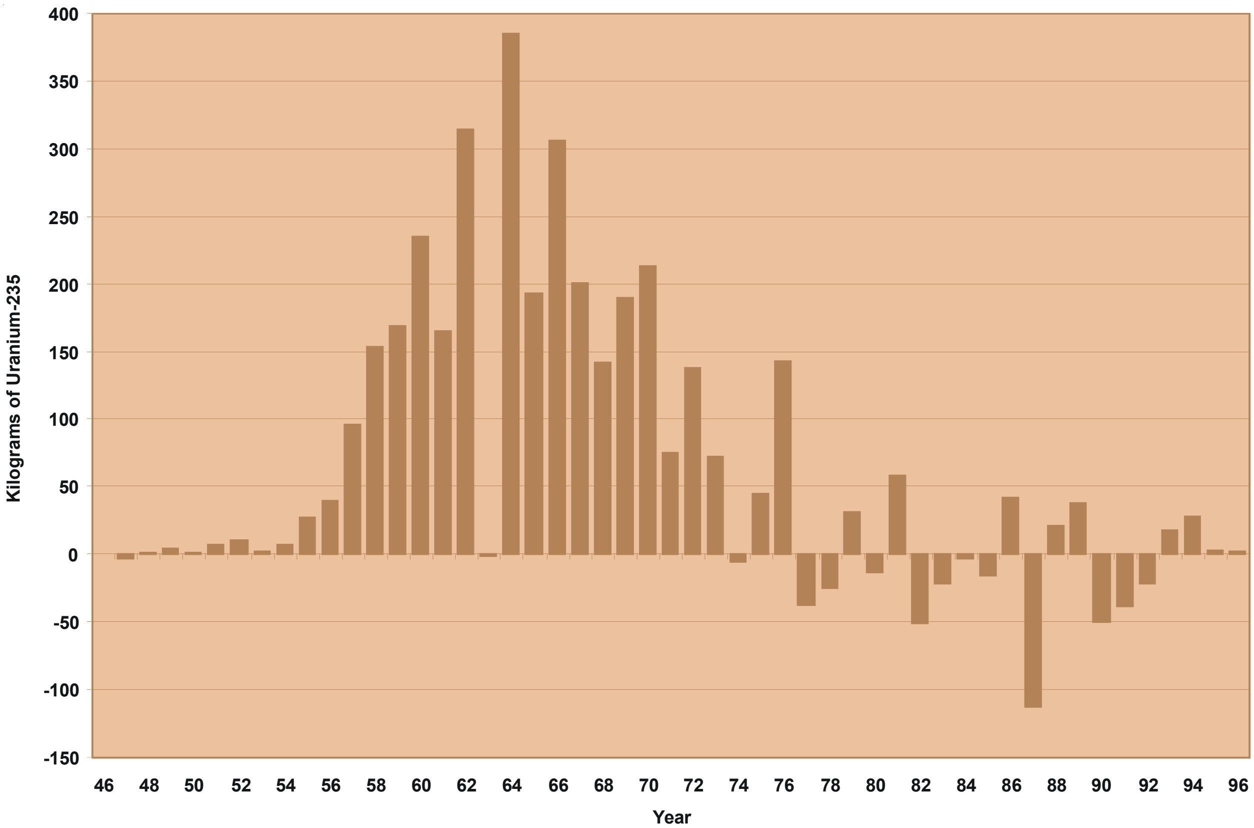


Notes:

1 A positive inventory difference means an apparent loss of material. A negative inventory means an apparent gain of material.

2 Inventory differences may arise from measurement uncertainties or other acceptable technical reasons. If an inventory difference cannot be reasonably attributed to such causes, the possibility of diversion is considered.

Figure 6-5 Historical U.S. HEU Inventory Differences



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