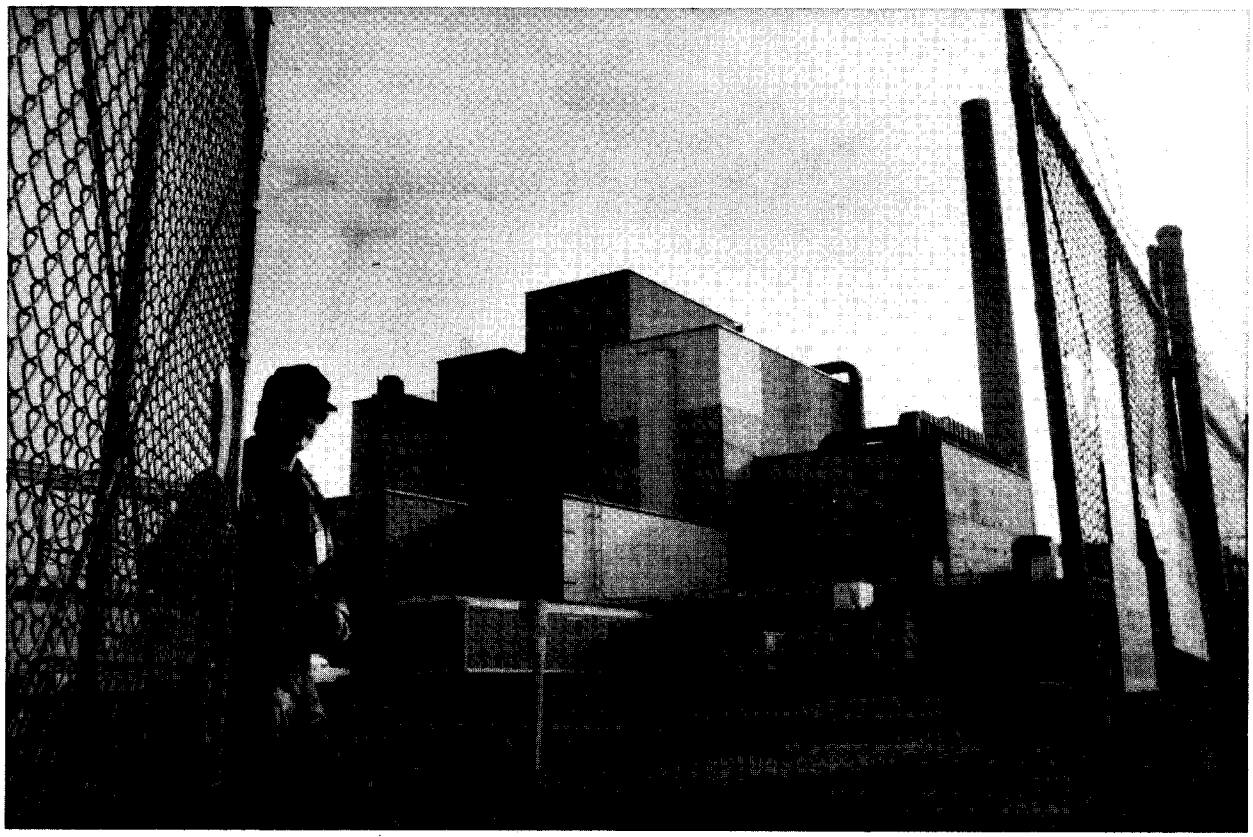
ROY KARLM I

# Plutonium: The First 50 Years

DOE/DP-0137
U.S. Department of Energy
February 1996



## United States plutonium production, acquisition, and utilization from 1944 through 1994

## On the cover

Hanford's B Reactor was the first plutonium-production reactor in the world. Plutonium created within this reactor fueled the first atomic explosion in the Alamogordo desert on July 16, 1945, and it formed the core of the bomb that exploded over Nagasaki on August 9, 1945. Built in less than a year, the B Reactor operated from 1944 to 1968. It has been designated a National Historic Mechanical Engineering Landmark. *Hanford Site, Washington. November 16, 1984.* The photograph on the cover is copyrighted by Robert Del Tredici and reprinted with permission by the photographer.

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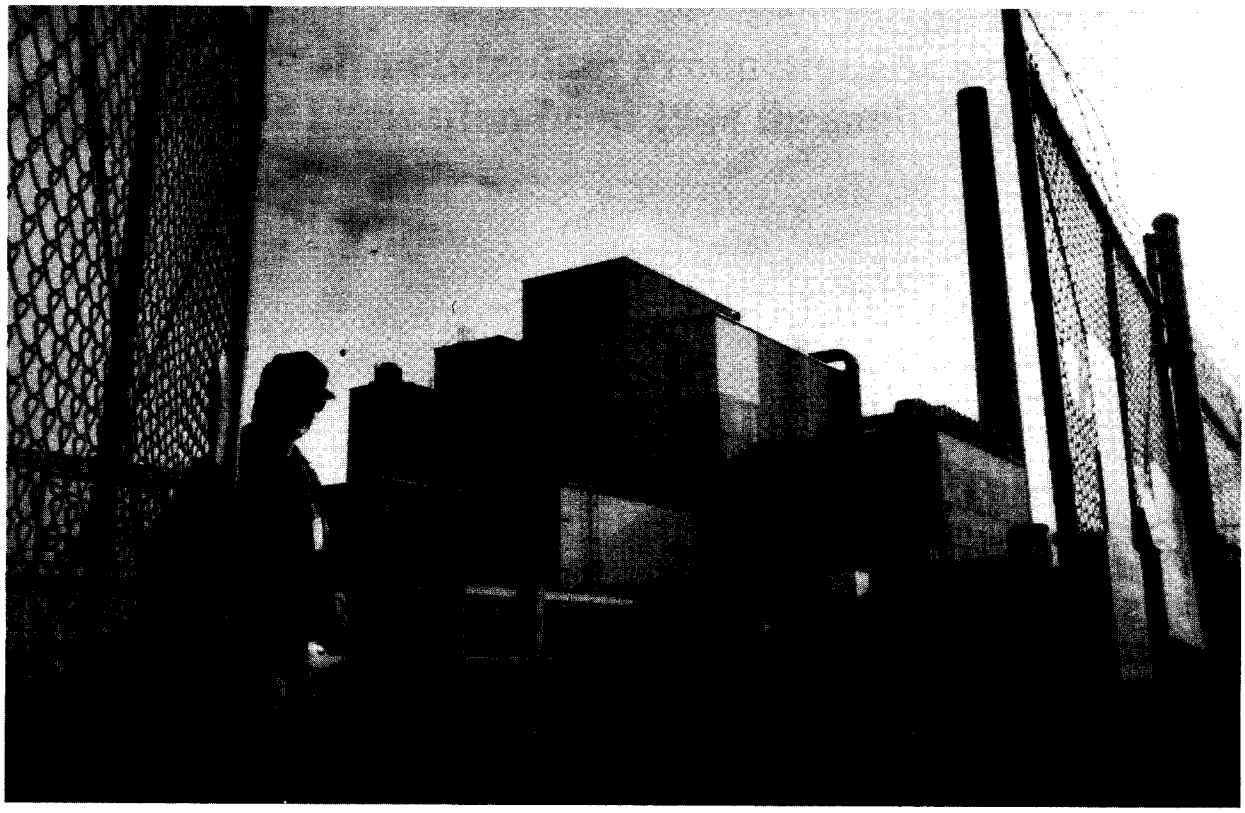

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# Plutonium: The First 50 Years

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# 1. EXECUTIVE SUMMARY

As part of the Secretary of Energy's Openness Initiative, the Department of Energy[1] (DOE) is committed to informing the public about United States Government plutonium production, acquisition, and utilization from the beginning of these activities. The focus of this report is on the historical plutonium acquisitions and removals that have resulted in the September 30, 1994 plutonium inventory. It satisfies Secretary O'Leary's commitment made at the June 27, 1994, Openness Press Conference to declassify and release additional information about plutonium.

The report contains important newly declassified information regarding the U.S. production, acquisition, and removals of plutonium. This new information, when combined with previously declassified data, has allowed the DOE to issue, for the first time, a truly comprehensive report on the total DOE plutonium inventory.

At the December 7, 1993, Openness Press Conference, the DOE declassified the plutonium inventories at eight locations totaling 33.5 metric tons (MT[2]). This report declassifies the remainder of the DOE plutonium inventory. Newly declassified in this report is the quantity of plutonium at the Pantex Site, near Amarillo, Texas, and in the U.S. nuclear weapons stockpile of 66.1 MT, which, when added to the previously released inventory of 33.5 MT, yields a total plutonium inventory of 99.5 MT.[3]

This report will document the sources which built up the plutonium inventory as well as the transactions which have removed plutonium from that inventory.

From 1944 to September 1994, the U.S. Government produced and acquired a total of 111.4 metric tons of plutonium. During the same period of time, 12.0 MT of plutonium were removed resulting in an actual inventory of 99.5 MT[4] as of September 30, 1994.

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[1] DOE is used to include its predecessor Government organizations, i.e., the U.S. Army Corps of Engineers Manhattan Engineer District, the Atomic Energy Commission (AEC) and The Energy Research and Development Administration (ERDA).

[2] Throughout this report metric tons (MT) and kilograms (kg) are used as the measure of the amounts of plutonium. One metric ton is 2,205 pounds, and one kilogram is approximately 2.2 pounds.

[3] The combined plutonium inventory of 99.5 MT is 0.1 MT less than its two component elements due to rounding to the nearest tenth of a metric ton.

[4] The acquisition and removal numbers are understated by 0.1 MT of plutonium due to transactions that remain classified for national security reasons, and to rounding of numbers.

This report identifies four sources that add plutonium to the DOE/DoD inventory, and seven types of transactions which remove plutonium from the DOE/DoD inventory (Figure 1).

- Sources of plutonium acquisitions are: plutonium produced in government production reactors; plutonium produced in government nonproduction reactors; plutonium acquired from U.S. civilian industry; and plutonium acquired from foreign countries.

- Transactions which remove plutonium are: plutonium expended in wartime and nuclear tests; plutonium inventory differences; plutonium to waste (normal operating losses); plutonium expended in fission and transmutation; plutonium lost to decay and other removals; plutonium transferred to U.S. civilian industry; and plutonium transferred to foreign countries.

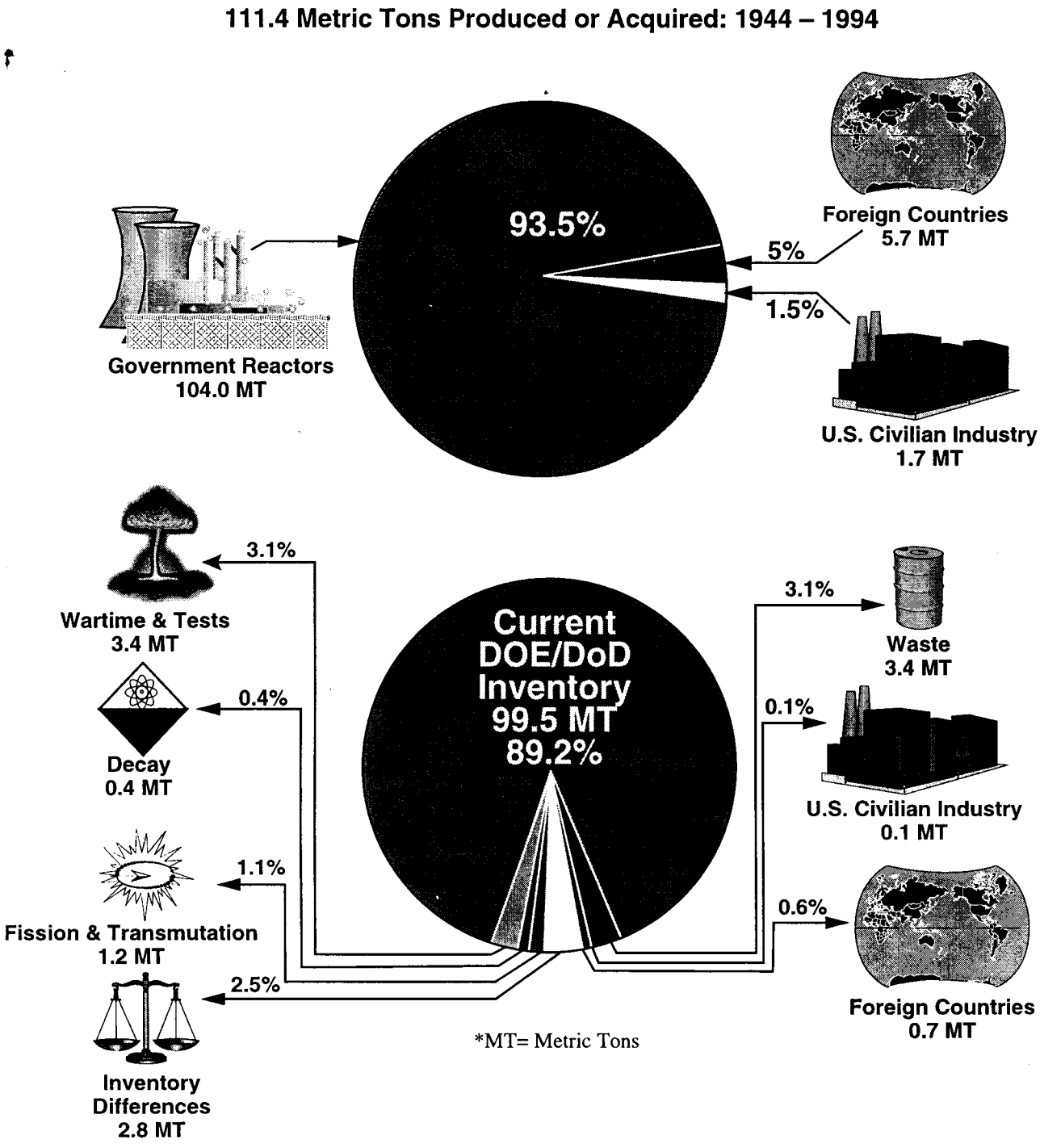
This report also discusses the nuclear material control and accountability system which records all nuclear material transactions, compares records with inventory and calculates material balances, and analyzes differences to verify that nuclear materials are in quantities as reported.

Typically, the number of transactions used to track the production, movement, and removal of the DOE plutonium from the inventory numbers in the hundreds of thousands per year. Many of these records currently exist only in summary form, particularly for the period prior to 1969 when the Atomic Energy Commission's (AEC) nuclear materials accounting system was first automated.

The international security environment has been shaped by recent events, most notably the end of the Cold War and the breakup of the Soviet Union. This has facilitated the current Administration's reconsideration of Government classification policies.

# Figure 1

## U.S. Plutonium:
## Where it Came From and Current Balance Statement



The philosophy behind declassification and release of information continues to be very dynamic. Recognizing that openness is essential to public accountability and trust, the DOE is continuing to take aggressive steps to declassify and inform the public about the Department's past and present activities where it does not jeopardize the U.S. national security or aid worldwide nuclear proliferation.

The DOE believes that this report will aid in discussions of plutonium storage, safety, and security with stakeholders as well as encourage other nations to declassify and release similar data. These data will also be available for formulating policies with respect to disposition of excess nuclear materials.

The information in this report is based on the evaluation of available records. The information contained in this report may be updated or revised in the future should additional or more detailed data become available.

# 2. INTRODUCTION

The breakup of the Soviet Union and the end of the Cold War has allowed the U.S. to reconsider its classification and declassification policies and practices. The release of this report is a result of new declassification initiatives, President Clinton's goal for greater openness in government, and commitments made by Secretary of Energy O'Leary at the June 27, 1994, Openness Press Conference.

This report covers the first 50 years of DOE plutonium activities, from the beginning of plutonium production by the Manhattan Engineer District in 1944 through September 1994. The report contains important newly declassified information regarding the U.S. production, acquisition, and removals of plutonium. This new information, when combined with previously declassified data, has allowed the DOE to issue, for the first time, a truly comprehensive report on the total DOE/DoD plutonium inventory.

The DOE believes that this report will aid in discussions of plutonium storage, safety, and security with stakeholders as well as encourage other nations to declassify and release similar data. These data will also be available for formulating policies with respect to disposition of excess nuclear materials.

Almost all of the information that was used to create this report came from the Nuclear Materials Management and Safeguards System (NMMSS). It is the official U.S. nuclear materials accounting system and is used to track U.S. nuclear material inventories, maintain compliance with the Nuclear Nonproliferation Treaty, and support International Atomic Energy Agency (IAEA) safeguards. When NMMSS data were not available, historical reports and memoranda were used.

This report attempts to strike a balance between national security and openness. The philosophy of declassification and release of information has evolved dramatically over time. In the 1940's, almost every aspect of U.S. atomic energy programs was classified. Following World War II, an effort was made to remove many of the classification constraints covering information on nuclear chemistry, metallurgy and physics, and initial declassification efforts were begun in the areas of nuclear weapons, tests, reactors, materials production, and weapon design and utilization data.

Recognizing that openness is essential to public accountability and trust, the DOE is taking aggressive steps to declassify as much information as possible about the

Department's past and present activities without jeopardizing the U.S. national security or aiding world wide nuclear proliferation.

The Department implements a comprehensive review for each and every declassification action including coordination with other agencies. The information is reviewed for its national security significance, including concern for nuclear weapons proliferation, terrorism, and foreign policy considerations. It is clear that some information requires continued classification under law, treaty, and regulations in the interest of nuclear nonproliferation and national security.

The release of this report does not threaten U.S. national security, run counter to our nuclear nonproliferation policy, or undermine the nuclear deterrent of the U.S.

# 3. MATERIAL CONTROL AND ACCOUNTABILITY

## 3.1 SAFEGUARDS EVOLUTION

From the beginning of the nuclear program in the 1940's through 1954, the U.S. nuclear effort was primarily military in character. During this period, all special nuclear material[5] was U.S. Government property and, with minor exceptions, held by the Atomic Energy Commission (AEC), AEC contractors operating government facilities, and the Department of Defense (DoD). Physical security systems and operations and security clearances for authorized personnel, coupled with stringent material control measures, were the principal means of protecting special nuclear material.

Nuclear materials accounting records, inventory procedures and reports were maintained as a matter of prudent management practice to verify that no material had been diverted or stolen. However, the controls were limited by the accuracy of the measurement techniques. Over time, improved nuclear material identification and measurement techniques were developed and standardized to support the growing U.S. nuclear program. Even with these improved measurement techniques, the measurement of nuclear material continued to include a significant degree of uncertainty.

President Eisenhower announced his Atoms for Peace Program in 1953 for providing technology and nuclear material with other nations, including nuclear materials for research and power reactor programs. The Atomic Energy Act of 1946 was amended in 1954 to allow civilian peaceful use, though not ownership, of special nuclear material and to allow U.S. assistance to foreign countries developing peaceful nuclear programs.

The AEC chose not to impose its pre-1954 safeguards systems on private (licensed) industry. However, physical security measures continued to be practiced to protect classified materials and technology at licensed facilities. The AEC concluded that licensee contractual financial responsibility for special nuclear material loss or degradation, and the severe criminal penalties provided by the Atomic Energy Act, adequately protected the national interest from the standpoint of material theft or diversion.

[5] Special nuclear material is defined in the Atomic Energy Act and includes plutonium and enriched uranium.

In the mid-1960's, a further amendment to the Atomic Energy Act permitted private ownership of special nuclear material. The potential nuclear proliferation problem and problematic experiences with licensees led the AEC to conclude that steps should be taken to place more positive requirements on the licensees for the safeguarding of special nuclear material in their possession. Consequently, regulations were issued in 1967 to establish specific material control and accounting procedures for licensees.

The following year, the regulatory office in the AEC assumed sole responsibility to oversee materials safeguards applicable to private industry. In response to the increase in international trade in nuclear material, the AEC issued regulations regarding nuclear material physical protection requirements for licensees to protect against terrorist and other threats. This regulatory office formed the foundation for the present Nuclear Regulatory Commission (NRC), which became an independent agency in 1975. When the NRC was formed in 1975, nuclear material control and accountability of government-owned materials at non-licensed facilities was transferred to ERDA, and subsequently to DOE.

## 3.2 SAFEGUARDS TODAY

Nuclear material safeguards at contractor-operated DOE facilities are applied through an integrated system designed to prevent, deter, detect, or respond to attempts at unauthorized possession or use of nuclear materials. The safeguards system contains the following elements:

- Physical Protection to inhibit unauthorized, forceful or surreptitious attempts to gain entry to facilities possessing special nuclear material and to prevent its removal.
  - -Perimeter intrusion detection systems, entry and exit controls, vaults, alarms, containment, concealment and trained protection forces

- Personnel Security Procedures to help assure that unauthorized acts involving nuclear material do not occur. These procedures serve to deter insiders from diverting, stealing and sabotaging nuclear materials.
  - - Security clearances and human reliability programs
  - - Security training and awareness

- Material Control to detect or deter theft or diversion of special nuclear material by positively controlling access to and utilization of special nuclear material.
  - Material surveillance
  - Internal control procedures
  - Verification of material characteristics
  - Material custody
  - Seals and tags

- Material Accountability to record all material transactions, to compare records with inventory and calculate material balances, and analyze differences to verify that nuclear materials are in quantities as reported and in authorized locations. The materials accounting procedures are also used to detect and verify process holdup in facilities to ensure effectiveness of physical protection practices. In addition, these procedures help determine levels of protection appropriate for nuclear materials inventories.
  - Measurements
  - Physical inventories
  - Records and reports
  - Audits
  - Inventory and shipper-receiver difference evaluation and analysis

- Administrative Controls to assure the above elements are effectively described, implemented, and operated to satisfy safeguards criteria and requirements. These controls also include checks-and-balances to maintain separation of responsibilities between operations and safeguards personnel.

## 3.3 SAFEGUARDS SYSTEM OPERATION

Physical protection along with material control and accountability and human reliability procedures combine to provide effective material safeguards. Precise and accurate inventory measurement records and statistical evaluation procedures provide independent verification that the physical protection and material control procedures have been effective. If statistical analysis indicates any anomalies, a detailed investigation is conducted to resolve the differences. By law, the Federal Bureau of Investigation is immediately informed if there is any evidence of theft, diversion, or sabotage of nuclear material.

Superimposed on this integrated safeguards system, which is implemented by the DOE contractor responsible for the materials, is a governmental oversight management system designed to review and verify that the DOE contractors are meeting their materials safeguards responsibilities. The responsible DOE field office and Headquarters conduct ongoing surveys and technical audits of their contractors to assure effective contractor procedures and performance. Inventory differences are carefully analyzed during these surveys and audits are made to verify and validate the contractor explanations.

Headquarters staff also conduct independent assessments of the total system capabilities and of the performance of field offices and the contractors in effectively safeguarding nuclear materials. Inventory differences and their explanations are again reviewed during these activities. Finally, independent Congressional reviews are performed by the General Accounting Office (GAO) and are normally focused on specific topical areas such as materials tracking.

Federal law provides for fines and criminal penalties for conspiracies or attempts to steal special nuclear material. Rewards are authorized for information leading to successful prosecution of anyone involved in a conspiracy to steal, divert, or illegally possess special nuclear material. To date, no incident involving these laws has occurred.

## 3.4 INTERNATIONAL SAFEGUARDS AND FOREIGN TRANSFERS

International nuclear cooperation was first offered by Present Eisenhower in 1953 through the Atoms for Peace Program. The 1954 amendments to the Atomic Energy Act (AEA) legally enabled nuclear cooperation for peaceful purposes. In 1957, the International Atomic Energy Agency (IAEA) was established to promote peaceful nuclear energy and control nuclear material. The Nuclear Nonproliferation Treaty (NPT) entered into force in 1970 and further provided support for international technical cooperation and "fullscope safeguards" by the IAEA. Passage of the Nuclear Non-Proliferation Act of 1978 (NNPA) increased requirements for controlling exported U.S. material. Most recently, indefinite extension of the NPT continued to strengthen support for technical cooperation and "fullscope safeguards."

The AEA and the NNPA require that nuclear material exported from the U.S. under agreements for peaceful nuclear cooperation be subject to safeguards and physical

protection measures. Agreements for peaceful nuclear cooperation are reviewed by Congress before they can be brought into force. The U.S. relies on the IAEA to apply international safeguards and conducts a program of reciprocal visits and exchanges of information on physical protections.

According to the terms of the AEA, the NNPA, and bilateral agreements for peaceful nuclear cooperation, exported U.S.-origin nuclear material is subject to international safeguards applied by the IAEA. Further, Article III (2) of the NPT and IAEA safeguards agreements with countries party to the NPT require IAEA safeguards on all nuclear material in the country, including any U.S.-origin material. For non-NPT countries, IAEA safeguards are limited to nuclear material transferred under bilateral agreements. In the case of European Union countries, safeguards are also applied by the European Atomic Energy Community (Euratom) under a "partnership" arrangement with the IAEA. However, U.S. agreements for cooperation also contain provisions for "fallback" safeguards to be applied by the U.S. in the event the IAEA is unable to implement safeguards. Starting in 1961, safeguards inspection rights in U.S. nuclear cooperation agreements began to be implemented by the IAEA. A firm policy was thereafter adopted of transferring safeguards implementation to the IAEA as new agreements were negotiated or old agreements were renewed.

IAEA safeguards consist of a three-tiered system. Individual facilities are required to maintain accurate and comprehensive records of nuclear material inventory including receipts, processing, and shipments. Such information, down to gram quantities, is provided to national authorities, which in turn provide inventory reports to the IAEA. The IAEA conducts on-site inspections to verify information provided by the state, and to ensure that nuclear material has not been diverted or nuclear facilities have not been used for unreported production of nuclear materials. The frequency of IAEA inspections at a given facility is determined by the type and quantity of nuclear material present. Material posing the highest proliferation risk is subject to the most frequent inspections. In particular, facilities processing plutonium are inspected most frequently. Facilities with a large amount of plutonium generally are subject to a full-time IAEA inspector presence. For countries having small amounts of plutonium, for example for use as neutron sources to calibrate nondestructive assay instruments, IAEA inspections

are much less frequent, taking into account inspection costs and need to make an annual statement of inspection goal attainment.

IAEA safeguards measures include verification of facility design information, including through visual observation; examination of records; sample-taking and measurement of nuclear material through destructive and non-destructive techniques; use of video and other surveillance equipment, as well as in-situ, unattended measurement systems, and application of seals to ensure "continuity of knowledge" during the periods of time when IAEA inspectors are not present.

The IAEA reports conclusions of its verification activities in the annual Safeguards Implementation Report, with a summary contained in the IAEA Annual Report. To date, the IAEA has concluded each year that there has been no diversion of nuclear materials safeguarded by the IAEA in countries containing U.S.-origin nuclear material.

In addition to IAEA safeguards, U.S. law (Atomic Energy Act as amended and the NNPA) and agreements for cooperation require that adequate physical protection measures be applied to exported U.S.-origin nuclear material. A determination of the adequacy of the physical protection measures to be applied to exported nuclear material is a condition for the export license from the Nuclear Regulatory Commission.

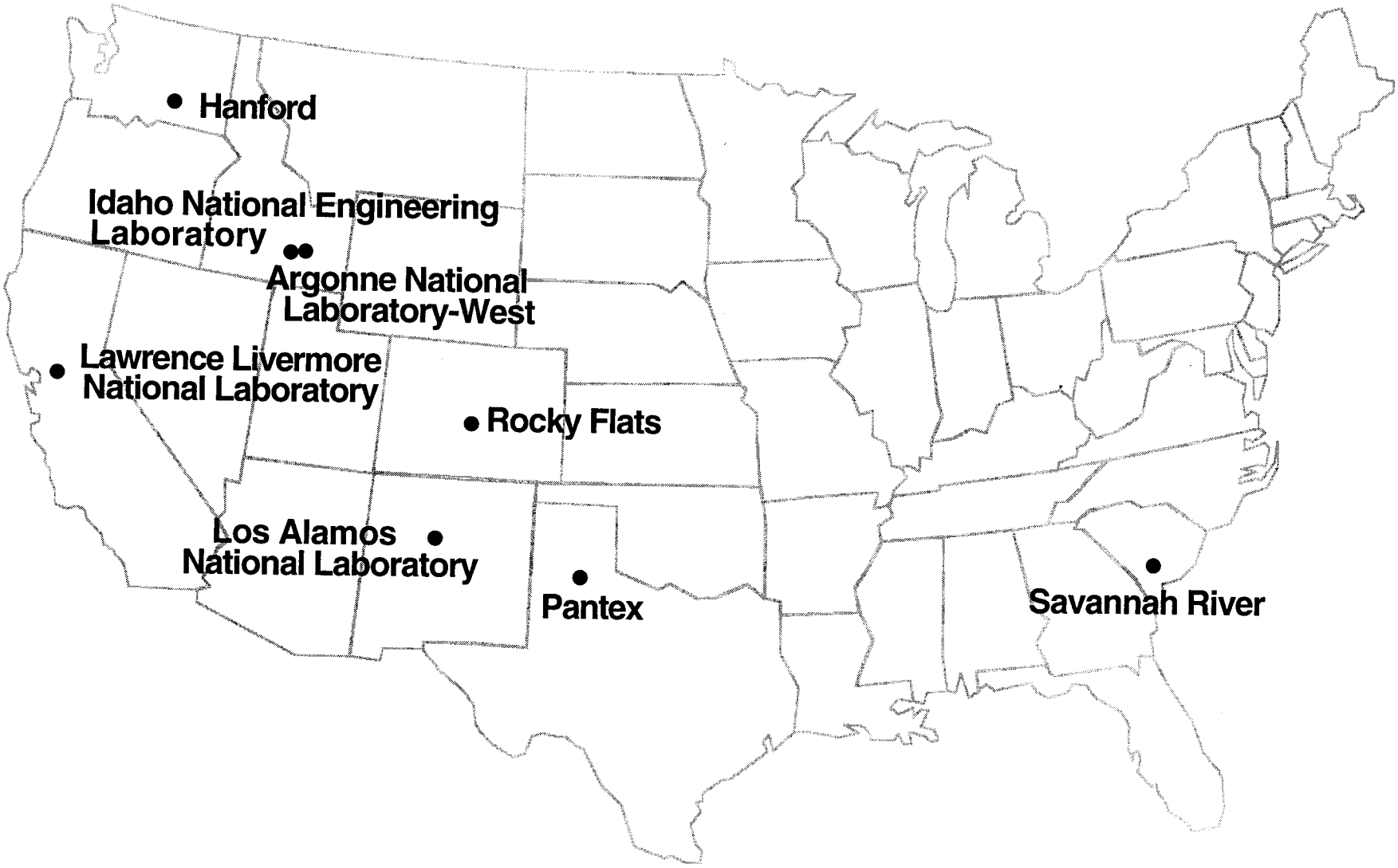
Since 1974, the Department of Energy, in cooperation with the Departments of State and Defense, and the Nuclear Regulatory Commission, has implemented a program of reciprocal visits and exchanges of information on physical protection. These visits help assure that U.S. exported materials are protected at the level called for in international guidelines issued by the IAEA in "The Physical Protection of Nuclear Materials" (INFCIRC/225/Rev. 3). Since this program began, U.S. experts led by the Department of Energy have made 76 trips to 46 countries, 39 countries with U.S. -origin plutonium, to exchange information with foreign national authorities and review physical protection measures at facilities with U.S. -origin nuclear material. The factors used to determine which countries to visit include the type and total quantity of U.S.-origin nuclear material; current threat of theft or sabotage; an impending export license application; and date of the last U.S. visit.

# 4. DOE FACILITIES

Over the 50 year history of the U.S. plutonium programs, there have been many different facilities involved in the production, processing, and utilization of U.S. plutonium. DOE-owned plants and equipment include reactors for the production of plutonium, isotopes and other reactor products; facilities for the fabrication and testing of weapons; reactors for testing materials and equipment components; reactor prototypes; and research laboratories.

Figure 2 is a map showing the location of the Department's plutonium facilities mentioned in this report.

# Figure 2
# DOE Plutonium Sites



# 5. SUMMARY OF PREVIOUSLY RELEASED DATA

Significant amounts of information concerning plutonium have been declassified. The following are examples of information declassified since 1993 concerning U.S. plutonium inventory data.

- The total and annual quantities of plutonium produced at the Hanford Site.
- The total and annual quantities of weapon grade plutonium produced at the Savannah River Site.
- Plutonium produced at Government-owned nonproduction reactors.
- The approximate total quantity of plutonium at Savannah River after August 1988.
- The United States total production of weapon grade plutonium.
- Current total plutonium inventories at DOE sites, excluding the Pantex Plant near Amarillo, Texas.
- Current and historical inventory differences for plutonium in the DOE complex.
- Total quantity of plutonium expended in all U.S. nuclear tests including wartime detonations, nuclear weapons tests, and peaceful nuclear explosions.
- Quantity of weapon grade plutonium involved in fires at the Rocky Flats Plant in 1957 and 1969.

For greater specifics on declassified information, refer to Drawing Back the Curtain of Secrecy, Restricted Data Declassification Policy, 1946 to the Present, RDD-1, U.S. Department of Energy, Office of Declassification, June 1, 1994.

# 6. SUMMARY OF NEWLY RELEASED DATA

The following is a summary of newly declassified information being released by this report.

- Total DOE/DoD plutonium inventory.
- Combined DOE/DoD plutonium inventory at the Pantex Site, near Amarillo, Texas, and in the U.S. nuclear weapons stockpile.
- Total plutonium received by barter from the United Kingdom (U.K.) under the 1958 U.S. and U.K. Mutual Defense Agreement.
- Total quantities of tritium and enriched uranium transferred to the United Kingdom by barter under Mutual Defense Agreements.

In addition, this report also summarizes 50 years of unclassified information including the following:

- Total plutonium received from other countries under bilateral agreements for international cooperation in the peaceful uses of atomic energy.
- Total plutonium transferred or sold to other countries under bilateral agreements for international cooperation in the peaceful uses of atomic energy.
- Total plutonium received from U.S. civilian industry including separated plutonium from the Nuclear Fuels Services facility located near West Valley, New York.
- Total plutonium transferred to U.S. industry.
- Total plutonium in waste as identified in NMMSS.

# 7. DOE/DoD PLUTONIUM INVENTORY

Plutonium is a silvery, metallic radioactive element with an atomic number of 94. Although found naturally in trace quantities in uranium ores, plutonium is abundantly produced in reactors by neutron bombardment of uranium. Plutonium has 15 isotopes[6] ranging from Pu-232 to Pu-246 and half-lives[7] from 20 minutes to 76 million years. The NMMSS tracks plutonium in three distinct categories, Plutonium, Plutonium-238, and Plutonium-242.

- Plutonium, sometimes referred to as Plutonium-239, is the most common plutonium isotope and is capable of sustaining a nuclear chain reaction and is used in nuclear weapons and for nuclear power production.

- Plutonium-238[8] is used in general purpose heat sources and radio isotope thermoelectric generators to produce electricity in spacecraft and is not addressed in this report.

- Plutonium-242[9] is used as target material for the production of other nuclear materials, and in nuclear physics research and is not addressed in this report.

Plutonium is identified as either weapon grade, fuel grade, or power reactor grade based on the percentage of Plutonium-240 that is contained in the plutonium. Weapon grade plutonium contains less than 7 percent Pu-240. Fuel grade plutonium contains from 7 percent to less than 19 percent Pu-240, and power reactor grade contains from 19 percent and greater Pu-240.

The U.S. plutonium inventory is composed of 85.0 MT of weapon grade, 13.2 MT of fuel grade, and 1.3 MT of reactor grade (Figure 3). Of the 85.0 MT of weapon grade plutonium, 38.2 MT have been declared excess to national security needs. The composition and location of this 38.2 MT can be found in Appendix A.

---

[6] Isotopes are different forms of the same chemical element that differ only by the number of neutrons in the nucleus. Most elements have more than one naturally occurring isotope. Many more isotopes have been produced in nuclear reactors and scientific laboratories.

[7] Half-life is the time it takes for one-half of any given number of unstable atoms to decay. Each isotope has a specific half-life.

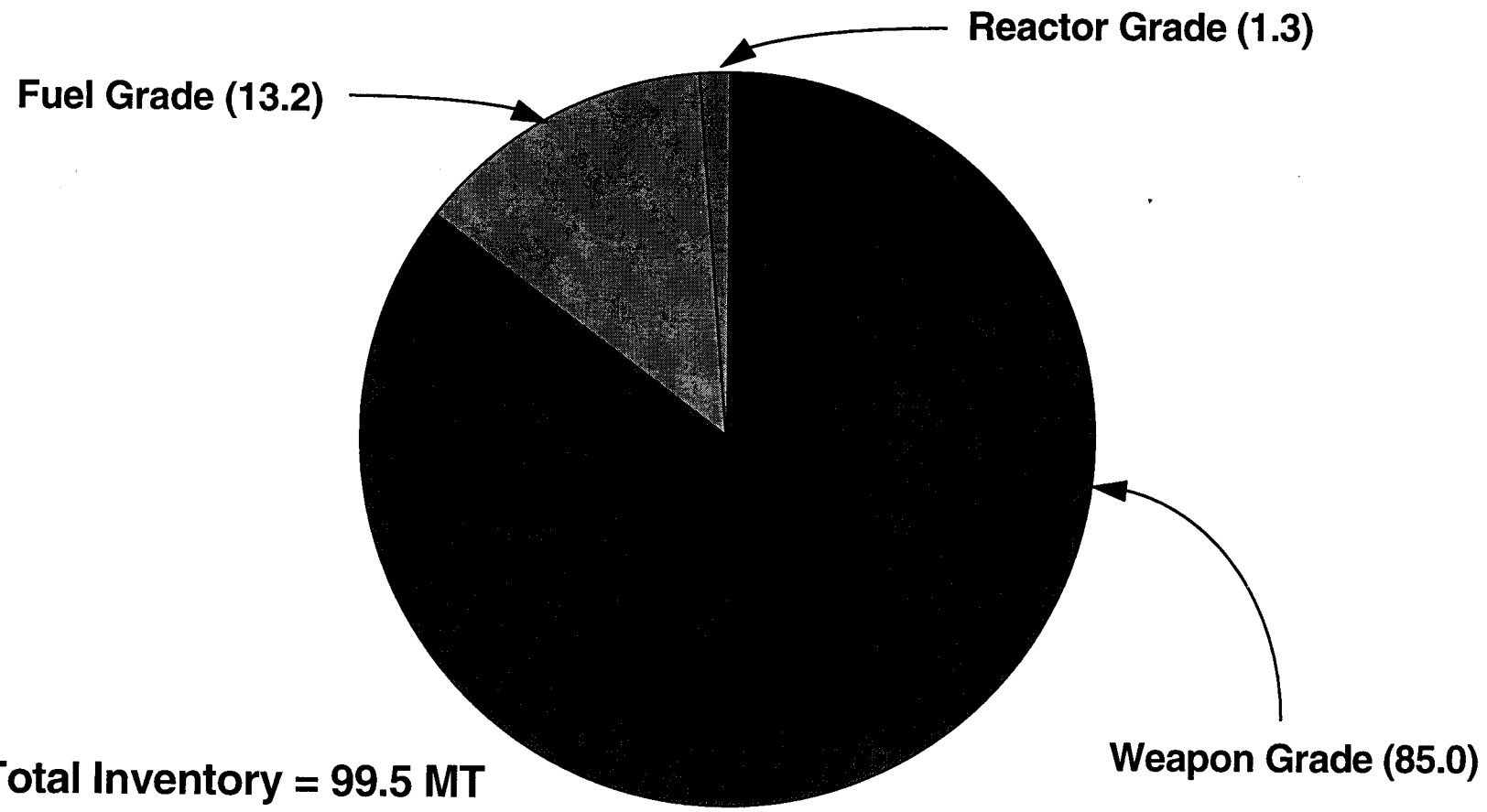
[8] Plutonium-238 has a Pu-238 content of greater than 10 percent by weight of the total plutonium.

[9] Plutonium-242 has a Pu-242 content of 20 percent or greater by weight of the total plutonium.

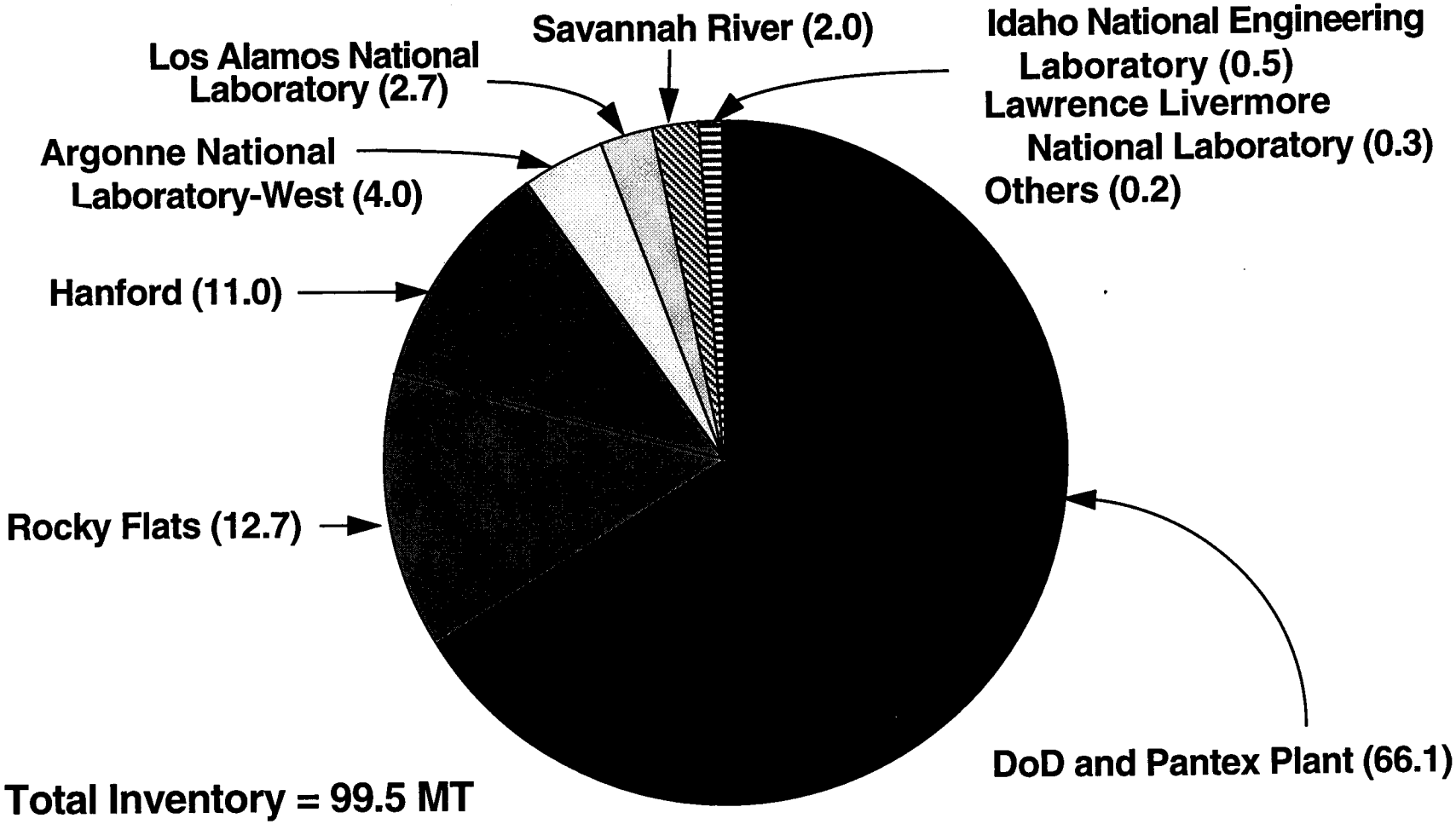
Figure 4 shows the location of the DOE/DoD 99.5 MT of plutonium as of September 30, 1994. In addition to the eight sites identified in Figure 4, DOE plutonium is also located at other DOE sites, primarily at the West Valley Demonstration Project located near Buffalo, New York. Small quantities are also located in foreign countries, and at NRC licensees. Plutonium in waste (e.g., in cribs, tanks, settling ponds, and waste disposal facilities) is not considered part of the DOE/DoD inventory, and is therefore not included in the 99.5 MT.

Most of the plutonium in waste -- technically "normal operating losses" -- has been removed from DOE/DoD inventory that requires safeguards and security. While this report refers to normal operating losses as waste, not all plutonium in waste is necessarily derived from normal operating losses. Other plutonium in DOE waste can be accounted for as accidental losses, approved write-offs, and inventory differences. In addition, some plutonium in waste has been received from sources outside of DOE. Further discussion of plutonium in waste can be found in Appendix B.

## Figure 3
# Plutonium Inventory By Grade
## (September 1994 - Metric Tons)



# Figure 4
# Location Of DOE/DoD Plutonium Inventory
## (September 1994 - Metric Tons)



# 8. HISTORICAL PLUTONIUM MATERIAL BALANCE

The data used to prepare this section were obtained primarily from the Department's nuclear material control and accountability system. The plutonium acquisition and removal categories used in this report contain the following elements:

- Plutonium acquisitions are divided into four distinct categories: plutonium produced in government production reactors; plutonium produced in government nonproduction reactors; plutonium acquired from U.S. civilian industry; and plutonium acquired from foreign countries.

- Plutonium removals are divided into seven categories: plutonium expended in wartime and nuclear tests; plutonium inventory differences; plutonium waste; plutonium expended in fission and transmutation; plutonium lost to decay and other removals; plutonium transferred to U.S. civilian industry; and plutonium transferred to foreign countries.

As shown in Table 1', the U.S. Government produced and acquired from 1944 to September 1994 a total of 111.4 metric tons of plutonium. During the same period of time, 12.0 MT of plutonium was removed resulting in an actual ending inventory of 99.5 MT[10].

[10] The acquisition and removal numbers are understated by 0.1 MT of plutonium due to transactions that remain classified for national security reasons, and to rounding of numbers.

## Table 1. Plutonium Material Balance

| Acquisitions | MT Pu |
|---|---|
| Government Production Reactors | 103.4[11] |
| Government Nonproduction Reactors | 0.6 |
| U.S. Civilian Industry | 1.7 |
| Foreign Countries | 5.7 |
| Total | 111.4 |
| **Removals** | |
| Expended in Wartime and Tests | 3.4 |
| Inventory Differences | 2.8 |
| Waste (Normal Operating Losses) | 3.4 |
| Fission and Transmutation | 1.2 |
| Decay and Other Removals | 0.4 |
| U.S. Civilian Industry | 0.1 |
| Foreign Countries | 0.7 |
| Total | 12.0 |
| Total Acquisitions | 111.4 |
| Total Removals | -12.0 |
| Classified Transactions & Rounding | 0.1 |
| Actual Inventory | 99.5 |

[11] The combined Hanford and Savannah River plutonium production figure is 0.1 MT less than the two subtotals due to rounding to the nearest tenth of a metric ton.

# 9. PLUTONIUM ACQUISITIONS

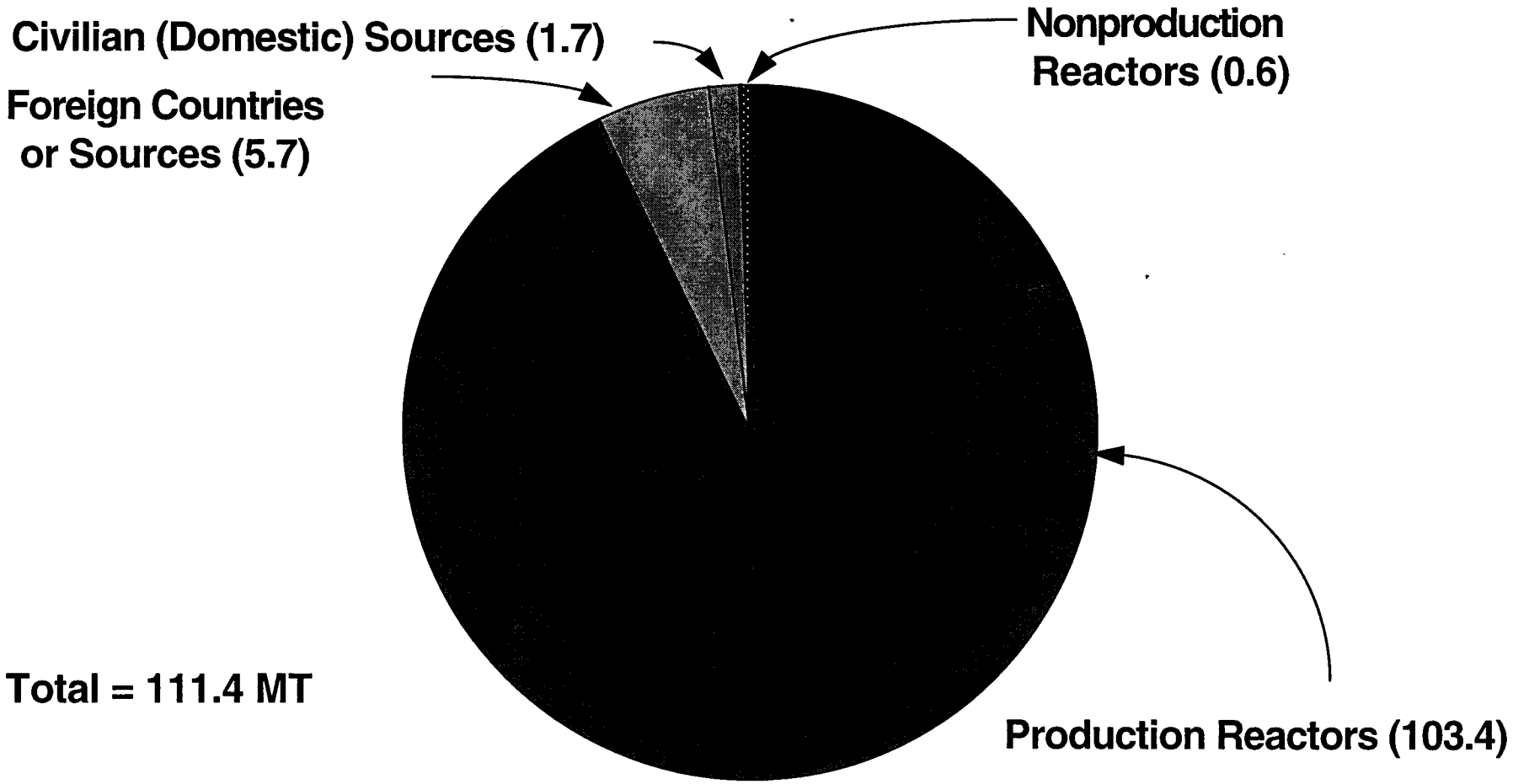
The total DOE plutonium acquisitions for the period 1944 to September 30, 1994, were 111.4 metric tons. Of the 111.4 MT plutonium acquired, 104 MT were produced in Government reactors; 103.4 MT in production reactors, and 0.6 MT in nonproduction reactors. In addition, 1.7 MT were acquired from U.S. civilian industry, and 5.7 MT from foreign countries. This section describes each of the acquisition categories in detail.

It should be noted that the acquisitions detailed in this report do not include small quantities of plutonium received from foreign governments under Military Agreements for Cooperation per Section 91C of the Atomic Energy Act of 1954. These transactions remain classified for national security reasons and are not discussed in this report.

As a result of treaty obligations, legislation, and intergovernmental policy decisions, some nonweapon grade plutonium acquired from U.S. civilian and foreign sources has been designated "restricted use" plutonium. Restricted use plutonium cannot be used in nuclear weapons. Restricted use plutonium is located primarily at the Hanford Site, the Savannah River Site, the Idaho National Engineering Laboratory facilities, and the Argonne National Laboratory West.

Figure 5 shows a comparison of the quantities of plutonium received from the four acquisitions categories that are used in this report.

# Figure 5
# Plutonium Acquisitions
## (Metric Tons)



## 9.1 GOVERNMENT PRODUCTION REACTORS

The United States Government has used 14 plutonium production reactors at the Hanford and Savannah River sites to produce plutonium for the U.S. nuclear weapons stockpile and DOE research and development programs. From 1944 to 1994, these reactors produced 103.4[12] metric tons of plutonium; 67.4 MT at Hanford, and 36.1 at Savannah River.

### 9.1.1 Hanford Reactors

Nine production reactors were built at the Hanford Site between 1944 and 1963. All were graphite moderated, light-water cooled reactors located in the north sector of the Site along the Columbia River. The first eight had single-pass (once-through) cooling systems, while the ninth, N-Reactor, had a recirculating primary coolant system and operated at higher pressures and coolant temperatures than the older reactors.

The chief product of the Hanford reactors was weapon grade plutonium, however, non-weapon grade plutonium and occasionally Tritium, Polonium-210, Uranium-233, Thulium-170, Iridium-192, and other special use isotopes were also produced. Specific dates of operations of the Hanford production reactors follow:

| Name | Start-Up Date | Shutdown Date |
|---|---|---|
| B-Reactor | September 1944 | February 1968 |
| D-Reactor | December 1944 | June 1967 |
| F-Reactor | February 1945 | June 1965 |
| H-Reactor | October 1949 | April 1965 |
| DR-Reactor | October 1950 | December 1964 |
| C-Reactor | November 1952 | April 1969 |
| KW-Reactor | January 1955 | February 1970 |
| KE-Reactor | April 1955 | January 1971 |
| N-Reactor | December 1963 | January 1987 |

The Hanford B, D, F and DR-Reactors were designed to operate at 250 megawatts (MW) thermal. H-Reactor was designed to operate at 400 MW, C-Reactor at 650 MW,

[12] The combined plutonium inventory figure is 0.1 MT less than the two subtotals due to rounding to the nearest tenth of a metric ton.

and KW and KE-Reactors at 1800 MW each. N-Reactor was designed to operate at 4000 MW.

In the 1950's, major upgrades were made at the first eight Hanford reactors to increase production. By the early 1960's, the following power levels had been achieved and sustained: 2210 MW at B-Reactor, 2165 MW at D-Reactor, 2040 MW at F-Reactor, 2140 MW at H-Reactor, 2015 MW at DR-Reactor, 2500 MW at C-Reactor, and 4400 MW each at KE and KW-Reactors. However, an administrative power limit of 4000 MW was imposed by the Atomic Energy Commission at the KE and KW-Reactors.

N-Reactor's power level did not change substantially over the years, and in 1966 a generating plant was constructed to convert part of the reactor's heat output to the production of electricity.

The Hanford reactors produced 67.4 metric tons of plutonium including 54.5 MT of weapon grade plutonium through 1987 before the last Hanford production reactor was shutdown. The annual fiscal year Hanford production is presented in Figure 6 and Table 2.

**Hanford Fuel Segregation Program**

In the mid-1980's, to increase the availability of weapon grade plutonium, Hanford initiated the Fuel Segregation Program. This program took advantage of the fact that some of the fuel assemblies discharged during the N-Reactor fuel grade campaigns contained weapon grade plutonium.

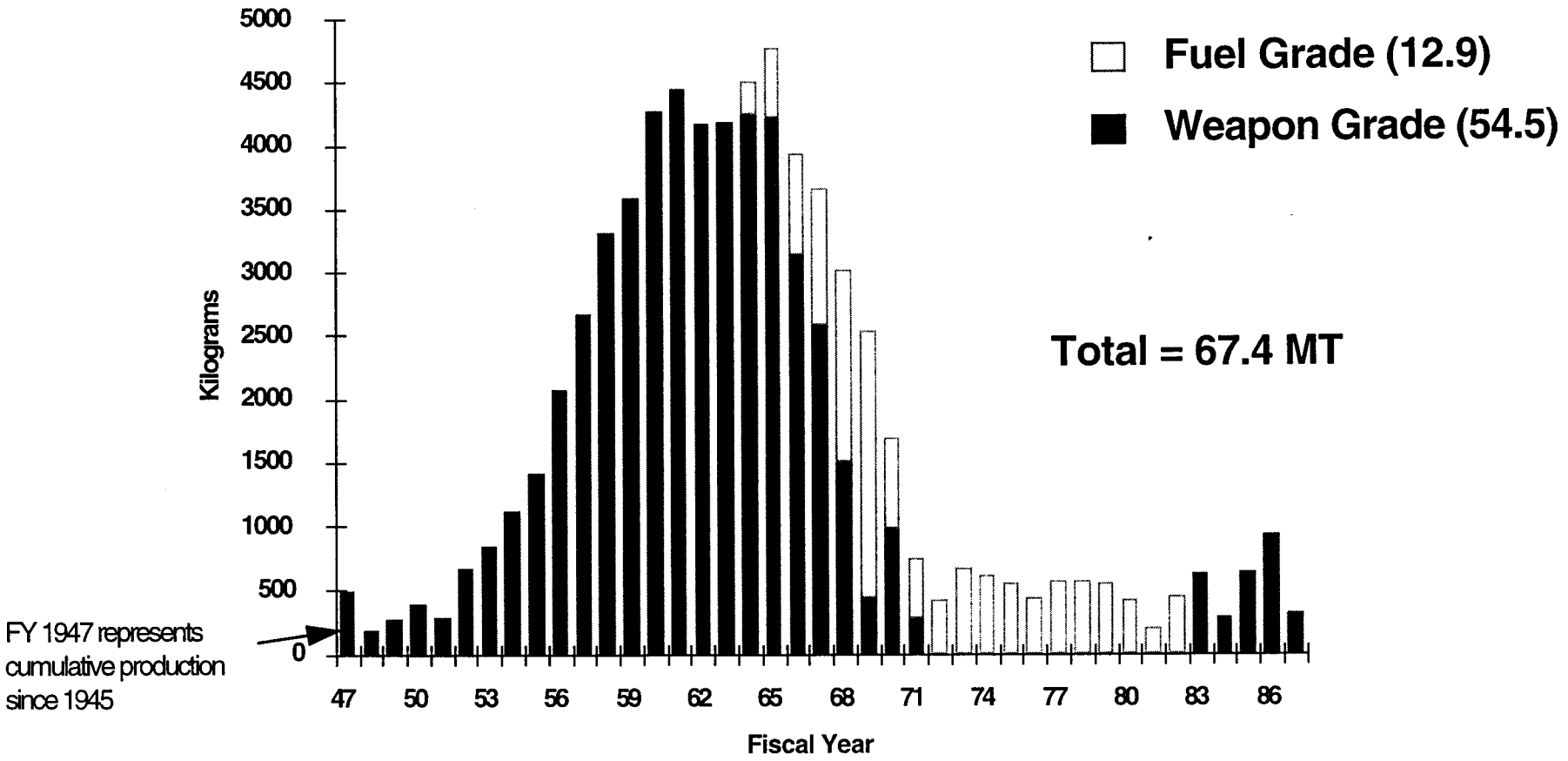
Plutonium production is based on fuel exposure by neutron bombardment, the amount of time that fuel is in a reactor, reactor heat/power operating conditions and the location of the fuel within the reactor. The neutron flux produced in a reactor varies across the reactor core. The exposure received by a fuel element at the end of a given tube will be different from the exposure received in the middle of the tube, where fuel irradiation is most concentrated.

Neutron flux variations also occurs between fuel elements having different positions within a reactor. Therefore, even if a reactor is operating in a fuel grade plutonium production mode, flux variations will cause the irradiated fuel to contain some weapons grade plutonium. By using special measuring instruments and understanding of the

above reactor properties, weapon grade plutonium was identified and chemically separated from the irradiated fuel.

From 1983 through 1984 Hanford extracted approximately 425 kg of weapon grade plutonium by the Fuel Segregation Program. While sorting increased the weapon grade plutonium inventory by 425 kg of plutonium, it also decreased the fuel grade plutonium by an equivalent amount.

# Figure 6
# Hanford Plutonium Production
## (Total of Weapon Grade and Fuel Grade)



## Table 2. Hanford Plutonium Production (kg Pu)

| Fiscal Year | Weapon Grade | Fuel[13] Grade | Annual Total | Cumulative Total | Fiscal Year | Weapon Grade | Fuel[14] Grade | Annual Total | Cumulative Total |
|---|---|---|---|---|---|---|---|---|---|
| 1947[15] | 493 | - | 493 | 493 | 1969 | 430 | 2,109 | 2,539 | 56,763 |
| 1948 | 183 | - | 183 | 676 | 1970 | 977 | 707 | 1,684 | 58,447 |
| 1949 | 270 | - | 270 | 946 | 1971 | 270 | 467 | 737 | 59,184 |
| 1950 | 392 | - | 392 | 1,338 | 1972 | - | 414 | 414 | 59,598 |
| 1951 | 288 | - | 288 | 1,626 | 1973 | - | 673 | 673 | 60,271 |
| 1952 | 662 | - | 662 | 2,288 | 1974 | - | 607 | 607 | 60,878 |
| 1953 | 838 | - | 838 | 3,126 | 1975 | - | 557 | 557 | 61,435 |
| 1954 | 1,113 | - | 1,113 | 4,239 | 1976 | - | 429 | 429 | 61,864 |
| 1955 | 1,413 | - | 1,413 | 5,652 | 1977 | - | 560 | 560 | 62,424 |
| 1956 | 2,074 | - | 2,074 | 7,726 | 1978 | - | 559 | 559 | 62,983 |
| 1957 | 2,662 | - | 2,662 | 10,388 | 1979 | - | 544 | 544 | 63,527 |
| 1958 | 3,303 | - | 3,303 | 13,691 | 1980 | - | 413 | 413 | 63,940 |
| 1959 | 3,581 | - | 3,581 | 17,272 | 1981 | - | 196 | 196 | 64,136 |
| 1960 | 4,266 | - | 4,266 | 21,538 | 1982 | - | 449 | 449 | 64,585 |
| 1961 | 4,449 | - | 4,449 | 25,987 | 1983 | 624 | - | 624 | 65,209 |
| 1962 | 4,169 | - | 4,169 | 30,156 | 1984 | 294 | - | 294 | 65,503 |
| 1963 | 4,187 | - | 4,187 | 34,343 | 1985 | 633 | - | 633 | 66,136 |
| 1964 | 4,247 | 256 | 4,503 | 38,846 | 1986 | 934 | - | 934 | 67,070 |
| 1965 | 4,208 | 562 | 4,770 | 43,616 | 1987 | 312 | - | 312 | 67,382 |
| 1966 | 3,130 | 800 | 3,930 | 47,546 | 1988[16] | -21 | - | -21 | 67,361 |
| 1967 | 2,586 | 1,069 | 3,655 | 51,201 | 1989[17] | 2 | - | 2 | 67,363 |
| 1968 | 1,494 | 1,530 | 3,023 | 54,224 | | | | | |

[13] Includes power reactor grade plutonium

[14] Ibid.

[15] Cumulative production since 1945

[16] Adjustment to previous years' production to reflect the difference between theoretical calculations of plutonium produced in the reactors and the measured value of plutonium recovered in the chemical separations plants.

[17] Ibid.

### 9.1.2 Savannah River Site Reactors

Five heavy water production reactors were built at the Savannah River Site (SRS) near Aiken, South Carolina between 1953 and 1955. The production reactors used heavy water as a moderator primary cooling medium. The primary coolant was completely contained in the reactor building. Heat was extracted through the use of heat exchangers cooled by water from the Savannah River.

Through 1988, the Savannah River reactors produced 36.1 metric tons of plutonium. The Savannah River production by fiscal year is presented in Figure 7 and Table 3.

While the main products of the Savannah River reactors were weapon grade plutonium and tritium, a variety of isotope products including Uranium-233, Americium-242, Curium-244, Polonium-210, Cobalt-60, Plutonium-238, Plutonium-242, and Californium-252 were also produced.

The order and dates of operations of the production reactors at the Savannah River Site are as follows:

| Name | Start-Up Date | Shutdown Date |
|---|---|---|
| R-Reactor | December 1953 | June 1964 |
| P-Reactor | February 1954 | August 1988 |
| K-Reactor | October 1954 | Standby July 1992 |
| L-Reactor | July 1954 | June 1988 |
| C-Reactor | March 1955 | June 1985 |

The five Savannah River reactors each were originally designed to operate at less than 500 megawatts (MW) thermal. During the period from 1955 through 1965, the thermal power levels of the reactors were increased to approximately 2500 MW by engineering enhancements such as installing larger pumps, more heat exchangers, larger pipes and optimizing the reactor physics, internal coolant flow designs and improved fuel element designs. Currently all reactors are shut down except for K-Reactor which is being maintained in cold standby, as a near term contingency for tritium production.

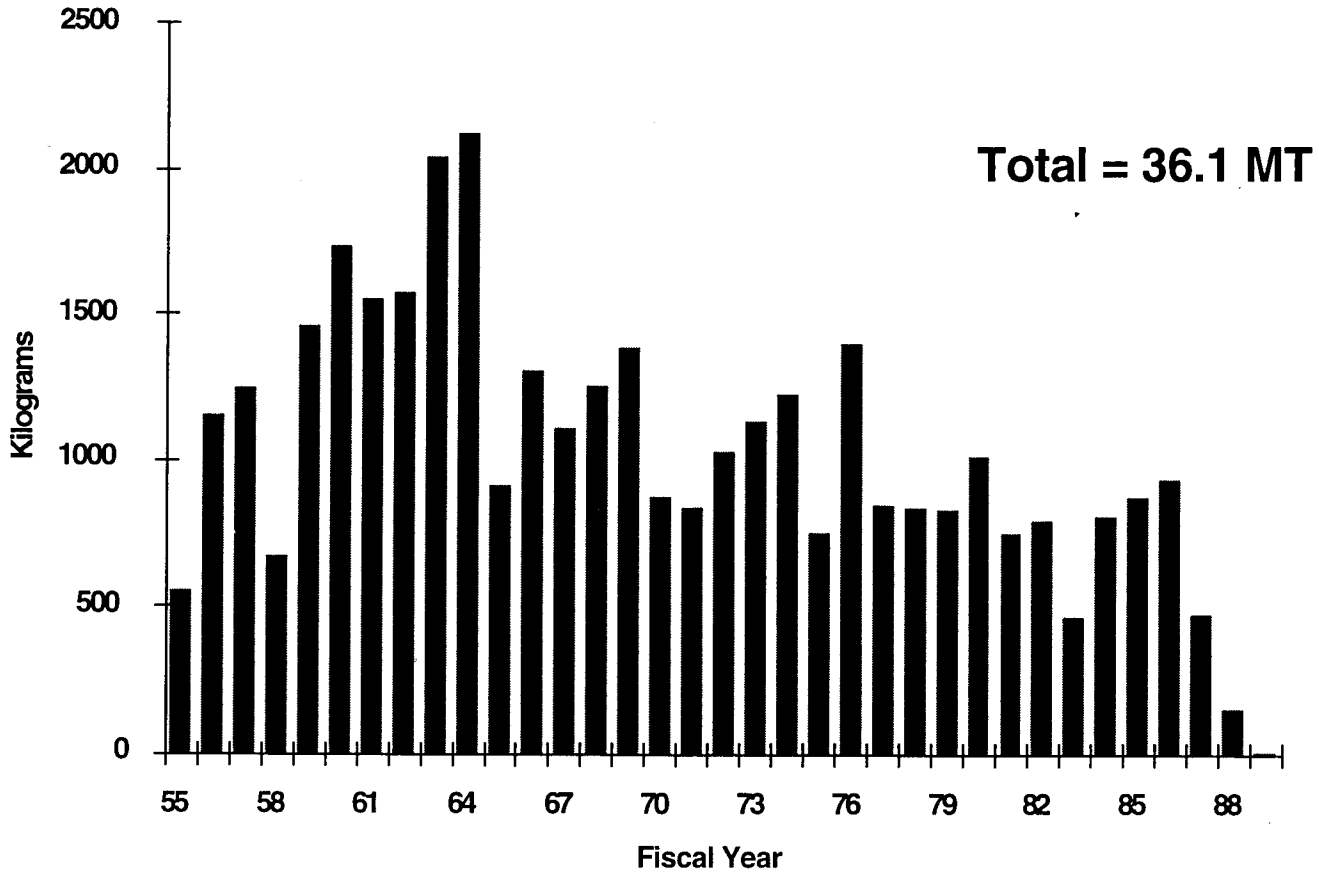
**Blending**

The Savannah River reactors produced primarily weapon grade plutonium with a Pu-240 content of about 6 percent. Starting in 1981, to increase the availability of plutonium for the weapons program, the Savannah River P, K, C-Reactors were operated to produce weapon grade plutonium with a 3 percent Pu-240 content. This

method of operating accelerated reactor operations, decreased target irradiation time, and increased fuel throughput.

From 1982 through 1990 the DOE was able to convert approximately 2.8 MT of fuel grade plutonium to weapon grade by blending the 3 percent Pu-240 with fuel grade plutonium. While blending increased the weapon grade plutonium inventory by 2.8 MT of plutonium, it also decreased the fuel grade plutonium by an equivalent amount. Of the 2.8 MT of fuel grade plutonium blended to weapon grade, 2.4 MT was blended at Savannah River, and 0.4 MT at Hanford.

# Figure 7
# Savannah River Plutonium Production



## Table 3. Savannah River Plutonium Production (kg Pu)

| Fiscal Year | Annual Total | Cumulative Total | Fiscal Year | Annual Total | Cumulative Total |
|---|---|---|---|---|---|
| 1955 | 553 | 553 | 1973 | 1,128 | 23,926 |
| 1956 | 1,151 | 1,704 | 1974 | 1,226 | 25,152 |
| 1957 | 1,245 | 2,949 | 1975 | 753 | 25,905 |
| 1958 | 672 | 3,621 | 1976 | 1,400 | 27,305 |
| 1959 | 1,459 | 5,080 | 1977 | 844 | 28,149 |
| 1960 | 1,734 | 6,814 | 1978 | 835 | 28,984 |
| 1961 | 1,552 | 8,366 | 1979 | 829 | 29,813 |
| 1962 | 1,578 | 9,944 | 1980 | 1,010 | 30,823 |
| 1963 | 2,042 | 11,986 | 1981 | 748 | 31,571 |
| 1964 | 2,123 | 14,109 | 1982 | 793 | 32,364 |
| 1965 | 909 | 15,018 | 1983 | 464 | 32,828 |
| 1966 | 1,302 | 16,320 | 1984 | 809 | 33,637 |
| 1967 | 1,107 | 17,427 | 1985 | 875 | 34,512 |
| 1968 | 1,253 | 18,680 | 1986 | 935 | 35,447 |
| 1969 | 1,382 | 20,062 | 1987 | 472 | 35,919 |
| 1970 | 872 | 20,934 | 1988 | 152 | 36,071 |
| 1971 | 836 | 21,770 | 1989[18] | 8 | 36,079 |
| 1972 | 1,028 | 22,798 | | | |

[18]Adjustment to previous years production to reflect the difference between theoretical calculations of plutonium produced in the reactors and the measured value of plutonium recovered in the chemical separations plants.

## 9.2 GOVERNMENT NONPRODUCTION REACTORS

The reactors in this category were not operated to produce plutonium, but rather were U.S. military reactors, government experimental power-reactors, government power reactors, naval propulsion reactors, and government test and research reactors. They included several DOE-owned and public utility-operated prototype reactors.

From 1952 to 1994 the nonproduction reactors, while operating to meet their respective missions, produced a total of 0.6 metric tons of plutonium; 0.1 MT weapon grade plutonium and 0.5 MT fuel grade plutonium. Quantities of plutonium produced in Government nonproduction reactors are shown by fiscal year in Figure 8 and Table 4.

Examples of nonproduction reactors that produced plutonium include the Experimental Breeder Reactor No. 2 in Idaho, the Fast Flux Test Facility at Hanford, the Shippingport Reactor in Pennsylvania, the La Crosse Boiling Water Reactor in Wisconsin, the Boiling Nuclear Superheat Reactor in Puerto Rico and the NS Savannah, the only U.S. cargo-passenger ship to be driven by nuclear power.

A complete listing of AEC, ERDA, DOE and DoD reactors including location, type, power, and operating time frames can be found in the report, Nuclear Reactors Built, Being Built, or Planned, DOE/OSTI-8200 (Revision 58) August 1995.

## Table 5. Plutonium Received From NFS West Valley (kg Pu)

| Plutonium Source | Reactor | Origin | | | |
|---|---|---|---|---|---|
| | | AEC | Commercial | Total | % Pu-240 |
| Atomic Energy Commission | N Reactor | 533.5 | | 533.5 | 12.0 |
| Commonwealth Edison | Dresden-1 | | 284.5 | 284.5 | 23.0 |
| Consolidated Edison | Indian Point-1 | | 104.0 | 104.0 | 16.4 |
| Consumers Power | Big Rock Point | | 63.4 | 63.4 | 14.9 |
| Nuclear Fuels Services, Erwin, Tennessee[19] | SEFOR | 95.2 | | 95.2 | 8.5 |
| Northern States Power | Pathfinder | | 7.0 | 7.0 | 7.9 |
| Puerto Rico Water Resources Authority | Bonus Superheater Bonus Boiler | 6.5 | | 6.5 | 9.2 |
| Yankee Atomic Electric | Yankee Rowe | | 435.7 | 435.7 | 14.6 |
| | **Total** | **635.2** | **894.6** | **1529.8** | |

[19] The material from Nuclear Fuels Services, Erwin, Tennessee was in the form of liquid residues generated during the fabrication of reactor fuel for the Southwest Experimental Fast Oxide Reactor (SEFOR).

### 9.3.2 Other U.S. Civilian Acquisitions

In addition to the plutonium purchased under the Plutonium Credit Activity, the DOE received an additional 0.8 metric tons of fuel grade plutonium from other U.S. civilian sources.

Of the 0.8 metric tons plutonium received, 0.7 MT was in spent fuel. Most of this material was received for storage and monitoring, and eventual disposal. Almost all of this spent fuel is currently stored at three facilities, the Idaho National Engineering Laboratory, the Savannah River Site, and at the West Valley Demonstration Project. As shown in Table 6, the spent fuel came from U.S. commercial light-water reactors, one-of-a-kind commercial reactors, and special fuels associated with universities, and private industry.

- The major sources of spent nuclear fuel were the Florida Power and Light Company, Turkey Point reactor (66 kg of plutonium); Virginia Electric Company, Surry 1 & 2 reactors (267 kg); and GPU Nuclear Corporation, Three Mile Island 2 reactor (158 kg).

- Smaller amounts of plutonium in spent fuel were received from other reactors including: the Omaha Public Power Company, Fort Calhoun 1 reactor; Wisconsin Electric Power Company, Point Beach 1 reactor; Connecticut Yankee Company, Haddem Neck reactor; and the Power Reactor Development Company, Enrico Fermi reactor.

In addition to spent nuclear fuel, the DOE also received 0.1 MT plutonium from commercial industry, universities, and hospitals, primarily in the form of scrap, sources, and mixed oxides. Generally, these were the return of U.S. Government plutonium that had been previously transferred to industry under various agreements.

## Table 6. Spent Fuel Received From U.S. Commercial/Research Reactors

| Source | Reactor | kg Pu |
|---|---|---|
| Baltimore Gas & Electric | Calvert Cliffs 1&2 | 13.0 |
| Carolina Power & Light | Robinson 2 | 3.5 |
| Carolinas-Virginia Nuclear Power Associates | CVTR | 0.2 |
| Commonwealth Edison | Dresden 1 | 3.0 |
| Connecticut Yankee | Haddam Neck | 3.9 |
| Consolidated Edison | Indian Point 1 | 0.1 |
| Consumers Power | Big Rock Point | 62.3 |
| Duke Power | Oconee 1&2 | 0.5 |
| Entergy Operations Incorporated | Arkansas 1 | 0.1 |
| Florida Power and Light | Turkey Point | 65.7 |
| General Electric, Pacific Gas & Electric | Vallecitos BWR | 2.5 |
| GPU Nuclear Corporation | Three Mile Island 2 | 158.2 |
| Nebraska Public Utility | Cooper | 3.1 |
| Northern States Power | Monticello | 0.7 |
| Omaha Public Power District | Fort Calhoun | 4.1 |
| Philadelphia Electric | Peach Bottom | 3.0 |
| Power Reactor Development Company | Enrico Fermi | 6.5 |
| Public Service Company of Colorado | Fort St. Vrain | 0.8 |
| Rochester Gas & Electric | R.E. Ginna 1 | 63.5 |
| State University of NY (Buffalo) | Pulstar | 0.8 |
| Virginia Electric Power Company | Surry 1&2 | 266.6 |
| Wisconsin Electric | Point Beach | 10.5 |
| | **Total** | **672.6** |

## 9.4 FOREIGN COUNTRIES

This category consists of plutonium received by barter under the 1958 U.S. and U.K. Mutual Defense Agreement, as well as plutonium received from foreign countries under Agreements for Cooperation for the peaceful uses of atomic energy. Total plutonium received from foreign countries was 5.7[20] metric tons of primarily fuel grade plutonium; 5.4 MT under the Mutual Defense Agreement with the United Kingdom, and 0.4 MT from Agreements for Cooperation.

### 9.4.1 Mutual Defense Agreement between the U.S. and the U.K.

Under the Mutual Defense Agreement with the United Kingdom from 1959 to 1980, the United States acquired a total of 5.4 MT of plutonium (5360 kilograms) in exchange for 6.7 kilograms of tritium and 7.5 MT of highly enriched uranium.

### 9.4.2 Agreements for Cooperation

Programs for international cooperation in the peaceful uses of atomic energy are carried out largely through Agreements for Cooperation with the IAEA, the European Atomic Energy Community (Euratom), and through bilateral agreements with other countries, as authorized by the Atomic Energy Act of 1954, as amended. Under these programs, the Department exchanged information on peaceful uses of nuclear materials with other nations and provided chemical reprocessing services to foreign countries.

A total of 0.4 metric tons of plutonium were obtained under these agreements, including 254 kg of plutonium from Canada, 79 kg of plutonium from Taiwan, and 50 kg from others.

- Of the 254 kg plutonium received under bilateral agreements with Canada, 252 kg were in spent fuel. The spent fuel was received at the Savannah River Site from 1959 to 1964, and processed. The remaining 2 kg of plutonium were received primarily at Hanford from 1962 to 1985, and consisted of oxides and sources.

[20] The total is 0.1 MT less than the two subtotals due to rounding to the nearest tenth of a metric ton.

- Of the 79 kg plutonium received under bilateral agreements with Taiwan, 78 kg were in spent fuel from the Taiwan Research Reactor. The spent fuel was received at the Savannah River Site, and 63 kg of plutonium were processed. The remaining 1 kg of plutonium was acquired in 1978 and is stored at the Los Alamos National Laboratory.

- The remaining 50 kg of plutonium were received from 13 other countries including Australia, Belgium, France, Germany, Italy, Switzerland, Sweden, and the United Kingdom. Generally, these smaller quantities were the return of U.S. plutonium that had been previously transferred to these countries under various agreements.

Quantities of plutonium received under international agreements for cooperation for the peaceful uses of atomic energy are shown by country in Table 7 and by year in Table 8.

## Table 7. Receipts From Agreements For Cooperation

| Country | kg Pu | Form | Year |
|---|---|---|---|
| Australia | 4.1 | Fuel elements | 1974 |
| Belgium | 4.6 | Oxide, samples | 1963 - 1991 |
| Canada | 254.2 | Spent fuel, oxide, sources | 1959 - 1985 |
| Denmark | 0.3 | Fuel elements | 1978 |
| France | 0.6 | Oxide, samples | 1965 - 1985 |
| Germany, West | 2.1 | Oxide, samples | 1967 - 1987 |
| IAEA | 0.1 | Sources | 1973 |
| Italy | 2.2 | Fuel elements | 1970 |
| Japan | 0.4 | Spent fuel | 1965 - 1978 |
| South Africa | <0.1 | Spent fuel | 1976 |
| Switzerland | 2.8 | Oxide, sources | 1957 - 1984 |
| Sweden | 8.4 | Spent fuel | 1963 - 1979 |
| Taiwan | 79.1 | Spent fuel, oxide | 1978 - 1991 |
| United Kingdom | 24.5 | Fuel elements | 1967 - 1988 |
| Vietnam, South | 0.1 | Source | 1975 |
| **Total** | **383.5** | | |

## Table 8. Annual Receipts from Agreements for Cooperation (kg Pu)

| Year | Annual Receipts | Cumulative Receipts | Year | Annual Receipts | Cumulative Receipts |
|---|---|---|---|---|---|
| 1959 | 6.3 | 6.3[21] | 1977 | 0.1 | 276.6 |
| 1960 | 38.7 | 45.0 | 1978 | 1.5 | 278.1 |
| 1961 | 58.4 | 103.4 | 1979 | - | 278.1 |
| 1962 | 75.8 | 179.2 | 1980 | - | 278.1 |
| 1963 | 34.7 | 213.9 | 1981 | - | 278.1 |
| 1964 | 37.9 | 251.8 | 1982 | 0.3 | 278.4 |
| 1965 | <0.1 | 251.8 | 1983 | 0.1 | 278.5 |
| 1966 | 0.1 | 251.9 | 1984 | - | 278.5 |
| 1967 | 0.9 | 252.8 | 1985 | 2.8 | 281.3 |
| 1968 | <0.1 | 252.8 | 1986 | 26.5 | 307.8 |
| 1969 | <0.1 | 252.8 | 1987 | 12.1 | 319.9 |
| 1970 | 6.9 | 259.7 | 1988 | 17.5 | 337.4 |
| 1971 | 1.1 | 260.8 | 1989 | 26.0 | 363.4 |
| 1972 | 2.6 | 263.4 | 1990 | 11.3 | 374.7 |
| 1973 | 8.0 | 271.4 | 1991 | 8.8 | 383.5 |
| 1974 | 4.8 | 276.2 | 1992 | - | 383.5 |
| 1975 | 0.1 | 276.3 | 1993 | - | 383.5 |
| 1976 | 0.2 | 276.5 | 1994 | - | 383.5 |

[21] This quantity is cumulative for the years prior to 1959

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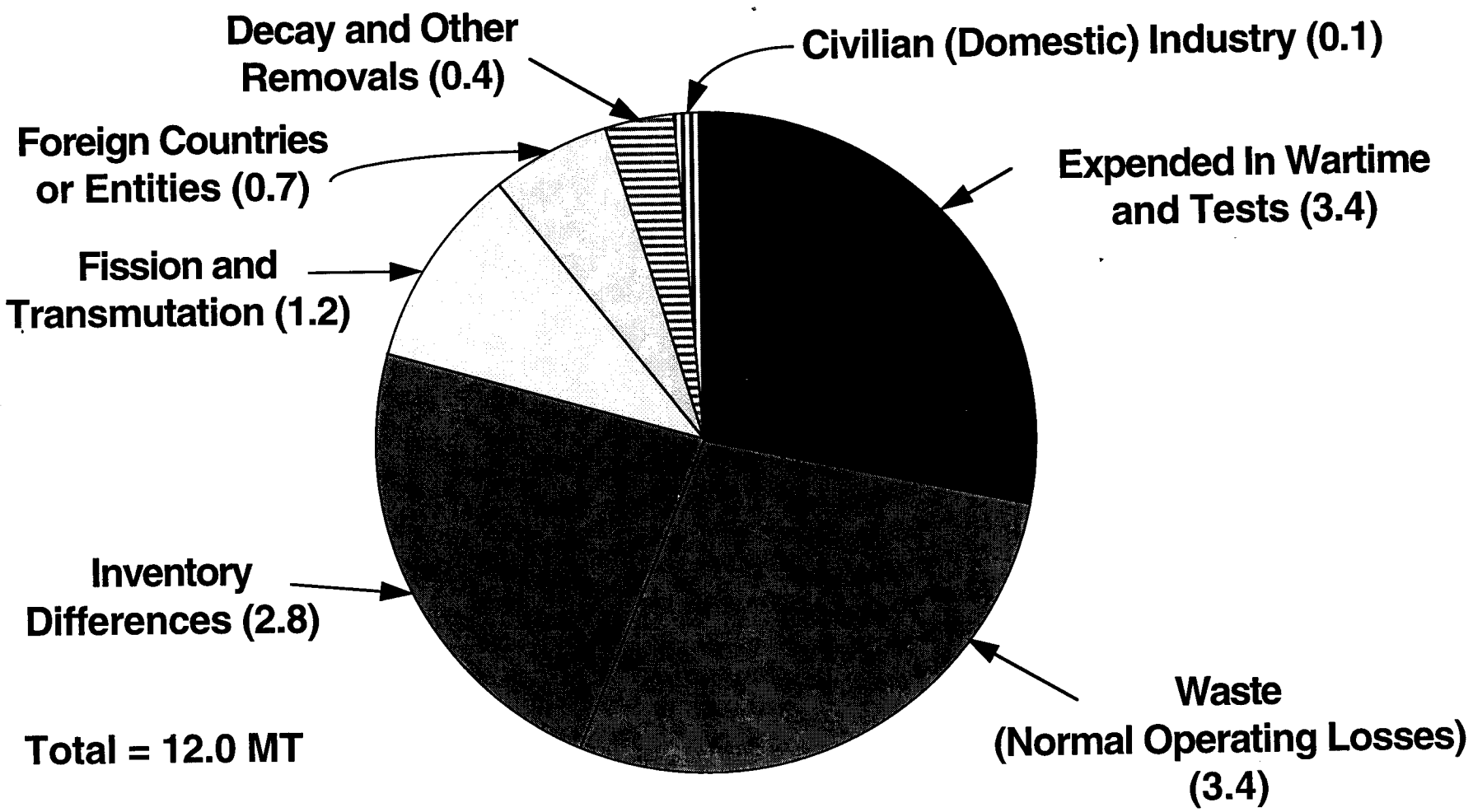
# 10. PLUTONIUM REMOVALS

The total plutonium removed from the DOE/DoD inventory for the period 1944 to September 1994 was 12.0 metric tons. Of the 12.0 MT removed 3.4 MT were Expended in Wartime and Nuclear Tests, 2.8 MT were Inventory Differences, 3.4 MT were Waste (Normal Operating Losses), 1.2 MT were consumed by Fission and Transmutation, 0.4 MT was Decay and Other Removals, 0.1 MT was transferred to U.S. Civilian Industry, and 0.7 MT was transferred to Foreign Countries.

As stated earlier, the removals detailed in this report do not include plutonium sent to foreign governments under Military Agreements for Cooperation per Section 91C of the Atomic Energy Act of 1954, and DoD losses. These transactions remain classified for national security reasons.

Figure 9 shows a comparison of the quantities of plutonium removed from inventory for the various removal categories that are used in this report.

## Figure 9
# Plutonium Removals
### (Metric Tons)



## 10.1 EXPENDED IN WARTIME AND NUCLEAR TESTS

A total of 3.4 metric tons of plutonium was expended in all U.S. nuclear weapons tests, wartime detonations, and peaceful nuclear explosions. Most of this plutonium was associated with weapons-related research and development. The first test of a nuclear weapon was in the atmosphere on July 16, 1945, in a remote part of New Mexico on what was then the Alamogordo Bombing Range, now called White Sands Missile Range.

Between June 1946 and November 1962, the U.S. conducted atmospheric and underwater tests in the Marshall Islands, Christmas Island, Johnston Atoll in the Pacific Ocean, and over the South Atlantic Ocean. In addition, atmospheric and underground nuclear tests were conducted in Nevada, Colorado, New Mexico, Mississippi, and on Amchitka, one of the Aleutian Islands off the coast of Alaska.

Several of these tests were for the Plowshare Program to develop industrial and scientific applications for nuclear explosives. This program was based on the premise that the tremendous and relatively inexpensive energy available from nuclear explosives could be useful for a variety of peaceful purposes.

On October 31, 1958, President Eisenhower announced a unilateral U.S. moratorium on nuclear weapons tests with the understanding that the Soviet Union would likewise refrain from conducting nuclear tests. The Soviet Union resumed testing in September 1961 with a series of the largest tests ever conducted and, on September 30, 1961, the U.S. resumed nuclear testing at the Nevada Test Site.

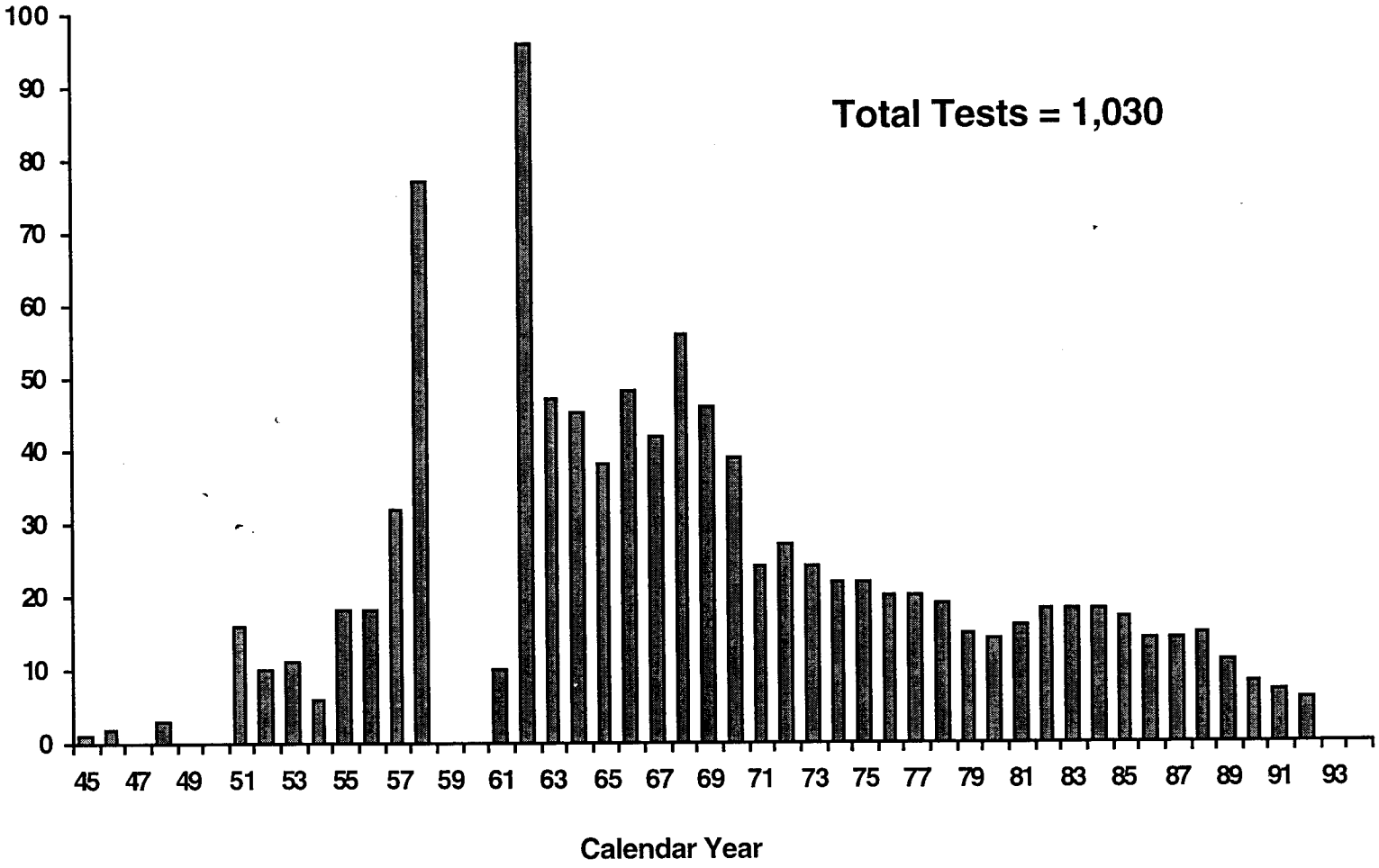
The Hatfield-Exon-Mitchell Amendment to the FY 1993 Energy and Water Appropriation Bill (Public Law 102-377) mandated a 10 month moratorium on U.S. nuclear testing and restricted the purposes and numbers of any tests to be conducted before a Comprehensive Test Ban Treaty (CTBT) is concluded. The Hatfield Amendment mandated that only five tests could be conducted per year, with a maximum over a four year period being 15 tests. Further, it stipulated that these tests could only be conducted for the purposes of ensuring the safety of warheads which were installed with modern safety features, or to test the reliability of U.S. nuclear weapons.

President Clinton has extended this moratorium on three occasions, most recently in January of 1995 when he extended the moratorium until a CTBT enters into force (on the assumption that a CTBT is concluded by September 30, 1996). The United States' goal is to conclude negotiations on a CTBT as soon as possible, so that the treaty can be open for signature at the 51st United Nations General Assembly in the fall of 1996.

As shown in Figure 10, the U.S. conducted 1,030 nuclear tests. The total does not include the two nuclear weapons detonated over Japan in World War II, which are not considered tests.

Information on nuclear tests is available in the DOE report, United States Nuclear Tests, July 1945 through December 1992, DOE/NV-209 (Revision 14), December 1994.

## Figure 10
# United States Nuclear Tests



## 10.2 INVENTORY DIFFERENCES

Inventory difference is the difference between the quantity of nuclear material held according to the accounting books and the quantity measured by a physical inventory. The cumulative plutonium inventory difference for the 50-year period from 1944 to 1994 is 2.8 metric tons.

Before 1978 inventory differences were identified as "material unaccounted for" (MUF). MUF was the more frequently used term in early days of nuclear materials accounting. MUF has at various times included the fractional amounts of nuclear materials lost in day to day operations and accumulated and accounted for as normal operating losses, accidental losses, and materials removed from a facility for quality control and safeguards analysis. Most historical data have been normalized over the past decade to the current practice of excluding these losses from the inventory difference calculation. Therefore, today's inventory difference values do not necessarily represent "losses" of nuclear material.

Inventory differences are not explained as losses but are explained as follows: (1) high measurement uncertainty of plant holdup[22]; (2) measurement uncertainties because of the wide variations of material matrix; (3) measurement uncertainties due to statistical variations in the measurement; (4) lack of measurement technology to accurately measure material; (5) measurement uncertainties associated with waste due to material concentration and matrix factors; (6) unmeasured material associated with accidental spills; and (7) recording, reporting and rounding errors

Since it is not prudent to discount the fact that a small inventory difference could possibly be due to theft, both DOE and contractors operating DOE facilities have always carefully investigated, analyzed and resolved every inventory difference to assure that a theft or diversion has not occurred.

In addition to detecting losses, analysis of inventory differences provides valuable information on the effectiveness of the safeguards system's physical protection and material control measures, as well as a check on the process controls and material management procedures. DOE and the contractors operating DOE facilities analyze and explain all significant inventory differences (i.e., outside strict statistical control limits) as well as missing items. If necessary, an operation may be shut down until any inventory differences are resolved.

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[22] Plutonium materials remaining in process tanks, piping, drains, ventilation ducts or other locations.

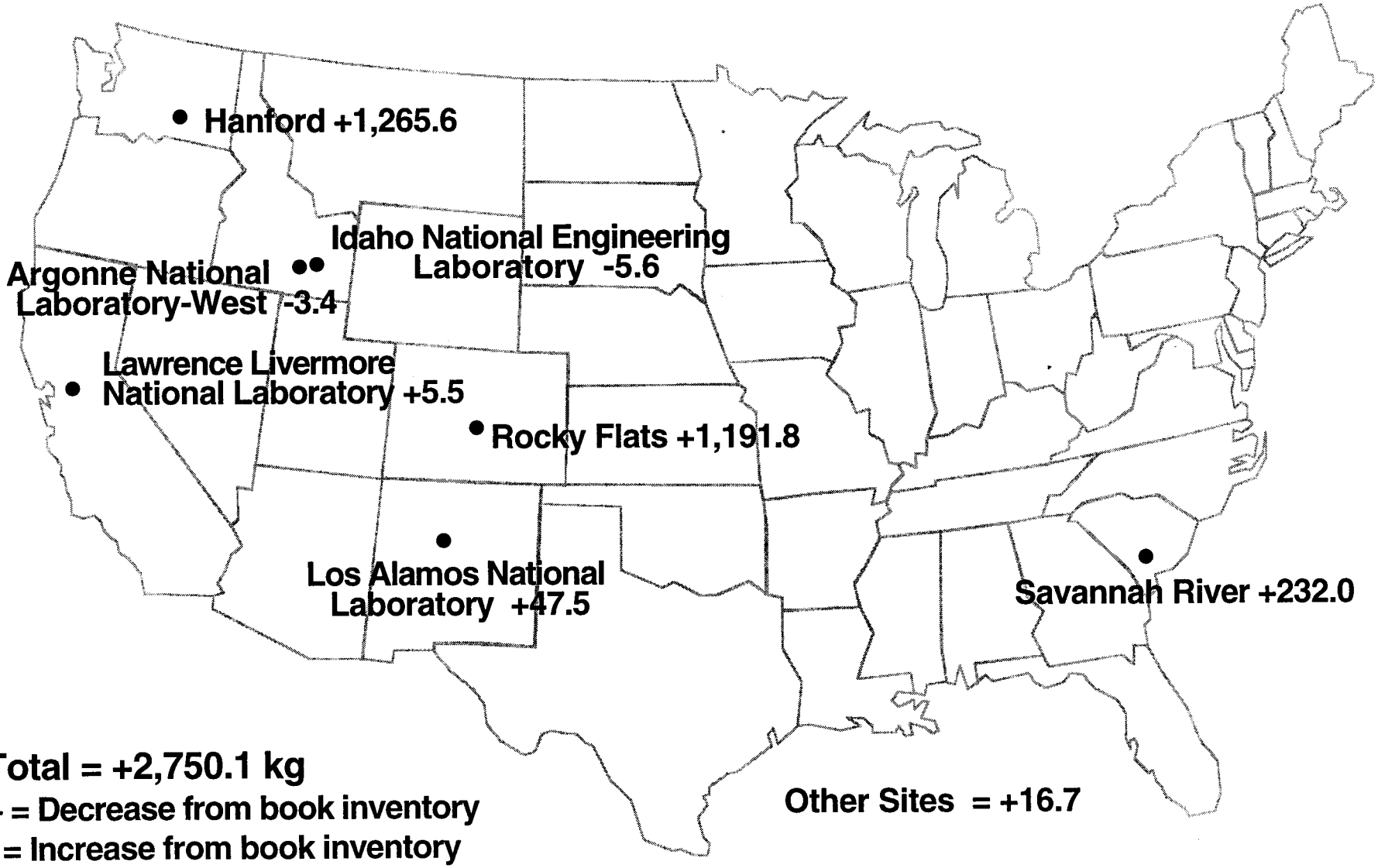
As part of the inventory difference evaluation, other security events are reviewed to ensure that inventory differences are not linked to breaches of physical security or insider acts. If there is no evidence of security breaches, then inventory differences are less likely to be caused by malevolent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

Data on inventory differences are presented in Figure 11 as a single, cumulative number for each of the major DOE sites from the beginning of operations through September 30, 1994. The 2,735.8 kg of plutonium identified at the June 27, 1994 Openness Press Conference, has been updated through September 1994. In addition, a single cumulative number for the inventory differences at other Department sites and commercial licensees which processed DOE plutonium is provided.

For a thorough discussion of inventory differences by fiscal year and DOE site, please refer to the Report on Strategic Special Nuclear Material Inventory Differences, ERDA 77-68, August 1977 and the periodic updates published through 1992.

By reviewing the above referenced documents it can be seen that 68% of the inventory difference occurred during the period prior to the late 1960's, when predictive reactor codes (i.e., conversion ratios) and materials measurement technologies were less accurate than today. It should also be noted that contractors operating the highest through-put sites also had the greatest inventory differences, suggesting that inventory differences are largely due to measurement and operations-related activities, and other non-security related events.

# Figure 11
# Plutonium Inventory Differences
## (Kilograms)




**Total = +2,750.1 kg**

**+ = Decrease from book inventory**

**- = Increase from book inventory**

## 10.3 WASTE (NORMAL OPERATING LOSSES )

Normal operating losses (NOL) occur when quantities of plutonium, determined by measurement or estimated on the basis of measurement, are intentionally removed from inventory as waste because they are technically or economically unrecoverable. As shown in Figure 12, a total of 3.4 metric tons of plutonium was removed from the inventory as waste from normal operating losses.

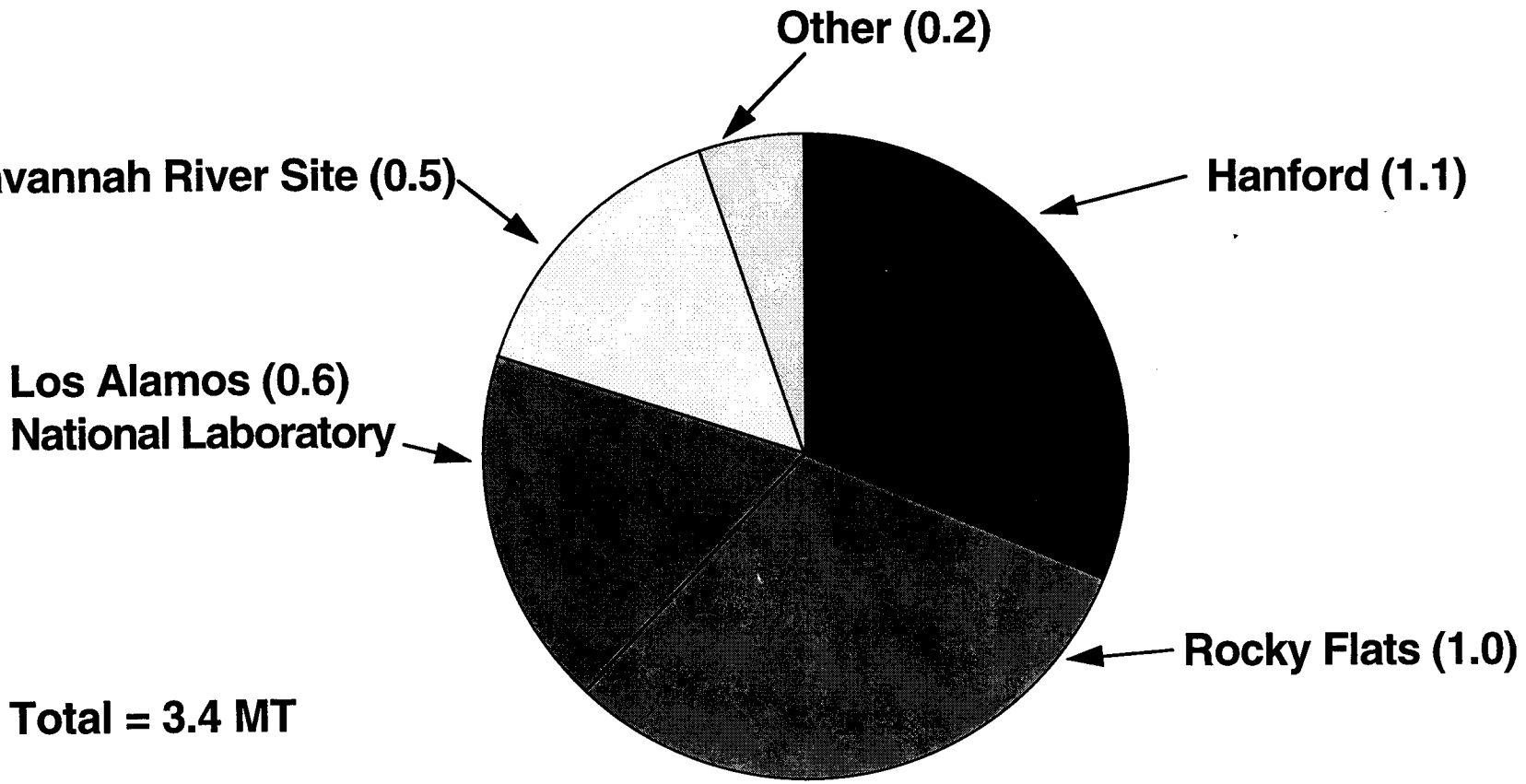
Some examples of waste are discharges to cribs, tanks, settling ponds, or to waste disposal facilities generically referred to as "burial sites." Major DOE burial sites are located at the Idaho National Engineering Laboratory Site, the Hanford Site, the Savannah River Site, and Los Alamos National Laboratory. Examples of plutonium bearing items sent to burial sites include discarded piping, spent ion exchange equipment, processing resins, and contaminated laundry and shoe covers.

The sites with the largest amount of plutonium in normal operating losses are Rocky Flats (1.0 MT), the Hanford Site (1.1 MT), Los Alamos National Laboratory (approximately 0.6 MT), and the Savannah River Site (0.5 MT). These are shown in Table 9.

The remaining 0.2 MT of plutonium in NOL occurred at the Lawrence Livermore National Laboratory, Oak Ridge National Laboratory, Argonne National Laboratory-West (Idaho), Argonne National Laboratory-East (Illinois), and U.S. companies that processed plutonium for the DOE.

As stated earlier, this report refers to "normal operating losses" as "waste." However, normal operating losses are actually just one estimation of the amount of plutonium managed as waste. The NMMSS data base on which this report is based differentiates between normal operating losses and waste. While all normal operating losses are considered waste, the reverse is not true. The total amount of plutonium in "waste" is 3.9 MT of which 3.4 MT is accounted for as NOL. In addition, these waste estimates within NMMSS may not agree with amount of plutonium in waste reported in other Departmental sources, such as the Integrated Database which collects information on waste volumes including plutonium in waste. A more complete explanation for these differences is found in Appendix B.

## Figure 12
# Plutonium in Waste (Normal Operating Losses) by Originating Site (Metric Tons)*




*As reported in the Nuclear Materials Management and Safeguards System
Note: Waste has been transferred between sites.

**Table 9. Plutonium in Waste (Normal Operating Losses) at Major DOE Sites (kg Pu)**

| Fiscal Year | Rocky Flats | Hanford Site | Los Alamos | Savannah River |
|---|---|---|---|---|
| 1944 | - | - | - | - |
| 1945 | - | - | - | - |
| 1946 | - | - | - | - |
| 1947 | - | - | - | - |
| 1948 | - | 0.1 | - | - |
| 1949 | - | 0.1 | - | - |
| 1950 | - | 0.1 | - | - |
| 1951 | - | 5.1 | - | - |
| 1952 | - | 12.8 | - | - |
| 1953 | - | 71.7 | - | - |
| 1954 | 0.1 | 12.3 | - | - |
| 1955 | 0.5 | 18.8 | - | 0.9 |
| 1956 | 2.6 | 21.9 | - | 3.4 |
| 1957 | 2.3 | 35.2 | - | 3.0 |
| 1958 | 4.5 | 23.8 | - | 3.2 |
| 1959 | 4.7 | 17.0 | - | 4.6 |
| 1960 | 4.4 | 24.8 | - | 11.9 |
| 1961 | 5.4 | 20.2 | - | 30.9 |
| 1962 | 6.0 | 16.7 | - | 1.4 |
| 1963 | 8.6 | 25.8 | - | 7.6 |
| 1964 | 21.2 | 25.3 | - | 13.6 |
| 1965 | 22.6 | 32.1 | - | 10.8 |
| 1966 | 31.9 | 28.5 | - | 7.3 |
| 1967 | 72.0 | 13.4 | - | 10.4 |
| 1968 | 68.1 | 26.2 | 4.3[23] | 5.4 |
| 1969 | 38.9 | 21.7 | 1.3 | 5.8 |
| 1970 | 38.7 | 18.5 | 0.3 | 6.0 |
| 1971 | 23.5 | 15.8 | 0.2 | 7.0 |

[23] This quantity is cumulative for the years prior to 1969

**Table 9. Plutonium in Waste (Normal Operating Losses) at Major DOE Sites (Kg Pu) (Continued)**

| Fiscal Year | Rocky Flats | Hanford Site | Los Alamos | Savannah River |
|---|---|---|---|---|
| 1972 | 12.6 | 26.4 | 0.4 | 5.3 |
| 1973 | 24.1 | 15.3 | 0.7 | 25.8 |
| 1974 | 26.3 | 11.4 | 5.3 | 11.7 |
| 1975 | 51.4 | 19.9 | 5.0 | 5.9 |
| 1976 | 29.2 | 18.4 | 4.6 | 9.8 |
| 1977 | 35.1 | 6.5 | 4.2 | 8.4 |
| 1978 | 20.4 | 49.3 | 8.2 | 12.4 |
| 1979 | 14.6 | 34.0 | 13.1 | 10.2 |
| 1980 | 15.3 | 53.0 | 20.0 | 14.0 |
| 1981 | 18.3 | 30.7 | 22.1 | 21.7 |
| 1982 | 48.5 | 43.2 | 55.1 | 18.0 |
| 1983 | 51.3 | 8.3 | 69.7 | 11.0 |
| 1984 | 61.2 | 28.5 | 78.9 | 17.3 |
| 1985 | 64.8 | 51.7 | 92.4 | 49.4 |
| 1986 | 95.1 | 46.8 | 84.8 | 49.9 |
| 1987 | 33.4 | 43.6 | 24.7 | 33.7 |
| 1988 | 34.7 | 22.2 | 26.9 | 34.6 |
| 1989 | 21.4 | 17.3 | 28.8 | 5.5 |
| 1990 | 6.3 | 24.9 | 18.9 | 9.1 |
| 1991 | 1.7 | 3.1 | 2.0 | 4.0 |
| 1992 | 1.3 | 3.9 | 4.6 | 1.5 |
| 1993 | 0.1 | 11.6 | 24.9 | 0.5 |
| 1994 | 1.2 | 2.9 | 8.6 | 15.5 |
| **Total** | **1,024.3** | **1,060.8** | **610.0** | **508.4** |

## 10.4 FISSION AND TRANSMUTATION

Fission and transmutation removals account for plutonium consumed by nuclear irradiation as a result of exposure in a reactor. Fission and transmutation can be divided into two distinct categories: isotope production and burn-up. A total of 1.2 metric tons plutonium was removed from the inventory by these processes. Annual fiscal year removals are shown in Figure 13 and Table 10.

### 10.4.1 Isotope Production

Plutonium was transformed to other materials as part of the Department's isotope development program. The objective of the program was to develop, produce and demonstrate applications of radioisotopes for industry, medicine and nuclear and radiation research. The isotope development program aimed to develop technology for the production, separation, purification, and encapsulation of isotopes utilizing resources of both the Department and industry.

This category was used to report plutonium that was transformed to other materials such as Plutonium-242, Plutonium-244, Americium, Curium, and Californium-252.

Californium-252 was produced in the Savannah River Site reactors and in the Oak Ridge National Laboratory (ORNL) High Flux Isotope Reactor in the late 1960's. Californium-252 is an excellent spontaneous fission neutron source for oil well logging, industrial radiography, reactor start-up, nuclear physics research, and medical applications.

Plutonium-242 was produced in the SRS reactors in the late 1960s. It is useful as target material for production of Plutonium-244, and nuclear physics research and applications in weapons programs. Plutonium-244 was produced in the SRS reactors in the late 1960s for use as a standard reference material for nuclear analysis and in nuclear fuel tagging.

### 10.4.2 Burn-up

The burn-up category accounts for plutonium that was consumed in the operation of experimental fast neutron and breeder reactors. The fuel for these reactors was fabricated from plutonium provided by the Government. Some of the reactors that used plutonium fuels included Southwest Experimental Fast Oxide Reactor (SEFOR) in Arkansas, the Fast Flux Test Facility (FFTF) in Washington State, and the Experimental Breeder Reactor 2 (EBR 2) in Idaho.

# Figure 13
# Plutonium Consumed In Fission and Transmutation

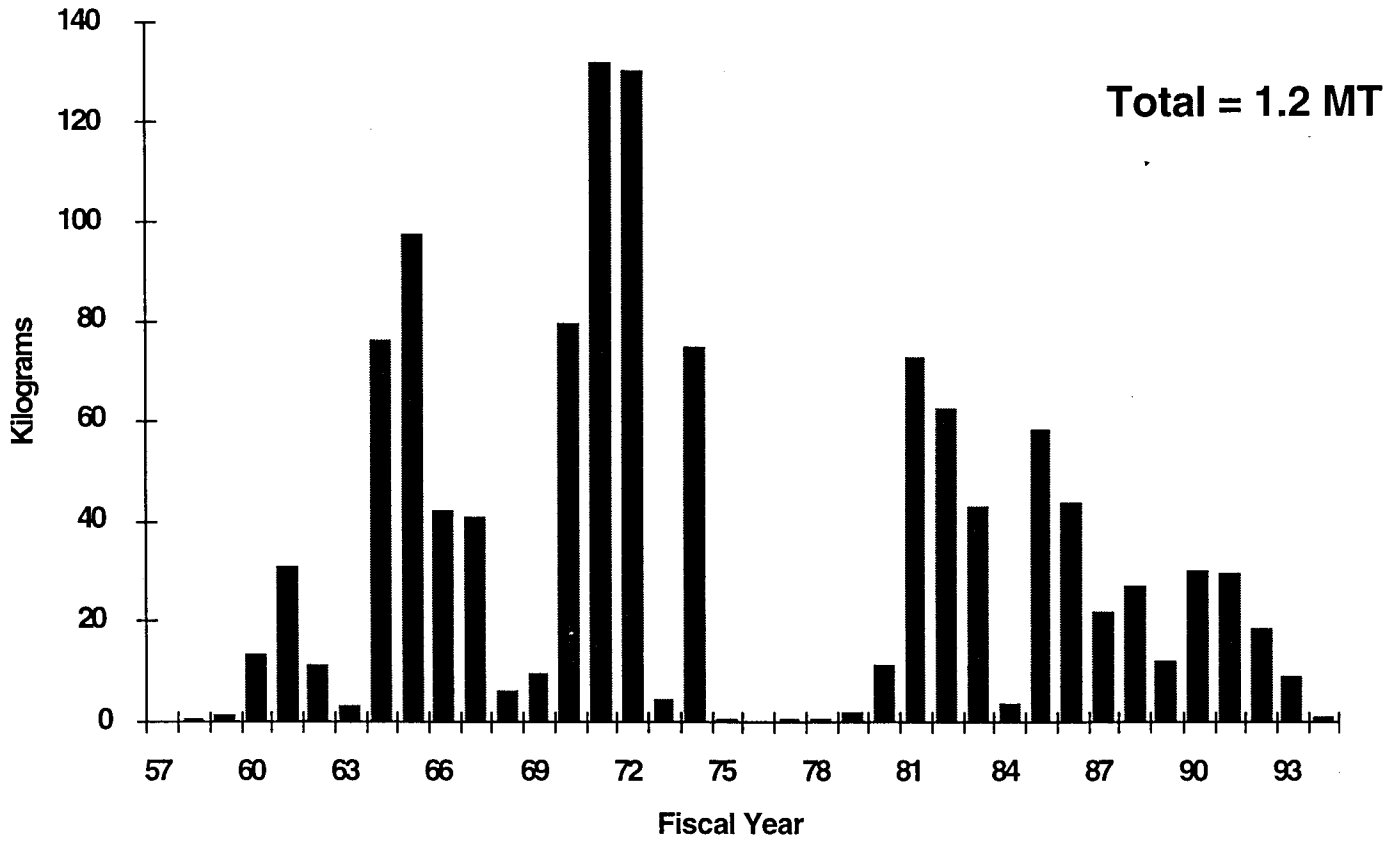


**Table 10. Plutonium Consumed in Fission and Transmutation (kg Pu)**

| Fiscal Year | Annual Consumed | Cumulative Consumed | Fiscal Year | Annual Consumed | Cumulative Consumed |
|---|---|---|---|---|---|
| 1957 | 0.1 | 0.1 | 1976 | - | 752.5 |
| 1958 | 0.3 | 0.4 | 1977 | 0.5 | 753.0 |
| 1959 | 1.3 | 1.7 | 1978 | 0.7 | 753.7 |
| 1960 | 13.2 | 14.9 | 1979 | 1.8 | 755.5 |
| 1961 | 30.9 | 45.8 | 1980 | 11.4 | 766.9 |
| 1962 | 11.0 | 56.8 | 1981 | 72.8 | 839.7 |
| 1963 | 3.0 | 59.8 | 1982 | 62.6 | 902.3 |
| 1964 | 76.0 | 135.8 | 1983 | 42.8 | 945.1 |
| 1965 | 97.4 | 233.2 | 1984 | 3.6 | 948.7 |
| 1966 | 41.8 | 275.0 | 1985 | 58.1 | 1,006.8 |
| 1967 | 40.5 | 315.5 | 1986 | 43.7 | 1,050.5 |
| 1968 | 6.0 | 321.5 | 1987 | 21.8 | 1,072.3 |
| 1969 | 9.6 | 331.1 | 1988 | 27.0 | 1,099.3 |
| 1970 | 79.6 | 410.7 | 1989 | 11.9 | 1,111.2 |
| 1971 | 132.0 | 542.7 | 1990 | 30.0 | 1,141.2 |
| 1972 | 130.4 | 673.1 | 1991 | 29.4 | 1,170.6 |
| 1973 | 4.2 | 677.3 | 1992 | 18.3 | 1,188.9 |
| 1974 | 74.9 | 752.2 | 1993 | 8.9 | 1,197.8 |
| 1975 | 0.3 | 752.5 | 1994 | 1.0 | 1,198.8 |

## 10.5 DECAY AND OTHER REMOVALS

This category accounts for all plutonium lost through radioactive decay, accidental losses, and approved write-offs. A total of 0.4 metric tons of plutonium was removed from the material balance using this category, almost all through decay.

### 10.5.1 Decay[24]

Decay losses are primarily due to the decay of Plutonium-241, which has a half-life of 14.35 years and decays to Americium-241 in aged plutonium. Other isotopes of plutonium have also decayed over time as well, primarily to uranium. A total of 0.4 MT plutonium was removed from the material balance using this category.

### 10.5.2 Accidental Losses

Accidental losses occur infrequently and usually involve small quantities of material. A total of 4.5 kg of plutonium was removed from the material balance using this category. Quantities of plutonium removed as accidental losses are shown in Table 11.

Accidental losses are similar to Normal Operating Losses in that these removals generally involve discards to cribs, tanks, settling ponds, or waste disposal facilities referred to as "burial sites." While a Normal Operating Loss is an intentional or planned removal from the inventory, an accidental loss is an unplanned removal.

An example of an accidental loss would be material spilled in a processing cell. The material is collected in a sump, pumped to a holding tank, and measured prior to being transferred to a waste tank.

[24] Plutonium decay is the spontaneous emission of alpha or beta particles resulting in the change of the element plutonium to other elements.

## Table 11. Accidental Losses (kg Pu)

| Fiscal Year | Annual Removal | Cumulative Removals | Fiscal Year | Annual Removal | Cumulative Removals |
|---|---|---|---|---|---|
| 1969 | - | 0.8[25] | 1983 | - | 4.0 |
| 1970 | - | 0.8 | 1984 | 0.1 | 4.1 |
| 1971 | - | 0.8 | 1985 | - | 4.1 |
| 1972 | 2.6 | 3.4 | 1986 | - | 4.1 |
| 1973 | - | 3.4 | 1987 | 0.1 | 4.2 |
| 1974 | - | 3.4 | 1988 | 0.3 | 4.5 |
| 1975 | 0.5 | 3.9 | 1989 | - | 4.5 |
| 1976 | 0.1 | 4.0 | 1990 | - | 4.5 |
| 1977 | - | 4.0 | 1991 | - | 4.5 |
| 1978 | - | 4.0 | 1992 | - | 4.5 |
| 1979 | - | 4.0 | 1993 | - | 4.5 |
| 1980 | - | 4.0 | 1994 | - | 4.5 |
| 1981 | - | 4.0 | | | |
| 1982 | - | 4.0 | | | |

[25] This quantity is cumulative for the years prior to 1969.

### 10.5.3 Approved Write-offs

A total of 4 kg plutonium was removed from the plutonium inventory under this category, and are shown in Table 12.

Approved write-offs occur when plutonium is written off the inventory because accountability is no longer deemed necessary for that material. An example of this would be small amounts of plutonium fixed on concrete in operating cells of process facilities. The plutonium is not easily removed and will eventually end up as a discard to a waste management site. If the facility is later decontaminated and the plutonium is recovered, the previously estimated approved write-off would be debited from the accounting inventory and the actual quantity would be reentered into the inventory. Approved write-offs occur infrequently and require the approval of the cognizant DOE field organization.

## Table 12. Approved Write-offs (kg Pu)

| Fiscal Year | Annual Write-offs | Cumulative Write-offs | Fiscal Year | Annual Write-offs | Cumulative Write-offs |
|---|---|---|---|---|---|
| 1965 | 6.1 | 6.1 | 1980 | - | 3.4 |
| 1966 | 1.4 | 7.5 | 1981 | - | 3.4 |
| 1967 | -3.7[26] | 3.8 | 1982 | - | 3.4 |
| 1968 | 0.2 | 4.0 | 1983 | - | 3.4 |
| 1969 | - | 4.0 | 1984 | - | 3.4 |
| 1970 | - | 4.0 | 1985 | - | 3.4 |
| 1971 | - | 4.0 | 1986 | 0.7 | 4.1 |
| 1972 | 0.2 | 4.2 | 1987 | - | 4.1 |
| 1973 | -0.7 | 3.5 | 1988 | - | 4.1 |
| 1974 | 34.7 | 38.2 | 1989 | - | 4.1 |
| 1975 | -34.5 | 3.7 | 1990 | - | 4.1 |
| 1976 | -0.4 | 3.3 | 1991 | - | 4.1 |
| 1977 | 0.1 | 3.4 | 1992 | - | 4.1 |
| 1978 | - | 3.4 | 1993 | - | 4.1 |
| 1979 | - | 3.4 | 1994 | - | 4.1 |

[26] A negative number is an increase to the inventory.

## 10.6 U.S. CIVILIAN INDUSTRY

This category consists of plutonium that has been sold or permanently transferred by the Department to U.S. civilian industry. A total of 0.1 metric ton of plutonium is included in the material balance using this category.

Mandatory government ownership of special nuclear material in the U.S. was ended on August 26, 1964 with the Private Ownership of Special Nuclear Materials Act. As a result of this law, plutonium produced in some AEC-owned and public utility-operated prototype reactors was transferred from the Government to the operators of the utility. For example, in 1974 the AEC transferred the ownership of 42 kg of plutonium to the Dairyland Power Cooperative. The Dairyland Power Cooperative operated the La Crosse boiling water reactor, an AEC owned reactor located on the Mississippi River near Genoa, Wisconsin.

The balance of the plutonium was sold or donated to universities, hospitals, and other industry, primarily in the form of sealed sources.

## 10.7 FOREIGN COUNTRIES

Removals to foreign countries consists of plutonium transferred under Agreements for Cooperation. A total of 0.7 metric ton of fuel grade plutonium was removed from the material balance using this category.

The Department's international activities are authorized by the Atomic Energy Act of 1954, as amended and the Nuclear Nonproliferation Act of 1978. In addition to authorizing foreign exchanges and sales of nuclear material, these acts require that nuclear material exported under that authority be subject to safeguards and physical protection measures.

Section 3.4 of this report discusses in detail how these requirements are satisfied. Generally, U.S.-origin nuclear material is subject to international safeguards applied by the International Atomic Energy Agency (IAEA) and the determination of the adequacy of physical protection measures of the U.S.-origin material is the responsibility of the U.S. Government. The Department of Energy, in cooperation with the Departments of State and Defense, and the Nuclear Regulatory Commission conducts a program of bilateral reviews of physical protection for U.S.-origin nuclear material at foreign facilities.

### 10.7.1 Agreements for Cooperation

Under the Atoms for Peace Program, started during the Eisenhower Administration, the Department exchanged information on peaceful uses of nuclear materials with other nations, including the sale of nuclear fuels for power and research reactors.

Agreements for Cooperation in the civil uses of atomic energy provided the framework for these activities. Almost forty agreements covering foreign exchanges and sales were in effect. An important part of each agreement was the establishment of procedures to assure that the materials or equipment supplied was not diverted from peaceful to military uses.

A total of 0.7 metric ton of plutonium was shipped to foreign countries, primarily to countries participating in the European Atomic Energy Community (Euratom), Japan, and the United Kingdom. Euratom was established in 1957 and originally consisted of

six countries (Belgium, France, Italy, Luxembourg, the Netherlands, and Germany). The U.S. also participated in joint projects with the European Nuclear Energy Agency and with individual countries under bilateral agreements. Cooperative research was being conducted in many areas such as fast breeder reactors, reprocessing of nuclear fuels, lowering fuel cycle costs in power reactors, food irradiation, and dual purpose nuclear power-desalting plants. However, the majority of the plutonium exported to foreign countries was for use in breeder reactor research.

Five of the six Euratom countries received approximately 575 kilograms of plutonium from the U.S. Government. This plutonium was shipped in accordance with bilateral agreements with the individual countries or under the United States-Euratom Agreement for Cooperation.

- From 1961 to 1989, approximately 518 kg plutonium was sent to West Germany. The largest shipments occurred from 1965 to 1969 when 515 kg plutonium in the form of oxide was sold and shipped to the Kern facility in West Germany.

- From 1957 to 1991, approximately 42 kg plutonium was sent to France. The largest shipments occurred in 1968 when 30 kg plutonium as oxide was shipped to the Rapsodie reactor in Cadarache, France.

- Approximately 15 kg plutonium was sent to Belgium, Italy, and the Netherlands in various forms.

From 1962 to 1991, approximately 114 kg of plutonium were exported to Japan. The largest shipments occurred in 1969 and 1970 when 104 kg of plutonium in the form of reactor fuel elements and oxide were shipped to Japan, primarily to the Fast Critical Assembly at Tokai-Mura.

From 1974 to 1988, approximately 34 kg of plutonium were sent to the United Kingdom. The largest shipments occurred in 1980 and 1981 when 32 kg of plutonium in the form of reactor fuel elements were shipped to the Sellafield fuel fabrication facility.

Austria, Canada, Israel, Switzerland, and Sweden received about 24 kg of plutonium under various Agreements for Cooperation. Most of this plutonium was in the form of fuel elements and oxide.

Twenty-seven additional countries and the IAEA received the remaining 2 to 3 kilograms of plutonium exported under Agreements for Cooperation. Most of this plutonium was in the form of sources. Sources are used for calibration of radiation measuring and monitoring instruments and in nuclear research and development activities.

Quantities of plutonium exported are shown by country in Table 13 and by year in Table 14.

## Table 13. Removals under Agreements for Cooperation

| Country | kg Pu | Form | Years |
|---|---|---|---|
| Argentina | <0.1 | Samples, standards | 1969 - 1980 |
| Austria | 0.2 | Sources, samples | 1960 - 1965 |
| Australia | 6.4 | Fuel elements, sources | 1960 - 1970 |
| Belgium | 11.8 | Oxide, metal, samples | 1957 - 1991 |
| Brazil | 0.1 | Sources, samples | 1963 - 1978 |
| Canada | 3.5 | Oxide, sources, samples | 1957 - 1990 |
| Columbia | 0.1 | Sources | 1964 |
| Czechoslovakia | <0.1 | Samples, standards | 1977 - 1982 |
| Denmark | 0.1 | Sources, samples | 1959 - 1963 |
| Finland | <0.1 | Samples, standards | 1975 - 1979 |
| France | 41.5 | Oxide, sources, samples | 1957 - 1991 |
| Germany, West | 518.1 | Oxide, metal, sources, samples | 1961 - 1989 |
| Greece | 0.2 | Sources | 1963 |
| IAEA | 0.4 | Sources, standards, samples | 1964 - 1994 |
| Ireland | <0.1 | Sources | 1963 |
| India | 0.1 | Sources, samples | 1968 - 1973 |
| Iran | 0.1 | Sources | 1967 |
| Iraq | <0.1 | Sources | 1975 |
| Israel | 0.6 | Sources, samples | 1960 - 1969 |
| Italy | 2.3 | Fuel elements, sources | 1960 - 1978 |
| Japan | 113.5 | Fuel elements, oxide, sources | 1962 - 1991 |
| Korea, South | <0.1 | Sources, samples | 1961 - 1989 |
| Mexico | 0.2 | Sources, samples | 1967 - 1973 |
| Netherlands | 0.9 | Oxide, sources, samples | 1960 - 1982 |
| New Zealand | 0.1 | Sources | 1961 |
| Norway | <0.1 | Samples, standards | 1958 - 1966 |
| Pakistan | 0.1 | Sources | 1965 - 1972 |
| Philippines | <0.1 | Sources | 1962 |
| Portugal | <0.1 | Samples | 1980 |
| South Africa | 0.2 | Sources | 1965 |

**Table 13. Removals under Agreements for Cooperation (Continued)**

| Country | kg Pu | Form | Year |
|---|---|---|---|
| Switzerland | 4.3 | Oxide, sources, samples | 1959 - 1986 |
| Spain | <0.1 | Samples, standards | 1963 - 1967 |
| Sweden | 9.3 | Fuel elements, sources | 1957 - 1984 |
| Taiwan | 0.1 | Sources, samples | 1959 - 1973 |
| Thailand | 0.1 | Sources | 1962 |
| Turkey | 0.4 | Sources | 1961 - 1966 |
| United Kingdom | 33.9 | Fuel elements, sources | 1974 - 1988 |
| Uruguay | 0.1 | Sources | 1965 |
| Venezuela | <0.1 | Sources | 1960 |
| Vietnam, South | 0.1 | Sources | 1962 |
| **Total** | **748.8** | | |

**Table 14. Annual Removals under Agreements for Cooperation (kg Pu)**

| Year | Annual Exports | Cumulative Exports | Year | Annual Exports | Cumulative Exports |
|---|---|---|---|---|---|
| 1959 | 0.5 | 0.5 | 1977 | - | 709.9 |
| 1960 | 1.5 | 2.0 | 1978 | - | 709.9 |
| 1961 | 2.2 | 4.2 | 1979 | 0.1 | 710.0 |
| 1962 | 1.6 | 5.8 | 1980 | 25.8 | 735.8 |
| 1963 | 12.6 | 18.4 | 1981 | 6.6 | 742.4 |
| 1964 | 5.7 | 24.1 | 1982 | 0.4 | 742.8 |
| 1965 | 242.7 | 266.8 | 1983 | 0.2 | 743.0 |
| 1966 | 169.0 | 435.8 | 1984 | 2.1 | 745.1 |
| 1967 | 8.8 | 444.6 | 1985 | - | 745.1 |
| 1968 | 36.2 | 480.8 | 1986 | 3.0 | 748.1 |
| 1969 | 171.4 | 652.2 | 1987 | - | 748.1 |
| 1970 | 45.8 | 698.0 | 1988 | - | 748.1 |
| 1971 | 3.1 | 701.1 | 1989 | 0.1 | 748.2 |
| 1972 | 8.1 | 709.2 | 1990 | 0.6 | 748.8 |
| 1973 | 0.2 | 709.4 | 1991 | - | 748.8 |
| 1974 | 0.2 | 709.6 | 1992 | - | 748.8 |
| 1975 | 0.1 | 709.7 | 1993 | - | 748.8 |
| 1976 | 0.2 | 709.9 | 1994 | - | 748.8 |

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# APPENDIX A: EXCESS WEAPON GRADE PLUTONIUM

Over the years, DOE has produced, acquired and maintained large inventories of plutonium for nuclear weapons production and non-defense related missions. With the end of the Cold War and resulting diminished strategic military threat, opportunities presented themselves for the Department to redirect its priorities from weapons production activities to other critical national security missions. With the reduction in nuclear weapons, significant quantities of weapons grade plutonium became excess to national defense needs.

On September 27, 1993, the President issued a Nonproliferation and Export Control Policy which set forth the framework for U.S. efforts to prevent the proliferation of weapons of mass destruction. As a key element of the President's policy, the U.S. committed to eliminating, where possible, the accumulation of stockpiles of highly enriched uranium and plutonium and to ensure that where these materials already exist, they are subject to the highest standards of safety, security, and international accountability.

In support of this policy, the Departments of Energy and Defense performed an in-depth review of the fissile material required to support the nuclear weapons program and other national security needs. This was compared to available materials and as a result, 38 MT of weapon grade plutonium were declared excess to national defense needs (Table 15).

In keeping with the President's policy, the Secretary of Energy announced on December 20, 1994, that plutonium and weapons usable highly enriched uranium that was separated and/or stabilized during the phase out, shutdown, and cleanout of weapons complex facilities would be set-aside as restricted use material and not used for nuclear explosive purposes.

On March 1, 1995, in a speech at the Nixon Center for Peace and Freedom, President Clinton stated, "To further demonstrate our commitment to the goals of the Treaty[27], today I have ordered that 200 tons of fissile material -- enough for thousands of nuclear weapons -- be permanently withdrawn from the United States nuclear stockpile. It will never again be used to build a nuclear weapon."

[27] Nuclear Nonproliferation Treaty

## Table 15. Excess Weapon Grade Plutonium (MT Pu)

| Location | Metal | Oxides | Reactor Fuel | Irradiated Fuel | Other Forms | Total |
|---|---|---|---|---|---|---|
| Pantex /future dismantlements | 21.3 | - | - | - | - | 21.3 |
| Rocky Flats | 5.7 | 1.6 | - | - | 4.6 | 11.9 |
| Hanford Site | <0.1 | 1.0 | - | 0.2 | 0.5 | 1.7 |
| Los Alamos | 0.5 | <0.1 | <0.1 | - | 1.0 | 1.5 |
| Savannah River | 0.4 | 0.5 | - | 0.2 | 0.2 | 1.3 |
| INEL | <0.1 | - | 0.2 | 0.2 | <0.1 | 0.4 |
| Other Sites | <0.1 | - | - | <0.1 | <0.1 | 0.1 |
| **Total** | **27.8** | **3.1** | **0.2** | **0.6** | **6.4** | **38.2** |

Note: Totals may not add due to rounding to the nearest tenth of a metric ton.

# APPENDIX B: PLUTONIUM WASTE

The report, Plutonium: The First Fifty Years, focuses on the U.S. Government production, acquisition, and utilization of plutonium during the past fifty years and the Nuclear Materials Management and Safeguards System (NMMSS) which is used to track and account for this plutonium. Information in the NMMSS has changed over the years reflecting improved measurement technologies and increased accounting requirements. This appendix addresses the plutonium in waste that the Department manages. Plutonium in waste is not included in the DOE/DoD 99.5 MT plutonium inventory as presented earlier in this report. In addition, this appendix explains the differences between quantities of plutonium in "normal operating losses" and the "waste" accounts within the NMMSS. It also presents how data from the NMMSS compare to other Departmental materials inventory systems that track plutonium in waste.

**Normal Operating Losses Compared with Plutonium in Waste in NMMSS.**

Section 10.3 of this report identifies the amount of plutonium in a NMMSS category referred to as "normal operating losses" (NOL). Plutonium that is technically or economically unrecoverable and intentionally sent to waste is referred to as NOL and removed from the DOE/DoD plutonium inventory. The DOE/DoD plutonium inventory requires strict safeguards and security. The plutonium in waste is not subject to the same degree of rigorous safeguards and security as the DOE/DoD plutonium inventory.

- The quantities of plutonium removed from the DOE/DoD inventory and placed in waste as NOL are determined by either direct measurements or estimated based on measured sampling methods and practices -- for example, all liquid wastes are sampled and analyzed prior to being sent to a waste tank. The NMMSS indicates that a total of 3.4 MT of plutonium was sent to waste by way of NOL.

- The method used in estimating plutonium in waste burial sites and tanks was based on extrapolation from direct measurements of the waste -- for example, a small

sample of radioactive waste is taken from a waste tank, the amount of plutonium in that sample is analyzed, and the amount of plutonium is estimated by multiplying this small sample times its relative proportion in the larger waste volume. The total amount of plutonium in NMMSS waste accounts is 3.9 MT (see Figure 14 and Table 16).

Because the NMMSS was originally designed for nuclear materials safeguards purposes, there was no need to reconcile the NOL quantities with the later quantities recorded in the NMMSS waste accounts for materials management purposes. The 0.5 MT difference in NMMSS between the NOL estimate of 3.4 MT and the 3.9 MT "waste" estimate is attributable to two primary causes:

1. Waste inventories are tracked for environmental, safety and health reasons, and are therefore not necessarily calculated like normal operating losses. Waste inventory calculations and normal operating losses both rely on independent measured estimates, which lead to some degree of uncertainty in each. The normal operating losses are used for safeguards and security purposes and may not include all the information that may be required for waste inventory.

   In the early 1970s, sites began reporting details of plutonium in waste for the first time to NMMSS. At most sites the estimates of the amount of plutonium in waste were based on direct measurements of waste and provided confirmation of the NOL estimates of waste. In the case of Hanford, however, the 1974 estimate indicated 0.4 MT more plutonium in waste than in normal operating losses. This difference could be either: an accounting error at the site, such as reporting plutonium already included in the normal operating losses; or additional plutonium not captured by the normal operating losses tracking system, and therefore likely reported as "inventory differences."[28] While site records do not allow the Department to determine the source of this inconsistency at this time, the Department has

[28] Inventory differences are defined as the difference between the actual physical inventory and the estimated inventory. Additional information on the relationship between waste and inventory differences can be found in the Report on Strategic Special Nuclear Material Inventory Differences, ERDA, 77-68, August 1977, and the periodic updates published through 1992.

performed additional analysis supporting the higher estimate of plutonium in waste and, using this higher estimate, has determined that there are no imminent health, safety, or environmental risks. Since 1974, the annual normal operating losses and waste inventories have tracked very closely.

2. Waste includes off-site sources, including plutonium waste from the Navy and from licensed commercial facilities. Most commercial waste came from two facilities that fabricated fuel for reactors: the Nuclear Fuel Services at Erwin, Tennessee, and Cimarron Corporation at Cresent, Oklahoma. Normal operating losses include only waste generated from government on-site production. Since 1974, the remaining 0.1 MT inconsistency tracks closely to wastes received from sources outside of the Department.

**Waste Quantities in the NMMSS Compared to Other Departmental Waste Material Databases.**

In addition to the difference between waste and normal operating losses within NMMSS, the amount of plutonium waste in this report may not agree with the amount of plutonium in waste reported in other Departmental sources, such as the Integrated Database (IDB) or site-specific waste tracking systems. Two primary reasons for these apparent inconsistencies include: (1) the NMMSS waste data reflect only fissile plutonium inventories (i.e., Pu-239), while other sources include all isotopes of plutonium; and (2) the IDB does not differentiate between waste that requires nuclear materials safeguards, and therefore is still recorded as part of the inventory, and waste that has actually been removed from the inventory and physically sent to a waste burial site. Because of different intended uses of these databases, differing quantities of plutonium in waste can arise.

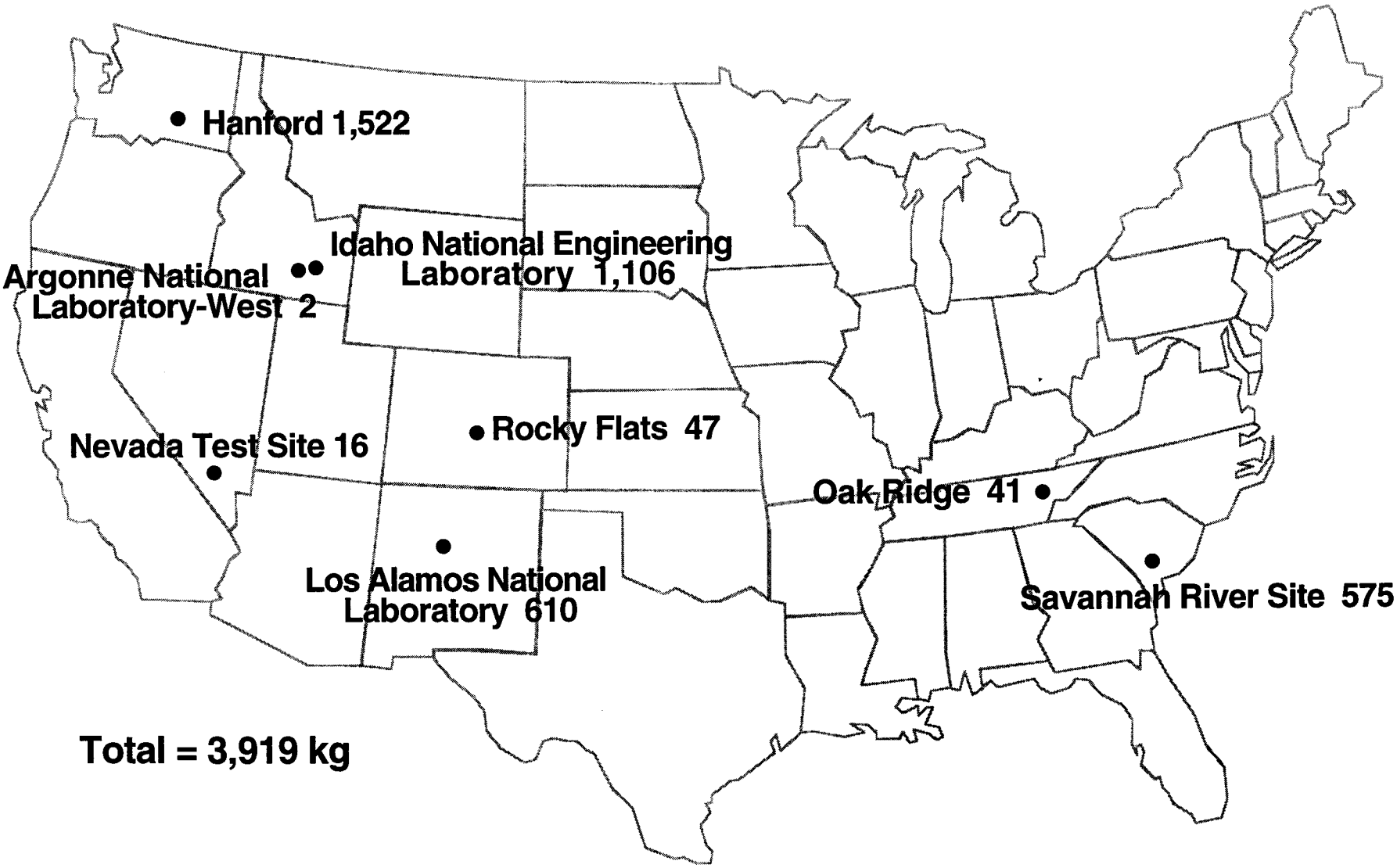
The Department has formed a working group to analyze NMMSS, IDB, and other Departmental tracking systems and to make recommendations on the appropriateness of integrating the various inventory systems or developing a new tracking system for all forms of plutonium.

For more information on the environmental, safety and health problems related to waste across Departmental sites and what the Department is doing to address those problems, please refer to the DOE Office of Environmental Management report, Closing the Circle on the Splitting of the Atom, January 1995.

Figure 14

# Plutonium Inventory in Buried and Stored Wastes*

(Kilograms)




*As reported in the Nuclear Materials Management and Safeguards System

## Table 16. Plutonium In Waste Inventory

| Location | kg Pu | Description |
|---|---|---|
| Savannah River Site Burial Ground | 193 | Solid waste stored in containers. Waste consists of many forms when packaged - nitrates, fluorides, oxides, and oxalates. Over time, the oxidizing conditions force the chemistry of the metals to their most stable form. At this time, the primary form of material in the containers is an oxide or a complex form involving oxygen. |
| | 382 | Liquid waste in high level waste tanks. This material will eventually be converted to a glass form for long term storage. |
| Los Alamos National Laboratory Burial Ground | 610 | Solid waste in various forms. |
| Nevada Test Site Burial Ground | 16 | Solid waste received from Rocky Flats Plant and Pantex Plant is stored in retrievable land burial or in above ground containers. |
| Argonne National Laboratory-West | 2 | Plutonium embedded in irradiated reactor test loops and reactor blanket assemblies stored in dry storage tubes underground. |
| Hanford Site | 455 | High level waste in the tank farms. |
| | 875 | Solid waste in burial grounds. |
| | 192 | Waste in cribs, trenches and ponds. |
| Oak Ridge National Laboratory | 41 | Particulate waste, as sediment in a settling basin, dry solids and oxides in above and below surface burial grounds, and solution and sludge in storage tanks. |
| Idaho, Waste Management | 1,026 | Solid waste in drums and boxes received primarily from Rocky Flats Plant is stored in above ground pads covered with earthen berms. |
| Idaho, Idaho Chemical Processing Plant Waste Farm | 8 | Solutions stored in tank farms. |
| | 72 | Calcined waste stored in bins. |
| Rocky Flats - Awaiting Disposition | 47 | Solid waste packaged in drums and crates awaiting shipment to a burial site. |
| **Total** | **3,919** | |

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