Department of Energy
Washington, DC 20585

February 2, 2006

Mr. Stephen Aftergood
Federation of American Scientists
1717 K Street, NW, Suite 209
Washington, D.C. 20036

Dear Mr. Aftergood:

We are writing in regard to your Freedom of Information Act (FOIA) request and subsequent appeal for the draft report entitled "Highly Enriched Uranium: Striking a Balance" (Report). The Department of Energy (Agency) issued a final determination to withhold in its entirety the draft Report on January 24, 2005. On March 7, 2005, the Department of Energy Office of Hearings and Appeals granted your Appeal (Case Number TFA-0088) in part and denied it in all other aspects as set forth in the reference decision and order.

Pursuant to the decision by the Office of Hearings and Appeals the Office of Security and Safety Performance Assurance, in conjunction with other offices, conducted a further review of the draft Report. The Agency has prepared a redacted version of the Report following this review. FOIA requires that "any reasonable segregable portion of a record shall be provided to any person requesting such record after deletion of the portions which are exempt." 5 U.S.C. 552(b). As a result, the Agency is releasing all reasonably segregable information contained within the Report pursuant to the March 7, 2005, DECISION and ORDER. The Agency is withholding information pursuant to Exemption 5 and Exemption 2(high) of the FOIA.

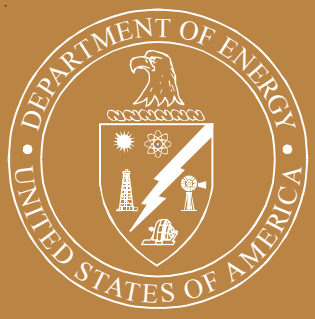
FOIA Exemption 5 covers interagency, deliberative, predecisional materials containing information unavailable to other parties. Information redacted consists of deliberative material reflecting the process of commenting, recommending and revising procedures governing certain defense agreement exchanges with the United Kingdom. FOIA Exemption 2 covers materials "related solely to the internal personnel rules and practices of an agency." The Agency redacted from the Report information regarding the location and quantity of fissile material withholdable under Exemption 2(high). This sensitive information regarding Agency practices constitutes predominantly internal information, and release of the information would cause Agency harm by risking the circumvention of Agency regulations or statutes or interfering with Agency operations necessary to safeguard this material.

Sincerely,

Michael A. Kilpatrick
Deputy Director
Office of Security and Safety
Performance Assurance

Enclosures

Cc: Office of Hearings and Appeals (w/o enclosure)



HIGHLY ENRICHED URANIUM: STRIKING A BALANCE

A HISTORICAL REPORT ON THE UNITED STATES HIGHLY ENRICHED URANIUM PRODUCTION, ACQUISITION, AND UTILIZATION ACTIVITIES FROM 1945 THROUGH SEPTEMBER 30, 1996

U.S. DEPARTMENT OF ENERGY
NATIONAL NUCLEAR SECURITY ADMINISTRATION
OFFICE OF THE DEPUTY ADMINISTRATOR
FOR DEFENSE PROGRAMS

JANUARY 2001

REVISION 1

OFFICIAL USE ONLY

Contains information which may be exempt from public release under the Freedom of Information Act (5 U.S.C. 552), exemption number 2. Approval by the Department of Energy prior to public release is required.

Reviewed by: Bill Benton Date: 2/7/05

Table of Contents

List of Appendices

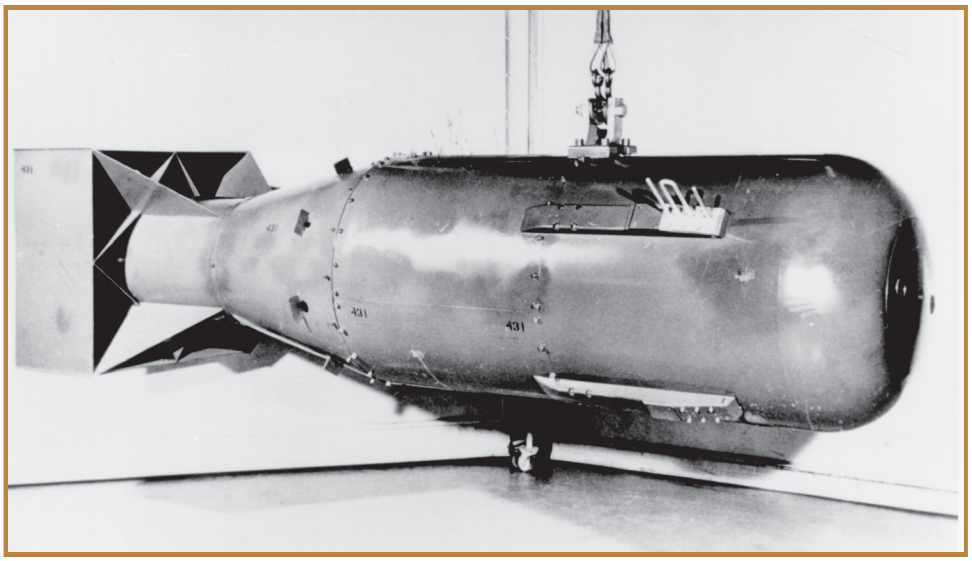
List of Figures

List of Tables

ACRONYMS AND ABBREVIATIONS

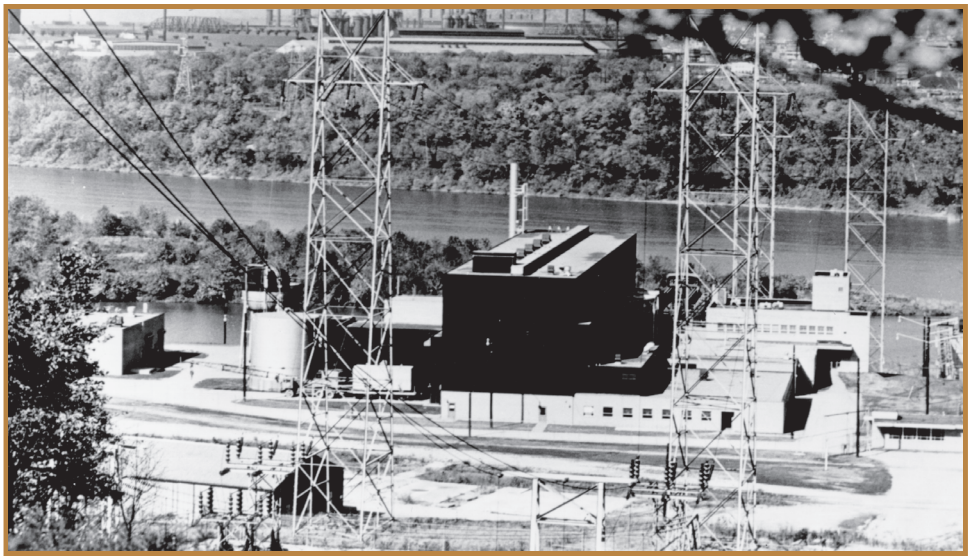
AEC	Atomic Energy Commission
BNL	Brookhaven National Laboratory
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
ERDA	Energy Research and Development Administration
Euratom	European Atomic Energy Community
GDP	gaseous diffusion plant
HEU	highly enriched uranium
IAEA	International Atomic Energy Agency
ICPP	Idaho Chemical Processing Plant
INEEL	Idaho National Engineering and Environmental Laboratory
kg	kilograms
LANL	Los Alamos National Laboratory
LEU	low enriched uranium
LLNL	Lawrence Livermore National Laboratory

MC&A	material control and accountability
MTU	metric tons of uranium
MTU-235	metric tons of uranium-235
NIST	National Institute of Standards and Technology
NMMSS	Nuclear Materials Management and Safeguards System
NOL	normal operating losses
NPT	Treaty on the Non-Proliferation of Nuclear Weapons
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
RFETS	Rocky Flats Environmental Technology Site
SNL	Sandia National Laboratories
SRS	Savannah River Site
TRIGA	Training, Research, Isotope, General Atomics reactors
UF_6	uranium hexafluoride
USEC	United States Enrichment Corporation



Pictured is a museum display of Little Boy, the first uranium bomb.

The U.S.S. Nautilus was commissioned in 1955 and was the first nuclear-powered submarine.



The Shippingport Atomic Power Station in Shippingport, PA, began operation in 1957 and was the Nation's first full-scale nuclear generating station.

EXECUTIVE SUMMARY

BACKGROUND

Highly Enriched Uranium

- ✓ Definition: HEU is uranium that has been enriched to a uranium-235 isotopic content of 20 percent or more.
- ✓ Uses: For over 50 years, HEU has been used in nuclear weapons, naval reactors, and research reactors.

In February 1996, the Department of Energy (DOE) commissioned a comprehensive effort to document and declassify the United States inventory and other information needed to present a complete picture of the production, acquisition, and utilization of highly enriched uranium (HEU). *Highly Enriched Uranium: Striking A Balance* presents the results of that study. The effort was commissioned to facilitate discussions of HEU storage, safety, and security with stakeholders, to encourage other nations to declassify and release similar data, and to support the national policy on transparency of nuclear materials. This information will also be available for formulating policies involving the identification and disposition of surplus nuclear materials.

Highly Enriched Uranium: Striking A Balance contains details of the U.S. HEU inventory as of September 30, 1996, and provides a historical material balance that summarizes over 50 years of U.S. activities that produced, acquired, and utilized HEU. This report focuses on the facilities and activities that have produced and used HEU during the 50-year history of the nuclear weapons complex. The report contains important newly declassified HEU information regarding the total U.S. inventory, including the quantities required to support ongoing Departmental programs. Other newly declassified information includes details about the HEU produced in the U.S. uranium enrichment facilities and the total quantity of HEU transferred to the United Kingdom under a Mutual Defense Agreement.

This report also updates the quantities of HEU declared surplus to the Department's needs at the DOE February 6, 1996, Openness Press Conference. It also revises the quantity for the total U.S. production of HEU released at the June 27, 1994, Openness Press Conference.

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 U.S. national security or aid worldwide nuclear proliferation. In this way, this report "strikes a balance" between openness and the necessity to protect information that needs to remain classified for nonproliferation and national security reasons.

By constructing a historical material balance, this report also attempts to "strike a balance" between the September 30, 1996 HEU inventory and the processes that produced, acquired, and used HEU. While other DOE reports have provided much of this information separately, this report

combines previously released data along with newly declassified information that has allowed DOE to issue, for the first time, a comprehensive report on HEU.

Scope of This Report

- ✓ Overall: A historical report on U.S. HEU production, acquisition, and utilization activities.
- ✓ Timeframe: 1945 through September 30, 1996.
- ✓ Relationship to Other Countries: This report provides quantities of HEU sent to foreign countries. This report also provides quantities of HEU received from foreign countries. This report does not account for retransfers of U.S.-origin HEU between foreign countries. Transactions between foreign countries are the responsibility of the IAEA.

Section 1 introduces the reader to the predecessor organizations to the DOE, the nuclear material control and accountability system, and the Department's "Openness Initiative." Section 2 provides some perspective on the production and uses of HEU, including the Department's nuclear weapons complex. The two most important sections of this report are Sections 3 and 4 where details of the U.S. HEU inventory and the historical material balance are presented. Sections 5 and 6 contain the details for the historical material balance and much of the newly declassified HEU information. Annual quantities are presented by fiscal year. The appendices provide information on HEU facilities, U.S. HEU spent nuclear fuel inventory, the Navy Nuclear Propulsion and Army Nuclear Power Programs, and Agreements for Cooperation with foreign countries.

This report was prepared using official Department historical information including facility material control and accountability (MC&A) records, historical MC&A summary reports, and individual site inventory and transaction data as reported in the Nuclear Materials Management and Safeguards System (NMMSS). When site MC&A records or NMMSS data were not available, historical reports and memoranda were used to augment these data. This report is based on the evaluation of those records and represents the Department's best interpretation. The information in this report may be updated or revised in the future should additional or more detailed data become available.

U.S. HEU Inventory

As of September 30, 1996, the total U.S. inventory of HEU was **740.7** MTU[1] containing **620.3** MTU-235[2]. Of the total 740.7 MTU, **562.9** MTU are required to support ongoing and future programs, and **177.8** MTU are surplus to the Department's needs.

The 177.8 MTU of surplus HEU represents a 3.5 MTU increase over the quantities previously released by the Department in February 1996. This increase is a result of ongoing site material

[1] MTU is defined as metric tons of elemental uranium and includes all isotopes of uranium.

[2] MTU-235 is defined as metric tons of uranium-235.

stabilization activities, material disposition actions, and Defense Programs' stockpile management and stewardship activities.

Material Balance

The primary objective of a material balance is to provide assurance that all material quantities are present in the correct amount. In terms of uranium-235, the weapons-usable isotope of interest in this report, the Department was able to achieve a material balance equaling the actual inventory of 620.3 MTU-235. A material balance in terms of total uranium was not possible due to data limitations, which are discussed in Section 4.

Newly Declassified Information

A summary of newly declassified information in this report is provided in the text box. Details are provided in Sections 3 through 6.

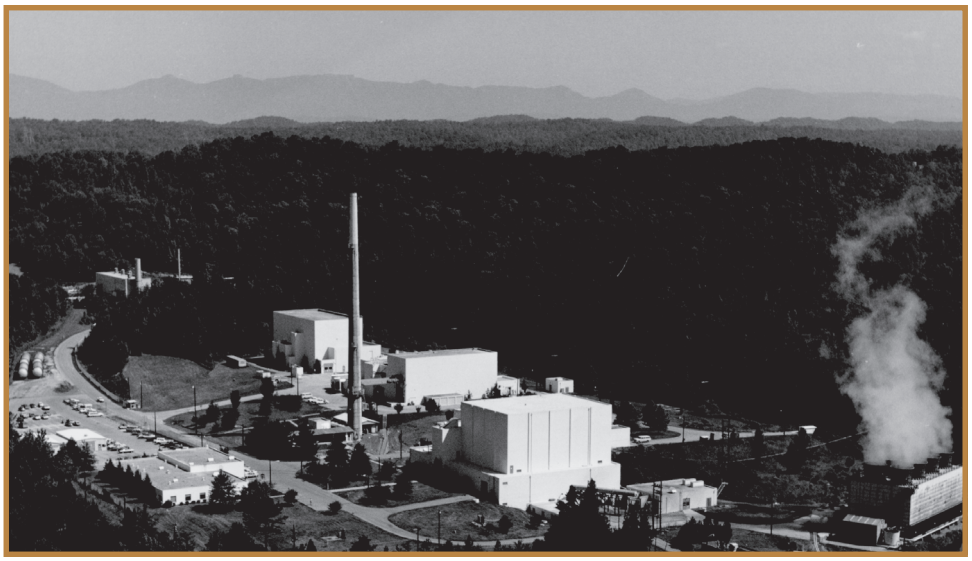
Summary of Newly Declassified Information

- ✓ Historical HEU production by assay.
- ✓ Historical HEU refeed by assay at all gaseous diffusion plants.
- ✓ The total quantity of HEU transferred to the United Kingdom under a Mutual Defense Agreement <deleted>. b(5)

Corrections to Previously Released Data

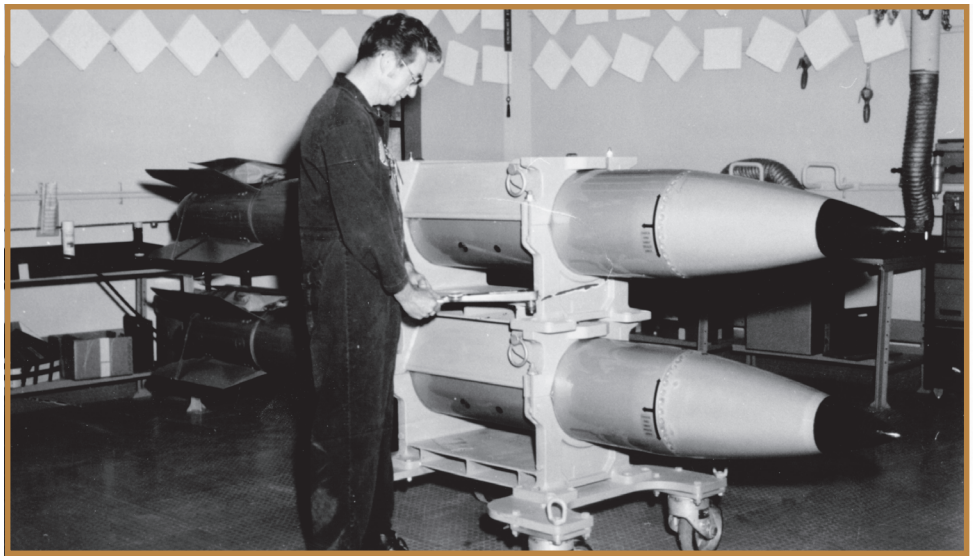
The following are corrections made in this report to previously released data:

- U.S. HEU production quantity has been revised from 994 MTU to 1,045.4 MTU. Details are provided in Section 5.
- The cumulative inventory difference for the K-25 Site has been revised from –43 kilograms of uranium-235 to +113 kilograms of uranium-235. This represents a change of 156 kilograms from the book inventory. The –43 kilograms was the annual quantity reported for 1987 only and is not the cumulative quantity.



HEU is required as a fuel in many research and test reactors, including the High Flux Isotope Reactor (shown to the left) at the Oak Ridge National Laboratory.

All U.S. nuclear-powered warships currently use reactors fueled by HEU. Pictured is the U.S.S. Jefferson City (SSN 759), a Los Angeles-Class Attack Submarine.



HEU is required for nuclear weapons. Pictured is a Pantex Plant worker preparing to disassemble nuclear weapons.

SECTION 1
INTRODUCTION

PURPOSE OF THIS REPORT

The release of this report is a result of President Clinton's goal for greater openness in Government; commitments made by the Secretary of Energy at the February 6, 1996, Openness Press Conference (DOE 1996a); and new declassification initiatives. This report covers over 50 years of U.S. HEU activities from the beginning in 1945 through September 1996 and contains important newly declassified information regarding U.S. production, acquisition, and uses of HEU. This new information, coupled with previously declassified data, allows DOE to issue a comprehensive unclassified report on the U.S. inventory of HEU. This report strikes a balance between national security and the DOE's[3] commitment to conduct business in an open environment.

Purpose of this Report

- ✓ To inform the public about the U.S. Government's historical HEU activities.
- ✓ To aid in discussions of HEU storage, safety, and security with stakeholders.
- ✓ To encourage other nations to declassify and release similar data.
- ✓ To demonstrate the Department's commitment to openness in government.

For the 50 years during the Cold War era, the DOE produced and used HEU for a variety of purposes. Initial efforts in the 1940s focused on producing HEU for nuclear weapons. Beginning in the 1950s, HEU was used for other purposes such as naval propulsion reactors, research reactors, and nuclear power plants. Most HEU was produced, utilized, and consumed in a classified environment at geographically dispersed locations and under the auspices of several Federal agencies and departments. In the mid-1960s, production of HEU for nuclear weapons was discontinued. The breakup of the Soviet Union and the end of the Cold War provided an opportunity for the United States to re-evaluate its policies and practices related to classification and declassification of information. Consequently, the consolidation, analysis, and declassification of HEU inventory data was not possible until the end of the Cold War, and HEU was declared excess to national security needs and available for disposition.

The information in this report should aid DOE in discussions with stakeholders related to uranium storage, safety, and security. The publication of this data should encourage other nations to declassify and release similar data. Additionally, this data will assist those responsible for formulating policies with respect to the identification and 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

[3] The term DOE includes DOE and its predecessor Government organizations, i.e., the U.S. Army Corps of Engineers Manhattan Engineer District, the Atomic Energy Commission, and the Energy Research and Development Administration.

data become available. The release of this report does not threaten U.S. national security, run counter to our nuclear nonproliferation policy, or undermine the nuclear deterrence activities of the U.S. For more specifics on declassified information, refer to *Drawing Back the Curtain of Secrecy, Restricted Data Declassification Decisions, 1946 to the Present* (DOE 2000).

METHODOLOGY

This HEU report was prepared from data contained in facility material control and accountability (MC&A) records, historical MC&A summary reports, and individual site inventory and transaction data as reported in the Nuclear Materials Management and Safeguards System (NMMSS). When site MC&A records or NMMSS data were not available, historical reports and memoranda were used to augment these data.

The MC&A system is used to document all nuclear material transactions, compare records with inventory, calculate material balances, and analyze differences to verify that nuclear materials are on hand in quantities as reported. Typically, the number of transactions used to track the production, movement, and removal of HEU from the inventory is 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's) nuclear materials accounting system was first automated.

Methodology

Establish Framework

- ✓ Define acquisition categories
- ✓ Define removal categories
- ✓ Peer review of analytical framework

Gather Data

- ✓ Identify sources of data for each category
- ✓ Compile data on historic site missions

Assign Quantities to Acquisition and Removal Categories

- ✓ Compare data between sources
- ✓ Identify double-counted and unquantified materials
- ✓ Identify data gaps and develop assumptions
- ✓ Calculate inventory

Compare Calculated with Actual Inventory

Peer Review of Report

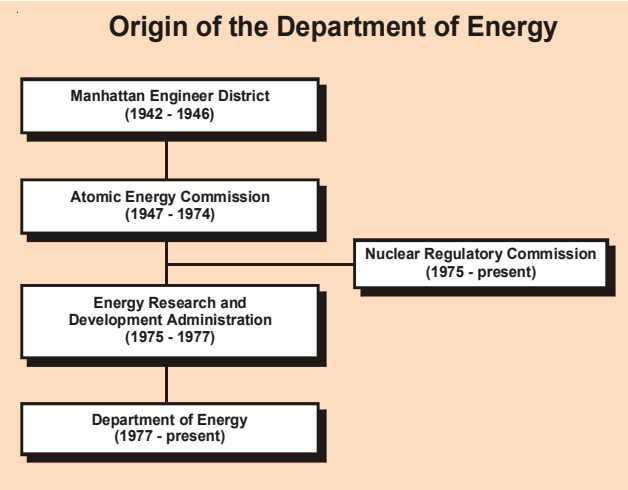
Since the early 1970s, the NMMSS has been the official U.S. nuclear materials accounting system and is used to track U.S. nuclear material inventories, maintain compliance with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), and support International Atomic Energy Agency (IAEA) safeguards.

When possible, site data were evaluated and compared to MC&A and NMMSS reports. A major difficulty in the preparation of this report was the absence of some detailed site records, which distinguished between low enriched uranium (LEU) and HEU. Even though MC&A procedures require accounting for the blending of LEU with HEU, availability of data and implementation of these MC&A blending requirements varied among sites, making accounting for the quantities blended difficult. These factors contributed to the accuracy of the material balance, the amount of time required to complete this report, and added to the difficulty associated with interpreting historical summary reports that were available only in terms of total enriched uranium.

Origin of the Department of Energy

Pre-Manhattan Engineer District: 1939–1942

Before World War II, the community of nuclear physicists was small and news of new theories or experimental results spread rapidly among the individuals. This occurred when a number of European physicists came to the United States to avoid political persecution in their native countries, such as Germany and Italy. These physicists brought with them the news that two German physicists, Otto Hahn and Fritz Strassmann, had split the uranium atom in late 1938, and Germany was pursuing development of the atomic bomb.



In July 1939, two immigrant physicists, Eugene Wigner and Leo Szilard, interrupted Albert Einstein's vacation on Long Island to brief him on the splitting of a uranium atom and the possibility of a chain reaction releasing vast quantities of energy. Einstein agreed to help alert the Federal government to the potential danger by sending a letter to President Roosevelt. The letter was drafted by the 1938 Nobel Prize winner Enrico Fermi in cooperation with other physicists at Columbia University. Einstein signed the letter on August 2, 1939 and forwarded it to a friend, Alexander Sachs, for delivery to the President at the earliest opportunity.

That opportunity became imminent when Germany invaded Poland on September 1, 1939; however, Sachs was unable to meet with President Roosevelt until October 11, 1939. When the President understood the potential danger, he authorized Fermi's group to study the possibility of developing a fission weapon before Germany. This was the start of the nuclear arms race.

While Fermi was developing the theory of the chain reaction and demonstrating the practicality of a nuclear reactor, Alfred Nier at the University of Minnesota completed the first separation of uranium-235 and uranium-238 in February 1940. The separated samples were used by Columbia University to prove that the uranium-235 atom underwent nuclear fission when struck by a slow neutron while uranium-238 did not. This information was used by the president of the Carnegie Institution, Vannevar Bush, and the president of the National Academy of Science, Frank Jewett, in a meeting with President Roosevelt to convince him to fund the creation of the National Defense Research Council (NDRC).

The NDRC was the first organization to consolidate nuclear research in the Federal government and provide an articulate lobby within the executive branch. James Bryant Conant, then president of Harvard, was named head of the NDRC. He initially requested $140,000 for research and construction of a carbon pile reactor. He was given $40,000 for research; but nothing for construction.

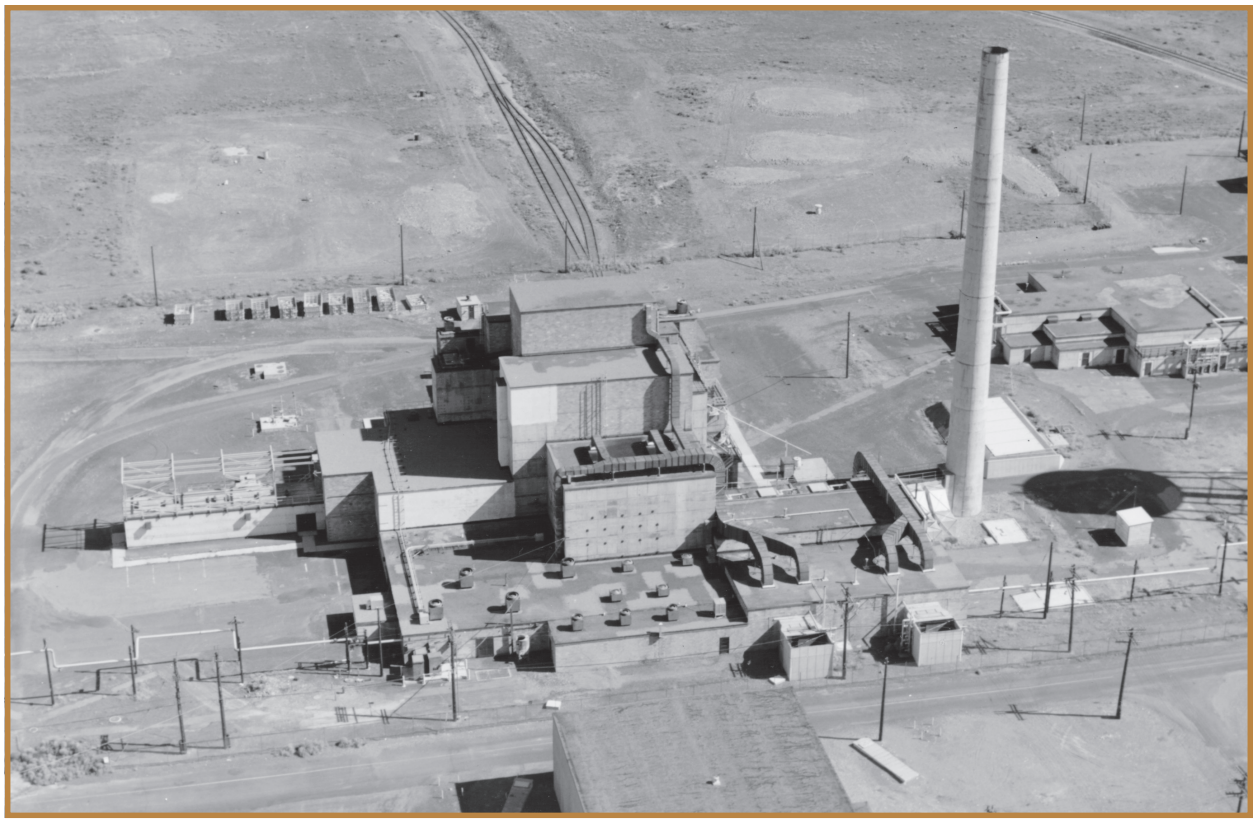
The power struggle for funding between the NDRC, university laboratories, and other organizations hindered U.S. research into atomic weapons. This struggle led to the creation of the Office of Scientific Research and Development (OSRD) in June 1941, which was given wide authority over all government science programs involved in the war effort. Vannevar Bush was named to administer the agency.

In January 1942, a month after the Japanese attack on Pearl Harbor, President Roosevelt approved the development of the atomic bomb. Vannevar Bush realized that a massive construction project was needed to comply with the President's request. He negotiated with the U.S. Army Corps of Engineers (COE) and agreed to put an Army officer in overall charge of the project in exchange for $54 million (about 60 percent of the COE's 1943 budget). During the summer of 1942, Colonel James C. Marshall was put in charge of the atomic weapon project, which was called "The Laboratory for the Development of Substitute Metals (DSM)." Colonel Marshall moved his office from Syracuse, New York, to New York City where he set up the Manhattan Engineer District on August 13, 1942. Under Colonel Marshall, the atomic bomb project was renamed the "Manhattan Project." On September 17, 1942, Colonel Leslie R. Groves replaced Colonel Marshall as head of the Manhattan Project. Colonel Groves was promoted to Brigadier General in late September when he moved the project's headquarters to Washington, D.C.

Manhattan Engineer District: 1942–1946

Between 1942 and 1946, the Manhattan Engineer District spent approximately $2.2 billion on developing production facilities and towns in Oak Ridge, Tennessee; Richland, Washington; and Los Alamos, New Mexico. By 1945, three uranium enrichment plants (electromagnetic separation, gaseous diffusion, and thermal diffusion) had been built at Oak Ridge, and three plutonium production reactors had been built at Richland.

The Manhattan Project was a success because it consolidated multiple independent research projects scattered across the United States into a single program to produce the materials and assemble and deliver three functional atomic weapons (Trinity, Little Boy, and Fat Man) in time to affect the outcome of World War II. After Japan surrendered ending World War II, the Manhattan Project continued research into atomic weapons by testing two more atomic bombs in July 1946 (Able and Baker at Bikini Atoll).



Hanford's B Reactor was the first reactor to produce plutonium in the world. Plutonium produced from this reactor fueled the first atomic explosion in the Alamogordo desert on July 16, 1945 ("Trinity"), and it formed the core of the bomb that exploded over Nagasaki, Japan on August 9, 1945 ("Fat Man").

Atomic Energy Commission: 1947–1974

On January 1, 1947, the Atomic Energy Act of 1946 replaced the Manhattan Engineer District with the Atomic Energy Commission (AEC). The AEC was created by Congress to put atomic weapons under a civilian agency that would provide for domestic development and control of atomic energy. The newly appointed Commissioners of the AEC set out to turn the U.S. atomic energy program from a hastily assembled wartime operation into a productive, industrial complex.

At the time of the transfer of responsibilities from the U.S. Army to the AEC, one gaseous diffusion plant existed at Oak Ridge, two plutonium production reactors were in operation at Hanford (one having been shut down), and 35 other facilities were connected with the production of nuclear materials. Since U.S. foreign policy was based on a steadily growing stockpile of nuclear weapons, the AEC recommended in 1947 that material for non-weapon purposes be limited. To address the plutonium shortage, the AEC approved the building of two additional reactors at Hanford.

With the start of the Berlin Airlift and increasing Cold War tensions, another increase in production was imperative. The Hanford B reactor, which had been shut down after the war, was restarted to produce plutonium. To further increase production of HEU, an addition to the Oak Ridge Gaseous Diffusion Plant (K-29 building) was approved in 1948.

However, even with this increase in production, the Joint Chiefs of Staff felt that the U.S. atomic bomb program was inadequate and asked that the total weapons requirement be increased. The urgency of this request was underlined when the President announced on September 23, 1949, that the Soviet Union had exploded their first atomic bomb. As a result, the Oak Ridge Gaseous Diffusion Plant was further expanded with the construction of the K-31 building.

In January 1950, President Truman directed the AEC "to continue its work on all forms of atomic weapons, including the so-called hydrogen or super-bomb." Not knowing the feasibility of such a bomb but wishing to avoid delay between the determination of feasibility and the possible start of weapons production, the AEC proposed to build two new reactors. These reactors were to produce either tritium or plutonium, in response to weapons requirements. These two heavy water reactors would be the primary source for the production of tritium. As soon as President Truman approved this proposal in June 1950, the du Pont Company accepted the responsibility to design, construct, and operate these two reactors at a site located on the Savannah River near Aiken, South Carolina.

With the outbreak of the Korean War in June 1950, production levels were increased once more. On October 2, a joint working group of the Department of Defense (DoD) and AEC personnel submitted a report to President Truman requesting the following:

- The construction of two gaseous diffusion facilities at a new site that would increase the production of uranium-235 by about 125 percent over that authorized in 1949;
- The construction of reactors at the new Savannah River tritium production site to increase the production of plutonium by about 50 percent over that approved by the President in June 1950; and
- The expansion of uranium ore acquisition and processing, weapons fabrication, and weapons storage facilities.

With Presidential approval, the site chosen for the two new gaseous diffusion facilities was the Kentucky Ordnance Works near Paducah, Kentucky. In order to meet the request for a 50 percent increase in plutonium, it was decided that five reactors, instead of just two, should be constructed at the Savannah River plant. By June 1951, construction had begun at both of these sites.

In 1952, the President approved the AEC request to add new reactors at Hanford, to build additional diffusion facilities at Oak Ridge and Paducah and a new gaseous diffusion plant at Portsmouth, Ohio, and to expand ancillary facilities for processing feed materials and fabricating and storing weapons. By February 1956, the expansion program of 1952 was completed.

Although in subsequent years there was an uncertainty about future long-range requirements for plutonium and tritium, the AEC, after consultation with the DoD, approved the construction of a dual purpose (production of plutonium and steam for electrical generation) reactor at Hanford in 1959. The "N-Reactor" began operation in 1963. By the end of 1963, surpluses of nuclear materials were beginning to accumulate. This was reflected in Congressional approval of the Private Ownership of Special Nuclear Materials Act of 1964. Under the Act, the AEC was authorized to sell, lease, or grant nuclear materials to industry for research and development activities.

Studies were initiated in 1963 by the AEC for reductions in materials production as a result of White House and DoD requests. Based on the recommendation of the AEC and the Bureau of the Budget, President Johnson, in his State of the Union Message of January 8, 1964, announced plans to cutback on the production of enriched uranium and plutonium. As a result of the production cutbacks, HEU production at Oak Ridge was terminated, and four nuclear production reactors at Hanford and Savannah River were shut down.

Thus the large growth in the production of special nuclear materials that began in 1942 came to an end. Presidential approval of further studies continued the trend for curtailment of nuclear materials production. By early 1971, only four reactors continued to operate, N-Reactor at Hanford and three reactors at Savannah River.[4]

Energy Research and Development Administration: 1975–1977

In 1975, Congress abolished the AEC with the enactment of the Energy Reorganization Act of 1974. Regulatory authority was transferred to the newly-formed Nuclear Regulatory Commission (NRC), and the AEC's production and research and development activities, including the nuclear weapons complex, were given to the newly-created Energy Research and Development Administration (ERDA). ERDA was created to achieve two goals:

- To focus the Federal government's energy research and development activities within a unified agency whose major function would be to promote the speedy development of various energy technologies, and;
- To separate nuclear licensing and regulatory functions of the NRC from the development and production of nuclear power and weapons.

[4] These reactors were subsequently shut down or placed in standby (DOE 1996b).

Department of Energy: 1977–Present

On October 1, 1977, the Department of Energy (DOE) became the twelfth cabinet-level department in the Federal government with the enactment of the Department of Energy Organization Act of 1977. The DOE assumed all of ERDA's responsibilities and parts of programs of several other agencies. The Department provided the framework for a comprehensive and balanced national energy plan by coordinating and administering the energy functions of the Federal government. DOE's responsibilities included long-term, high-risk research and development for improved energy technology, Federal power marketing, energy conservation, the nuclear weapons program, energy regulatory programs, and a central energy data collection and analysis program.

Since its establishment, the Department has shifted its emphasis and focus as the needs of the nation have changed. During the late 1970s, the Department emphasized energy development and regulation. In the 1980s, nuclear weapons research, development, and production took a priority. Since the end of the Cold War, DOE has focused on environmental clean up of the nuclear weapons complex, nonproliferation and stewardship of the nuclear weapons stockpile, energy efficiency and conservation, and technology transfer and industrial competitiveness.

Today, the Department contributes to the future of the nation by ensuring our energy security, maintaining the reliability, performance, and safety of the nuclear weapons stockpile, cleaning up the environment from the legacy of the Cold War, and developing innovations in science and technology. In addition, the Department has been taking aggressive steps in releasing detailed information on the nuclear weapons complex to the public with the launching of the Openness Initiative.

Openness Initiative

In 1993, the DOE launched the "Openness Initiative" to release many of its files to the public in response to President Clinton's goal of openness in government (DOE 1993a). The President stated that it is a "fundamental principle that an informed citizenry is essential to the democratic process and that the more the American people know about their Government the better they will be governed. Openness in government is essential to accountability…."

The intent of the Openness Initiative was to earn public trust, thereby fostering informed public participation in Government decision making. Recognizing that openness is essential to public accountability and trust, DOE is continuing to aggressively declassify as much information as possible concerning its past and present activities without jeopardizing U.S. national security objectives or aiding world-wide nuclear proliferation. Consequently, on December 22, 1997,

Summary of Previously Released Data

- ✓ Total quantity of HEU produced at the Oak Ridge Gaseous Diffusion Plant and at the Portsmouth Gaseous Diffusion Plant.
- ✓ Total quantity transferred to the United Kingdom under a Mutual Defense Barter Agreement with the U.S.: [**7.5** MTU]
- ✓ Total HEU inventories at thirteen DOE sites and laboratories, as of December 31, 1993.
- ✓ Historical inventory differences for DOE contractor sites, including the Oak Ridge Y-12 Plant and the Rocky Flats Environmental Technology Site, and NRC licensed facilities.
- ✓ The total quantity and form of HEU declared excess to national security needs, as of September 30, 1995.

the Secretary of Energy announced actions to ensure that the DOE's Openness Initiative becomes "business-as-usual."

DOE conducts a comprehensive review for each and every declassification action, including coordination with other agencies. Information considered for declassification 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 laws, treaties, and regulations in the interest of furthering national security and nuclear nonproliferation objectives.

Summary of Previously Released Data

Although there has been a considerable amount of HEU information released over the years, this is the first time DOE has consolidated the information in a single document.

Summary of Newly Released Data

DOE continues to deliver on the President's commitment for a more open government. The Department is declassifying information regarding U.S. production, acquisition, and removal of HEU with the issuance of this report. In addition, this report summarizes over 50 years of unclassified information. This new information, when combined with previously declassified data, is allowing DOE to issue a truly comprehensive report on the total U.S. HEU inventory.

Summary of Newly Released Data

Declassifications

- ✓ Historical HEU production by assay.
- ✓ Historical HEU refeed by assay at all gaseous diffusion plants.
- ✓ The total quantity of HEU transferred to the United Kingdom under a Mutual Defense Agreement (Barter plus other agreements): **<deleted>** **b(5)**

Material Control and Accountability

The following describes the evolution of DOE's safeguards system and the current U.S. and international safeguards systems.

Safeguards Evolution

From the beginning of the nuclear program in the 1940s 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 AEC, AEC contractors operating Government facilities, and the 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 nuclear material had been diverted or stolen. However, the controls were limited by the accuracy of the measurement techniques and instruments. 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 techniques however, the measurement of nuclear material includes some degree of uncertainty.

Beginning in the early 1950s, nuclear material became available to industry. In 1953, President Eisenhower announced his Atoms for Peace Program, which provided technology and nuclear material to 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 in regard to material theft or diversion.

In the mid-1960s, an amendment to the Atomic Energy Act permitted private ownership of special nuclear material. However, the potential nuclear proliferation issue and problematic experiences with licensees led the AEC to increase requirements on the licensees for the safeguarding of special nuclear material in their possession. Consequently, regulations were

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

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 themselves against terrorist and other threats. This regulatory office formed the foundation for the present NRC, which became an independent agency in 1975.

Elements of the Safeguard System

Nuclear material safeguards at contractor-operated DOE facilities are applied through an integrated system designed to prevent, deter, detect, and respond to attempts at unauthorized possession or use of special nuclear materials. The safeguards system contains the five major elements, as discussed in the text box.

Safeguards System Operation

Physical protection, material control and accountability, and human reliability programs and 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 are effective. If statistical analysis indicates any significant 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.

Elements of the Safeguards System

- ✓ ***Physical Protection*** - to inhibit unauthorized, forceful or surreptitious attempts to gain entry to facilities possessing special nuclear material and to prevent its removal. Physical protection includes the use of perimeter intrusion detection systems; entry and exit controls; vaults; alarms; and containment, concealment, and trained protection forces.
- ✓ ***Personnel Security Programs*** - to inhibit unauthorized acts involving nuclear material through the implementation of security clearance and human reliability programs, and security training and awareness. These programs serve to deter insiders from diverting, stealing, and sabotaging special nuclear materials.
- ✓ ***Material Control*** - to detect or deter theft or diversion of special nuclear material by positively controlling access to and utilization of special nuclear material. Such control consists of material surveillance, internal control procedures, verification of material characteristics and process holdup, material custody, and seals and tags.
- ✓ ***Material Accountability*** - to record all material transactions, compare records with inventory, calculate material balances, and analyze differences to verify that nuclear materials are in quantities as reported and in authorized locations. The materials accounting procedures also detect and verify process holdup in facilities to ensure effectiveness of physical protection practices. Additionally, these procedures help determine levels of protection appropriate for nuclear materials inventories. This is accomplished through measurements, physical inventories, records and reports, audits, and 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 include checks and balances to maintain separation of responsibilities between operations and safeguards personnel.

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. DOE Headquarters and the responsible field office conduct ongoing surveys and technical audits of their contractors to assure effective implementation of contractor procedures and verification of contractor performance. Inventory differences are carefully analyzed during these surveys, and audits are made to verify and validate the contractor explanations.

DOE Headquarters staff also conduct independent assessments of the total system capabilities and of the performance of its field offices and contractors in effectively safeguarding nuclear materials. Inventory differences and their explanations are again reviewed during these assessments. Finally, independent congressional reviews are performed by the General Accounting Office to address 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 such incident involving HEU has occurred.

International Safeguards and Physical Security

International nuclear cooperation was first offered by President Eisenhower in 1953 through the Atoms for Peace Program. In 1954, amendments to the Atomic Energy Act legally enabled nuclear cooperation for peaceful purposes. In 1957, the IAEA was established to promote peaceful nuclear energy and control nuclear material. The 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. In 1995, an indefinite extension of the NPT continued to strengthen support for technical cooperation and "fullscope safeguards." By 1998, the IAEA was authorized greater access to information and sites under a new Protocol against diversion of nuclear material and for detection of clandestine nuclear programs.

The Atomic Energy Act 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 Atomic Energy Act, the NNPA, and Bilateral Agreements for Peaceful Nuclear Cooperation, most U.S.-origin nuclear material exported 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 material of U.S.-origin. For non-NPT countries, IAEA safeguards are limited to nuclear material transferred under trilateral 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. 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 were implemented by the IAEA. In Argentina and Brazil, the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials also applies safeguards under a quadrilateral agreement with 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 require facilities to maintain accurate and comprehensive records of nuclear material inventory, including documents and receipts for processing and shipment activities. Such information, down to gram quantities, is provided to national authorities, who in turn provide inventory reports to the IAEA. The IAEA can conduct on-site inspections to verify information provided by the country and to ensure that nuclear material has not been diverted, that 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 materials present. Materials posing the highest proliferation risk, such as HEU, which is directly usable in nuclear weapons, are subject to the most frequent inspections, as are facilities capable of producing HEU. Facilities with large amounts of HEU generally have a full-time IAEA inspector present. For countries having small amounts of HEU (for example, neutron sources to calibrate nondestructive assay instruments), IAEA inspections are much less frequent, taking into account inspection costs and the need to make an annual statement regarding attainment of inspection goals.

The IAEA reports its verification activities in the annual Safeguards Implementation Report, with a summary contained in the IAEA Annual Report. These IAEA verification activities provide confidence that the HEU exported by the U.S. has been used only for peaceful purposes.

In 1967, President Johnson offered to place some U.S. facilities under IAEA safeguards. Since 1980, nuclear materials in U.S. facilities not having direct national security significance have been eligible for IAEA safeguards under the 1980 US/IAEA voluntary offer Safeguards Agreement. In 1993, President Clinton offered to place IAEA safeguards on selected nuclear material excess to U.S. defense needs; the IAEA began applying safeguards to excess HEU in 1994.

In addition to IAEA safeguards, U.S. law (the Atomic Energy Act as amended and the NNPA), the NPT, and Agreements for Cooperation with other countries require that adequate physical protection measures be applied to exported nuclear material of U.S. origin. 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 NRC.

Since 1974, in cooperation with the Departments of State and Defense and the NRC, DOE has visited foreign countries and exchanged information on the physical protection of nuclear material. The primary purpose of these visits is to help ensure that U.S. nuclear material provided to foreign countries is protected at the level recommended in international guidelines published by the IAEA in *The Physical Protection of Nuclear Material* (IAEA 1993).

During this time, U.S. experts led by DOE have conducted 125 visits to 41 countries with U.S.-origin enriched uranium. The experts review, with foreign officials, the legal and regulatory basis for physical protection and the perceived threat to nuclear material. The experts visit sites where U.S.-origin and other nuclear materials are used or stored, observe all elements of the sites' physical protection systems, and offer recommendations on improving the system. The factors used to determine what countries to visit include the type and quantity of U.S.-origin nuclear material, the date and findings of the last visit, the perceived threat of theft or sabotage, and impending export license applications for nuclear-related material and equipment.

Elements of the IAEA Safeguards System

- ✓ ***Nuclear Material Accounting*** includes countries reporting information on nuclear program activities and facility design; facility records on the location and quantity of nuclear material under their control; and information to the IAEA based on facility records.
- ✓ ***Containment and surveillance*** includes complementary techniques, such as tamper-indicating seals to prevent undetected movement of material, and film and television cameras or other monitoring devices to detect undeclared activities.
- ✓ ***Inspection*** includes onsite verification by IAEA inspectors of declared information such as reports and records, independent measurements of nuclear materials, and operation of inspection equipment.

Additionally, the DOE works closely with the IAEA to support its new International Physical Protection Advisory Service (IPPAS) that evaluates, for requesting countries, the adequacy of their nuclear material physical protection systems. DOE physical protection experts have participated in IPPAS missions to Bulgaria, the Czech Republic, Hungary, and Romania.

Reduced Enrichment for Research and Test Reactors Program

In the late 1970s, the international community realized that the fuel used in many nuclear research reactors was weapons-usable HEU and could be stolen or diverted for use in nuclear weapons. In 1978, the international community established the Reduced Enrichment for Research and Test Reactors (RERTR) program. Its mission was to develop a substitute fuel (i.e., LEU), which was not suitable for nuclear weapons. As substitute fuels were developed, existing reactors would be converted to LEU, and new reactors would be designed to use only LEU.

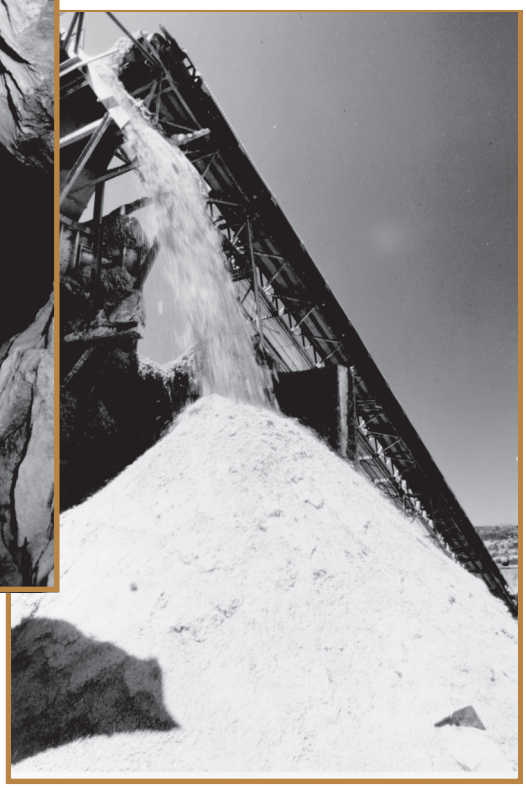
The RERTR program has proven to be remarkably successful, facilitating the conversion of dozens of reactors worldwide from weapons-usable to non-weapons-usable fuel and sharply reducing international commerce in HEU. In 1986, the NRC ordered that all licensed, domestic research reactors, where possible, use LEU. To date, several university research reactors have converted to LEU fuel. As of September 1995, of the 42 foreign research reactors with at least 1 megawatt of power, 37 either had been converted, were in the process of converting, or no longer needed fuel.

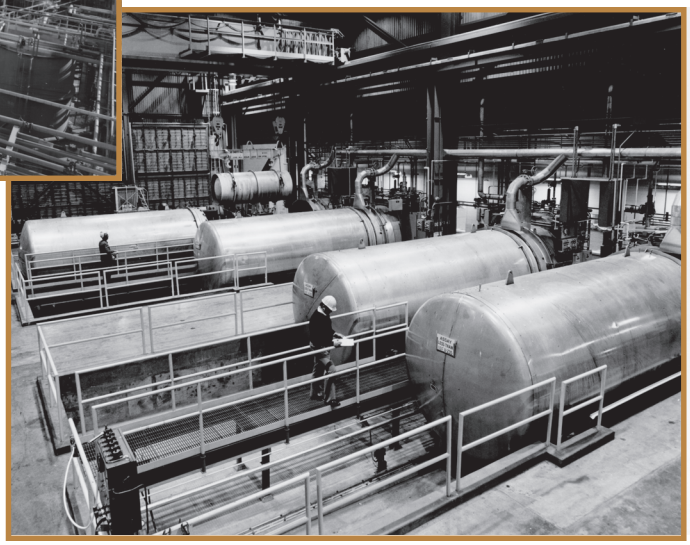
In 1986, the United States suspended the return of U.S.-origin spent nuclear fuel from foreign research reactors. This policy would later be revised. In May 1996, the DOE, in consultation with the Department of State, issued a Record of Decision to recover as much U.S.-origin HEU as possible while assisting foreign research reactor operators with their conversion to LEU.

Under the new policy, the first return of research reactor spent fuel was successfully completed in September 1996. It included 8 casks containing 280 elements with a total of approximately 97 kilograms of HEU. An additional three returns were completed in fiscal year 1997, consisting of 15 casks containing 542 elements with approximately 206 kilograms of HEU. During fiscal year 1998, an additional 5 returns were scheduled, including 35 to 40 casks of spent fuel from Europe, Asia, Australia, and South America. [Quantitites from returns in 1997 and 1998 are not included in the historical material balance of this report and are provided to demonstrate the success of the RERTR program.]

The RERTR program is one of the most successful aspects of the IAEA and the NPT. With the full support of the international community, the RERTR program could entirely eliminate commerce of weapons-usable HEU by the year 2008.

The first step in turning natural uranium into enriched uranium involves mining and milling. Mining and milling involves extracting uranium ore from the earth's crust and chemically processing it. Pictured to the right is an underground mine and a uranium mill at the United Nuclear Homestake Site in Grants, New Mexico.





Refining involves the chemical conversion of uranium concentrates into purified forms suitable as feed material for enrichment processes. The Feed Materials Production Center in Fernald, Ohio (above), was a uranium refinery that processed uranium feed materials into compounds and ultimately into uranium metal. The gaseous diffusion process involves the pumping of uranium hexafluoride gas through miles of piping and barrier-like structures that have millions of uniformly sized tiny holes. The Paducah Gaseous Diffusion Plant in Kentucky (right) is one of the three gaseous diffusion plants that enriched uranium in the United States.

SECTION 2
URANIUM PRODUCTION AND UTILIZATION

This section contains an overview of the uranium mining, milling, refining, and enrichment processes. It provides a historical perspective of the programs that produced and utilized HEU and lists the facilities involved.

OVERVIEW OF URANIUM

Uranium is a slightly radioactive material that occurs naturally throughout the earth's crust. Although considered rare, it is actually more plentiful than gold and silver. Uranium was discovered in 1789 by the German chemist Martin H. Klaproth. He named uranium after the planet Uranus, which had been discovered a few years earlier. Uranium is the heaviest naturally occurring element and is used chiefly as a fuel for nuclear power reactors. Uranium is also vital to the U.S. nuclear weapons program and the Naval Nuclear Propulsion Program.

Uranium has at least 17 isotopes[6], all radioactive, ranging from uranium-225 to uranium-242 and half-lives[7] from 0.08 seconds (uranium-225) to about 4.47 billion years (uranium-238) (DOE 1996c). All atoms of uranium have the same number of protons (92) in the nucleus. Different isotopes of uranium exist because of differing numbers of neutrons in the nucleus. Each isotope has its own unique atomic weight, which is the sum of the number of protons and neutrons. For example, uranium-235 has 92 protons and 143 neutrons and an atomic weight of 235. The higher the atomic weight, the heavier the isotope.

Of the 17 isotopes, only 3 are found in nature: uranium-238, uranium-235, and uranium-234. The most common isotope is uranium-238, which makes up about 99.28 percent by weight of all uranium found in nature. Uranium-238 cannot be readily split or fissioned under most conditions. The second most common isotope is uranium-235, which makes up about 0.711 percent by weight of all uranium found in nature. Uranium-235 is the only naturally occurring fissile[8] isotope of uranium. The remaining naturally occurring isotope of uranium is uranium-234.

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[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 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] The capability of being split by a low-energy neutron. The most common fissile isotopes are uranium-235 and plutonium-239.

Uranium-233 is another fissile isotope of uranium and, because of its fissile properties, has been considered for use in research, space, and power reactors. It is not found in nature but must be produced by reactor irradiation of thorium-232, the radioactive but very long-lived, naturally occurring isotope of thorium. A major drawback to the use of uranium-233 lies in the coincidental production of uranium-232 during irradiation, which is undesirable because of the extremely high radioactivity of uranium-232. The U.S. inventory of uranium-233 is relatively small and is not included in this report.

Uranium easily combines with most substances to form chemical compounds. For example, it combines with oxygen to produce several oxides including uranium octaoxide (U_3O_8). Uranium also reacts with fluorine to create uranium hexafluoride (UF_6).

There are four terms commonly used to describe the percentage of fissile material in uranium: natural, depleted, LEU, and HEU.

Because uranium in nature is a mixture of the naturally occurring isotopes of uranium, industrial processes like the gaseous diffusion process must be employed to isolate and concentrate the fissile isotope uranium-235. Concentrations of uranium-235 greater than or equal to 20 percent are considered to be weapons-usable material and are defined as HEU.

Four Terms Commonly Used to Describe Uranium

- ✓ *Natural uranium* is found in nature and contains approximately 0.711 percent uranium-235.
- ✓ *Depleted uranium* is produced when some of the uranium-235 isotope is extracted from natural uranium. The remaining uranium is called depleted since it has been depleted in the uranium-235 isotope. It contains less than 0.711 percent uranium-235, typically 0.20 to 0.40 percent.
- ✓ *Low enriched uranium* has been enriched in the uranium-235 isotope and contains more than 0.711 percent but less than 20 percent uranium-235.
- ✓ *Highly enriched uranium* has been enriched in the uranium-235 isotope and contains 20 percent or more of uranium-235. All HEU is considered weapons-usable.

The focus of this report is on the HEU used in the U.S. nuclear weapons program, the Naval Nuclear Propulsion Program, and government and commercial reactors. Most of the HEU information in this report is presented in two assay ranges: (1) HEU with a concentration of 90 percent or more of uranium-235, and (2) HEU with a concentration of 20 to less than 90 percent uranium-235. For HEU production, information is presented in four assay ranges of uranium-235:

(1) 20 to less than 70 percent,

(2) 70 to less than 90 percent,

(3) 90 to less than 96 percent, and

(4) 96 percent or greater.

URANIUM ACCOUNTABILITY

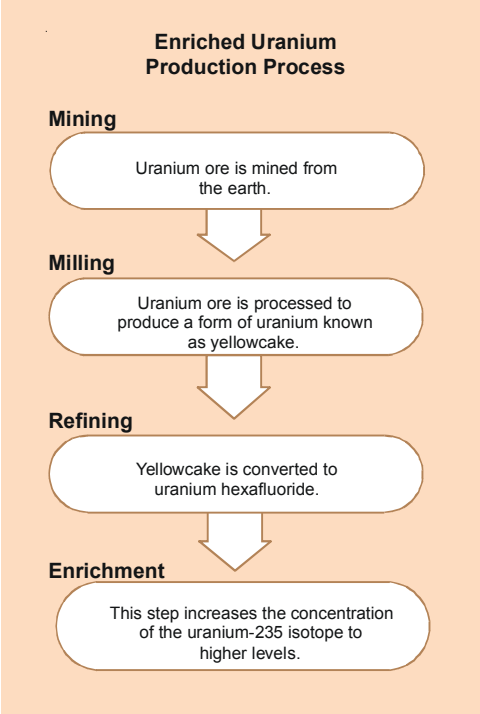
It is important to note that the nuclear material control and accountability (MC&A) program requires that all uranium transactions, inventories, and material balances be documented. In simple terms, the sites use one of three nuclear material ledgers to record uranium activities. There is a separate ledger for depleted uranium, natural uranium, and enriched uranium (includes all enrichments above 0.711 percent uranium-235).

Each of these nuclear material ledgers can, in simple terms, be thought of as a personal checkbook. With careful entries of checks written and deposits made, a current balance can be determined.

Because of the nature of the operation of a gaseous diffusion plant (GDP), uranium undergoing enrichment has a separate material ledger called "uranium in cascades." After being enriched, uranium is removed from the "uranium in cascades" ledger and added to the enriched uranium ledger. An examination of detailed plant records allows for the identification of material as either HEU or LEU based on the concentration of uranium-235. The HEU production numbers for this report were obtained by examining the GDP records for the uranium extracted from the cascades ledger with an isotopic concentration of equal to or greater than 20 percent uranium-235.

For security and accountability reasons, sites are usually subdivided into smaller more manageable accounts called Material Balance Areas (MBAs). An MBA could be a storage vault within the building or a well-defined physical area of a uranium processing plant. Each MBA has a set of uranium ledgers to record all MBA receipts and shipments. Inventories for each type of uranium are calculated by summing the many site MBA ledgers. To accomplish this, site accountability personnel submit MBA transaction information to the Nuclear Materials Management and Safeguards System (NMMSS) database maintained for that site. NMMSS is the national nuclear materials database that accounts for the overall uranium inventory. For more information on the safeguarding and accountability of nuclear materials, including NMMSS, see Section 4 of this report.

Production of Enriched Uranium



The process of turning natural uranium into enriched uranium can be summarized as follows: (1) natural uranium ore is mined and milled, (2) processed ore is refined and combined with fluorine to form uranium hexafluoride (UF_6), and (3) UF_6 undergoes an enrichment process to segregate and thereby increase the percentage of uranium-235.

Mining and Milling

Mining and milling involves extracting uranium ore from the earth's crust and chemically processing it. While many rocks, including coal, contain small amounts of uranium, only certain mineral deposits such as pitchblende and carnotite contain large amounts of uranium. Underground, open pit, and solution mining techniques are used to recover uranium around the world.

A uranium mill is a chemical plant designed to extract uranium from the ore. The milling process produces a uranium concentrate called "yellowcake," which generally contains more than 60 percent uranium including some impurities. Uranium ore contains typically between 0.1 and less than 1.0 percent uranium.

About half of the uranium used in the U.S. nuclear weapons complex was imported from Canada, Africa, and other areas. The remainder came from the domestic uranium industry that grew rapidly in the 1950s. The first imported uranium, high-grade "pitchblende" ore containing up to 65 percent oxide by weight, was milled in Canada. After World War II, imported uranium was purchased in the form of already-milled concentrates and high-grade ores. Domestic uranium was purchased as either ore or concentrate.

Refining

The product of a uranium mill is not directly usable as a fuel for a nuclear reactor. Refining involves the chemical conversion of uranium concentrates into purified forms suitable as feed material for enrichment processes. Refining, as discussed in this report, also involves the recycling of various production scraps, production residues, and uranium recovered from fuel reprocessing.

During World War II, uranium refining was performed by various contractors. After the war, the AEC built government-owned contractor-operated uranium refineries in Weldon Spring, Missouri, and Fernald, Ohio. These facilities operated until they were shut down in 1966 and 1989, respectively.

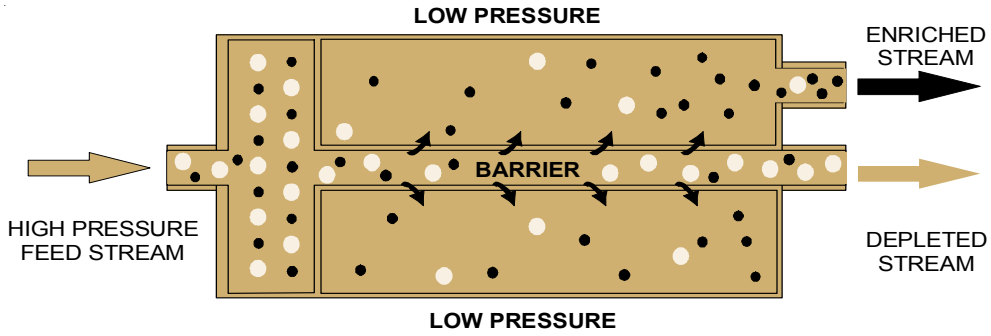
ENRICHMENT

The final step, which is the most difficult and costly, is the enrichment process. Several different methods (gaseous diffusion, electromagnetic separation, and thermal diffusion) have been developed to increase the concentration of the uranium-235 isotope. Most of the uranium enriched in the U.S. was produced using the gaseous diffusion method.

The enrichment process begins after refining, when UF_6 is received in solid form at a GDP and heated to form a gas. This UF_6 gas contains both uranium-235 and uranium-238 isotopes. In the gaseous diffusion enrichment process, UF_6 gas is pumped through miles of piping and barrier-like structures that have millions of uniformly sized, tiny holes. The weight differential between molecules containing uranium-235 and molecules containing uranium-238 determines the rate at which the isotopes pass through the holes. The gas molecules containing the lighter uranium-235 move slightly faster than those containing the heavier uranium-238 and diffuse through the barrier at a faster rate than do the molecules containing uranium-238. As a result, a partial separation of the uranium isotopes is accomplished, resulting in uranium-235 having a higher concentration on the downstream side of the barrier than on the feed side of the barrier.

About one-half of the feed stream diffuses through the barrier, and it is then fed to the next higher stage, where the process is repeated. The remaining gas, which is slightly depleted in the uranium-235 isotope, is recycled back to a previous stage (**Figure 2-1**). Because of the very small amount of separation occurring in a single stage, the process must be repeated thousands of times by coupling the stages in a series arrangement called a "cascade." When the uranium-235 concentration in the enriched stream meets requirements, the UF_6 is withdrawn from the process, cooled to a solid, and shipped to the customer or converted to an oxide or metal depending on the application.

Figure 2-1 Single Stage of the Gaseous Diffusion Process



In summary, the gaseous diffusion process consists of pumping gaseous UF_6 through diffusion barriers that separate the uranium-235 from uranium-238. Uranium-238 is removed from the system as depleted uranium. The maximum enrichment achieved using the gaseous diffusion process is between 97 and 98 percent. When uranium is enriched to a uranium-235 concentration of 20 percent or more, it is considered HEU.

Uranium Enrichment Production Sites

Gaseous diffusion plants were constructed at Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio. The DOE produced HEU at the Oak Ridge and Portsmouth Gaseous Diffusion Plants for nuclear weapons, naval reactors, and other reactor fuels beginning in the mid-1940s and ending in 1992. The Paducah Gaseous Diffusion Plant never produced HEU but instead produced large quantities of LEU enriched to about 1.0 percent uranium-235. This LEU was then shipped to the Portsmouth and Oak Ridge sites for further enrichment. **Table 2-1** summarizes general information for these sites. More specific information about the Oak Ridge and Portsmouth Gaseous Diffusion Plant operations, including detailed production information, is provided in Section 5 of this report.

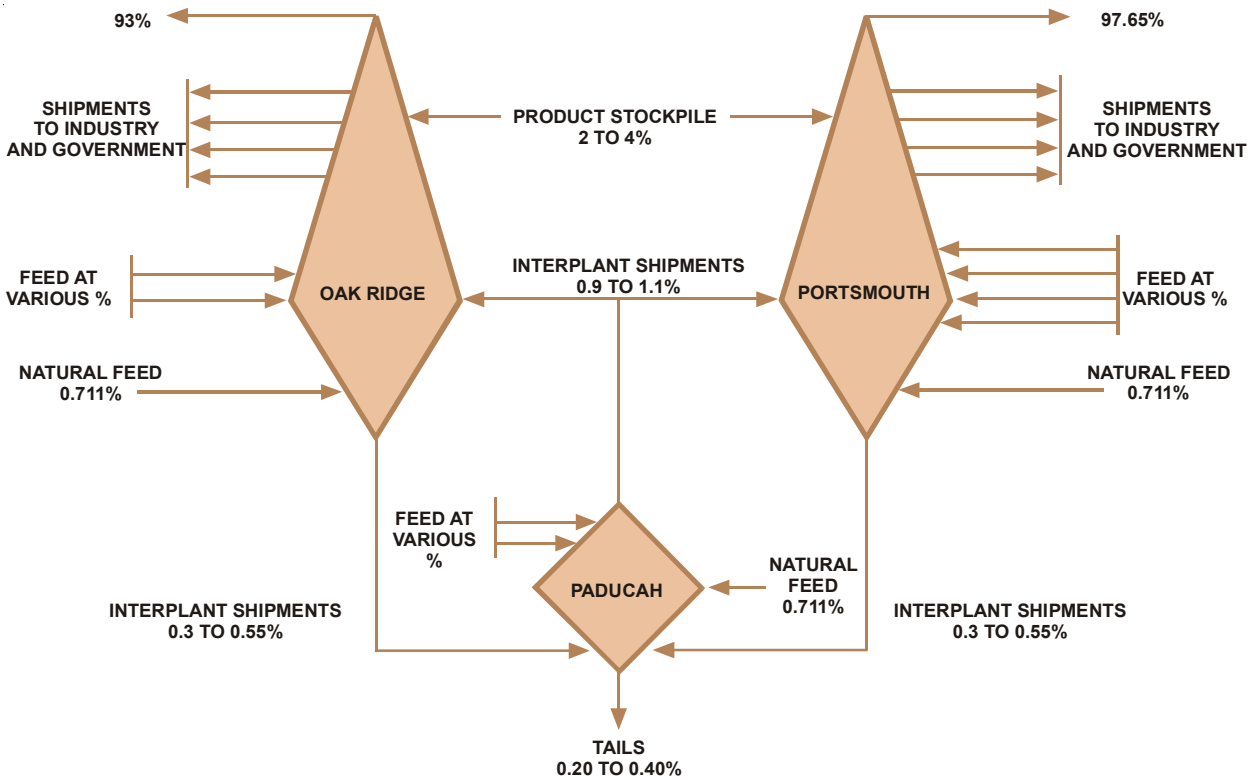
Before enriched uranium can be used for nuclear reactor fuel or weapons production, it must be chemically converted from uranium hexafluoride to an oxide or metal. This conversion is fairly straightforward, and several government-licensed chemical companies furnish conversion services to the civilian atomic industry routinely. As discussed earlier, the HEU was produced primarily for defense requirements while the principal use of LEU is for the civilian atomic power industry.

Table 2-1 Site Information of the Gaseous Diffusion Plants

Site Information	Oak Ridge	Paducah	Portsmouth
City/State	Oak Ridge, TN	Paducah, KY	Portsmouth, OH
Construction Began (year)	1943	1951	1953
Operation Began (year)	1945	1952	1954
Site Area (acres)	640	750	640
Process Building Floor Area (acres)	210	150	200
Enrichment Stages	5,104	1,760	4,020
Full Power (megawatts)	2,105	3,040	2,260
Shutdown	1987	--	--

Although the three GDPs could be operated individually, they were operated as an integrated production complex during full production. The uranium feed to all three plants consisted primarily of natural uranium UF_6 supplemented by varying amounts of feed materials of higher concentrations of uranium-235. From Paducah, a product enriched to approximately 1.0 percent uranium-235 was shipped to the Oak Ridge and Portsmouth sites for further enrichment. **Figure 2-2** illustrates the integrated operation of the three GDPs.[9]

Figure 2-2 Integrated Operation of the Gaseous Diffusion Plants



[9] In June 1999, the Secretary of Energy initiated an investigation into allegations that trace elements in feed material for the GDPs may have endangered the health of employees.

HEU Utilization and Facilities

For over 50 years, HEU has been used in nuclear weapons, naval reactors, and research and development (R&D) programs. These programs covered a wide spectrum of nuclear energy activities—from research on exotic elements to the production of nuclear components for weapons, power generation, medical purposes, and industrial uses.

Figure 2-3 provides the location of sites discussed in this report. It is important to note that this listing does not include waste sites. A brief narrative of the sites listed in Figure 2-3 is provided in Appendix B. Some of the sites were established by commercial entities when privatization was encouraged by legislation that precluded the Government from competing with industry.

U.S. programs involved in HEU utilization can be grouped into four general categories:

- U.S. Nuclear Weapons Program
- Space Propulsion
- Military Reactors
- Other Government and Commercial Reactors

A brief description of each of these categories is provided below.

U.S. Nuclear Weapons Program

From the beginning, the U.S. nuclear weapons program consisted of developing, designing, fabricating, and testing nuclear weapons as requested by the DoD and approved by the President. The design, development, and production of weapons systems requires a large number of manufacturing techniques and capabilities. Research and development in the program provides for the basic research necessary for advances in weapons technologies and the specific weapons development activities for meeting DoD-approved requirements.

A nuclear weapon is a complex device consisting of many parts. A number of these parts require special materials in their manufacture; all of them have rigorous specifications for assembly.

Primary HEU Utilization Sites in the U.S. Nuclear Weapons Program

- ✓ Materials Production: Savannah River Site[10]
- ✓ Weapons Component Fabrication: Y-12 Plant and the Rocky Flats Plant[11]
- ✓ Weapons Operations (assembly and dismantlement): Pantex Plant and Iowa Army Ordnance Plant[11]
- ✓ Research, Development, and Testing: Los Alamos, Lawrence Livermore, and Sandia National Laboratories, and the Nevada Test Site

[10] The Savannah River Site used HEU to produce plutonium and tritium for the weapons program.
[11] A former nuclear weapons site.

All nuclear weapons require fissile materieals, i.e., materials capable of being split or "fissioned" by low-energy neutrons. Fission releases energy and additional neutrons, leading to a self sustaining chain reaction. HEU is one of the fissile materials the U.S. uses to make nuclear weapons.

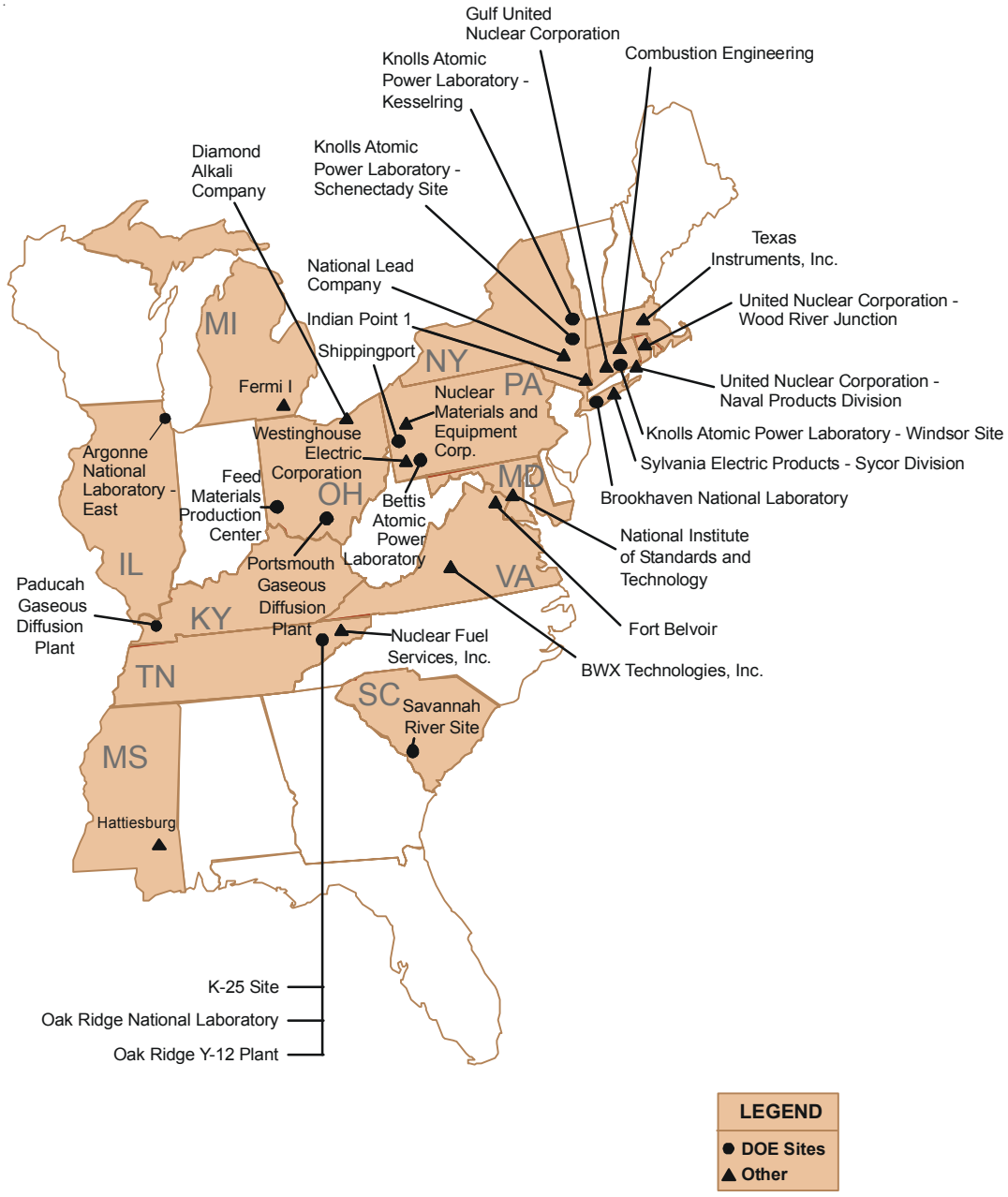
Military Reactors

HEU utilization in military reactors includes the Naval Nuclear Propulsion Program and the Army Nuclear Power Program. The Naval Nuclear Propulsion Program is a joint Department of the Navy and DOE program. The principal objective of the program is the continued development and improvement of naval nuclear propulsion plants and reactor cores for use in ships ranging in size from small submarines to large combatant surface ships. In conjunction with the basic research and development work on advanced reactor plants and long-life cores, DOE constructed and operated nine training platforms. As of September 30, 1996, the Navy had built over 200 nuclear-powered ships. Of these, 96 submarines, 8 aircraft carriers, and 4 guided missile cruisers were still in operation. Construction was underway on three additional nuclear-powered submarines and aircraft carriers.

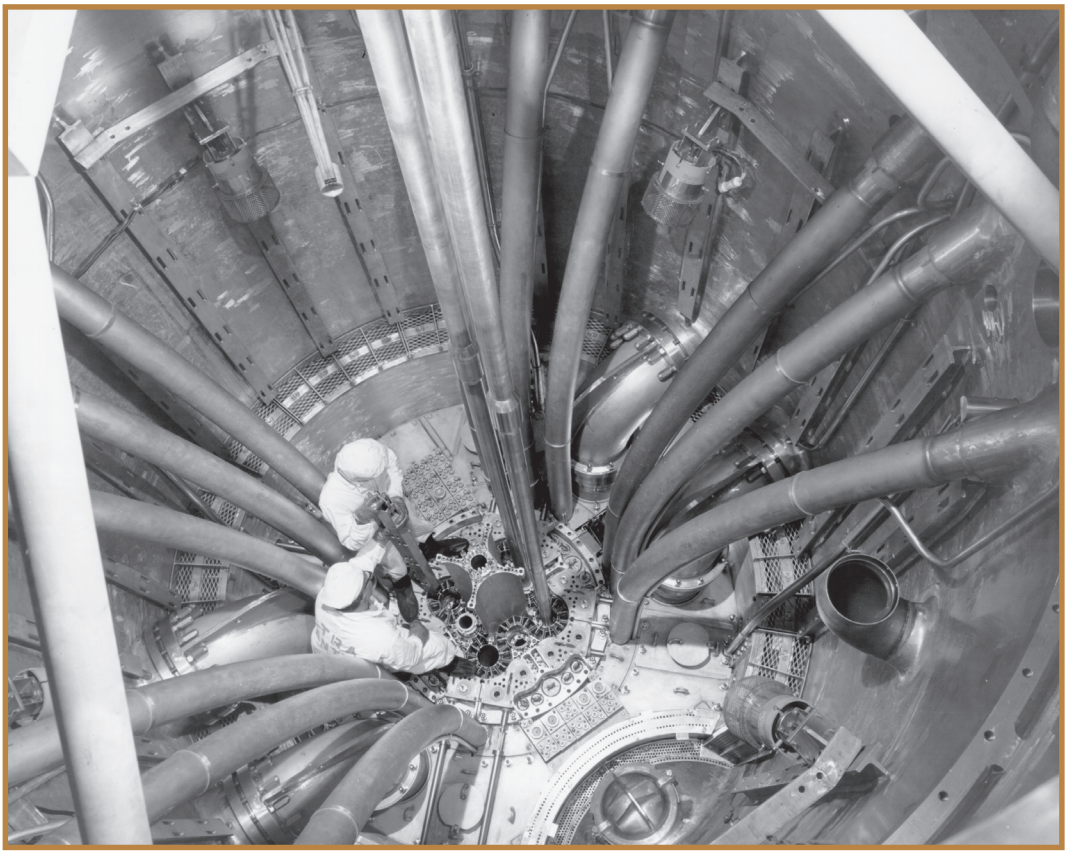
The Army Nuclear Power Program developed specialized nuclear power reactors that were operated by military services in some of the most remote areas of the world. These reactors largely eliminated the need for supplying large amounts of fossil fuel for power production. The first pressurized water reactor for Army use began operation at Fort Belvoir, Virginia, in 1957. During the life of the program (1954-1977), the Army designed, constructed, and deactivated nine nuclear power program facilities. A description of the reactors in the Army Nuclear Power Program and the Naval Nuclear Propulsion Program is provided in Appendix D.

Figure 2-3 Sites Discussed in this Report

Figure 2-3 Sites Discussed in this Report - continued



Pictured is an elevated port beam view of the nuclear-powered aircraft carrier U.S.S. Dwight D. Eisenhower (CVN 69) underway off the Virginia Capes.



Pictured is the core of the Advanced Test Reactor located at the Idaho National Engineering and Environmental Laboratory. Since 1968, this reactor has contributed substantially to reactor technology and development.

Space Propulsion-Project Rover/NERVA

In 1956, the U.S. Government initiated "Project Rover," a program at the Los Alamos National Laboratory, Westinghouse Astronuclear Laboratory, Aerojet-General Corporation, and other industrial partners, to determine the feasibility of utilizing nuclear energy for rocket vehicle propulsion. The goal of this joint AEC-National Aeronautics and Space Administration (NASA) program was to develop nuclear rocket propulsion systems for transporting heavy payloads and conducting missions in space, including manned missions to other planets.

In 1967, after 11 years of extensive research and development, the performance of the nuclear rocket had been demonstrated, and the technological basis had been established for the development of a flight engine called NERVA (Nuclear Engine for Rocket Vehicle Application). The NERVA used HEU fuel in a graphite matrix. The first experimental space propulsion reactor (Kiwi-A) was tested in Nevada in July 1959. In all, 23 nuclear reactor rocket engine tests were conducted at the Nuclear Rocket Development Station (NRDS) located at the Nevada Test Site. While many rocket engines were designed, built, and tested, they were never used in the space program. In 1971, the program to develop space propulsion systems was terminated.

Other Government and Commercial Reactors

Other government reactors also used HEU as fuel for research, training, and test purposes, and for the production of radioisotopes for medical and industrial uses. These reactors include: the Experimental Breeder Reactor-II; the High Flux Isotope Reactor; the Advanced Test Reactor; the High Flux Beam Reactor; some university reactors; and the National Institute of Standards and Technology research reactor. Commercial reactors that used HEU as fuel to produce electric power include: the Fort St. Vrain Nuclear Power Generating Station in Colorado; the Enrico Fermi Atomic Power Plant, Unit 1 in Michigan; and the Elk River Reactor in Minnesota.

Pictured is the Phoebus 1B reactor mounted on a test cart en route to the Nuclear Rocket Development Station at the Nevada Test Site. The Phoebus 1B was one of 23 nuclear reactor rocket engines tested in the 1960s as part of the space propulsion program.

Pictured is the Stationary Low Power Plant (SL-1) at the Idaho National Engineering and Environmental Laboratory. The SL-1 was part of the Army Nuclear Power Program constructed to gain experience in boiling water reactor operations, develop performance characteristics, train military crews, and test components. The SL-1 operated from August 11, 1958, through January 3, 1961, when it was destroyed in an accident.

HEU is contained in tens of thousands of individual items and in hundreds of unique chemical and physical forms. Some examples of forms include metals, oxides, other compounds, combustibles, residues, solutions, and irradiated materials. Pictured to the left is HEU in storage containers at the Oak Ridge Y-12 Plant.

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SECTION 3
U.S. HEU INVENTORY

As of September 30, 1996, the total U.S. HEU inventory was **740.7** MTU containing **620.3** MTU-235. In this report, HEU in waste is not reported as part of the U.S. inventory and is not included in the overall quantity. Most of the HEU in waste has been removed from the U.S. inventory as "normal operating losses" because it is technically too difficult or uneconomical to recover. Normal operating losses are also referred to as measured discards.

U.S. HEU Inventory (as of September 30, 1996)

Location	*MTU*
Y-12 Plant, Pantex Plant and Department of Defense	651.6
Idaho National Engineering & Environmental Laboratory	27.4
Savannah River Site	22.2
Portsmouth Gaseous Diffusion Plant	21.7
Rocky Flats Environmental Technology Site	6.0
Los Alamos National Laboratory	3.5
Other	8.3
Total	740.7

LOCATION OF THE U.S. HEU INVENTORY

Table 3-1 presents data on the location and total quantity of HEU in the U.S. inventory as of September 30, 1996. The information is provided in two assay ranges: (1) HEU with a concentration of 20 percent or more of uranium-235, but below 90 percent by weight, and (2) HEU with a concentration of 90 percent or more of uranium-235 by weight.

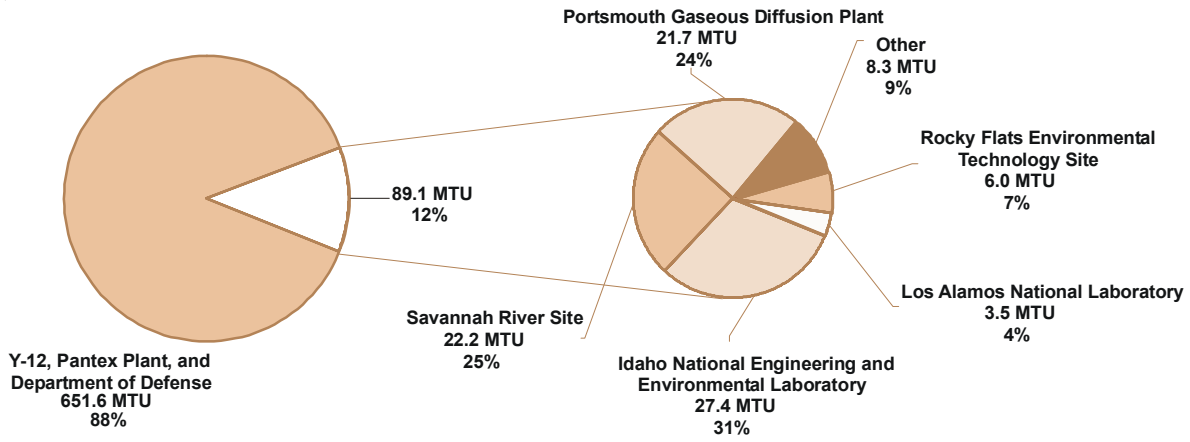
Y-12 PLANT, PANTEX PLANT AND DOD

Approximately 88 percent of the U.S. HEU inventory is located at the Y-12 Plant in Oak Ridge, Tennessee, the Pantex Plant near Amarillo, Texas, and in the custody of the DoD. This material (**651.6** MTU) is in the form of weapons, dismantled weapons parts, Naval Nuclear Propulsion Program reactors, solutions from chemical recovery operations, canned oxides, combustibles stored in drums, and canned residues.

The current mission at the Y-12 Plant consists of weapon component dismantlement; special nuclear material storage; maintenance of technical capability for weapons development and production, stockpile maintenance and evaluation, and nonproliferation and arms control; and technology transfer.

The Pantex Plant has a mission to assemble nuclear weapons for the Nation's nuclear weapons stockpile; evaluate, repair, and retrofit nuclear weapons in the stockpile; and disassemble weapons being retired from the stockpile.

Table 3-1 U.S. HEU Inventory as of September 30, 1996



Location	20 to <90% U-235		≥90% U-235		Total	
	MTU	MTU-235	MTU	MTU-235	MTU	MTU-235
Y-12 Plant, Pantex Plant & Department of Defense [a]					651.6	557.4
Idaho National Engineering and Environmental Lab.[b]	23.1	15.3	4.3	4.0	27.4	19.3
Savannah River Site	21.6	14.1	0.5	0.5	22.2	14.6
Portsmouth Gaseous Diffusion Plant	13.9	6.6	7.8	7.5	21.7	14.1
Rocky Flats Environmental Technology Site			6.0	5.6	6.0	5.6
Los Alamos National Laboratory	0.4	0.2	3.2	3.0	3.5	3.2
Other						
Oak Ridge National Laboratory	1.6	1.3			1.6	1.3
K-25 Site	1.4	0.7	0.1	0.1	1.5	0.8
Sandia National Laboratory	0.2	0.1	0.5	0.5	0.7	0.6
Hanford Site	0.5	0.2			0.5	0.2
Brookhaven National Laboratory	0.3	0.2			0.3	0.2
Miscellaneous	1.8	1.2	1.9	1.8	3.7	3.0
Total					**740.7**	**620.3**

Note: Totals may not add due to rounding.

a For purposes of national security, the HEU inventory for the Y-12 Plant, the Pantex Plant, and the Department of Defense is a total combined quantity. As part of the Department of Defense inventory, the Naval Nuclear Propulsion Program includes 100 metric tons of HEU in nuclear-powered submarines, surface ships, and training platforms. In addition, this category includes the BWX Technologies Naval Nuclear Fuel Division facility, the Knolls Atomic Power Laboratory, the Bettis Atomic Power Laboratory, and the Expended Core Facility at the Idaho National Engineering and Environmental Laboratory. For purposes of national security, only the total quantities of uranium and uranium-235 are provided since the quantities in each assay range remain classified.

b The Idaho National Engineering and Environmental Laboratory includes the Idaho Chemical Processing Plant and the Argonne National Laboratory - West.

For purposes of national security, the HEU inventory for Y-12 Plant, the Pantex Plant and DoD is reported as a total quantity rather than separate amounts. In addition, information by the two assay ranges is not provided. This is necessary since the amount and enrichment of HEU associated with nuclear weapons continues to be sensitive information, which is protected through classification.

Composition of the HEU Inventory

- ✓ Pits and disassembled nuclear weapons parts
- ✓ Metals
- ✓ Oxides
- ✓ Process residues
- ✓ Compounds
- ✓ Solutions
- ✓ Reactor fuel
- ✓ Holdup materials
- ✓ Samples, sources, and standards
- ✓ Irradiated spent nuclear fuel

Naval Nuclear Propulsion Program

The HEU inventory for the Naval Nuclear Propulsion Program was 100 metric tons of uranium as of September 30, 1996, and was part of the Department of Defense inventory. The majority of HEU assigned to the Naval Nuclear Propulsion Program is already in or has been used in naval reactor cores. The remainder will be fabricated into fuel in the near future. As of September 30, 1996, the Navy had 96 operating submarines, 4 surface ships, 8 aircraft carriers, and 4 training platforms.

Idaho National Engineering and Environmental Laboratory

The Idaho National Engineering and Environmental Laboratory (INEEL) is located near Idaho Falls, Idaho. Its original mission was to test nuclear reactor prototypes, recover HEU from spent fuel, and then return the HEU to the stockpile. The mission at INEEL has changed to the interim storage of HEU, facility decontamination and decommissioning, and environmental restoration. INEEL has **27.4** MTU, mostly in the form of oxides, unirradiated and irradiated reactor fuel elements, residues, and sources.

Savannah River Site

The Savannah River Site (SRS), located near Aiken, South Carolina, operated continuously for 40 years as one of the primary producers and processors of nuclear materials. HEU was a major feedstock for the nuclear materials production process. SRS has about **22.2** MTU in the form of irradiated reactor fuel assemblies, cast HEU and aluminum alloy ingots, process residues, and solutions. Small quantities of HEU are present as sources, calibration standards, and laboratory samples.

Portsmouth Gaseous Diffusion Plant

The Portsmouth Gaseous Diffusion Plant, near Piketon, Ohio, has enriched uranium for government programs and commercial nuclear power plants at levels ranging from 4 percent to over 97 percent uranium-235. In 1991, production of HEU was terminated, and the plant mission changed to uranium enrichment for commercial reactors. The Energy Policy Act of 1992 transferred responsibility for Portsmouth from the DOE to newly created entity known as the United States Enrichment Corporation (USEC). The enrichment facilities are leased from DOE to USEC. Approximately **21.7** MTU of DOE-owned HEU in various physical and chemical forms, mainly solids, are stored at Portsmouth.

Rocky Flats Environmental Technology Site

The Rocky Flats Environmental Technology Site, near Golden, Colorado, has **6.0** MTU on site. The original mission at Rocky Flats was the manufacture of nuclear weapon components and the recovery and purification of plutonium scrap/residues for reuse. Its current mission activities include special nuclear materials stabilization; packaging and consolidation; deactivation and decommissioning of facilities; environmental restoration; property disposition; and offsite shipment and waste disposition.

Los Alamos National Laboratory

The Los Alamos National Laboratory in Los Alamos, New Mexico, has approximately **3.5** MTU on site. The HEU material at Los Alamos is in various physical and chemical forms, including pure metal, fabricated weapon shapes, and compounds. The HEU is used in basic special nuclear material research in support of national defense and energy programs.

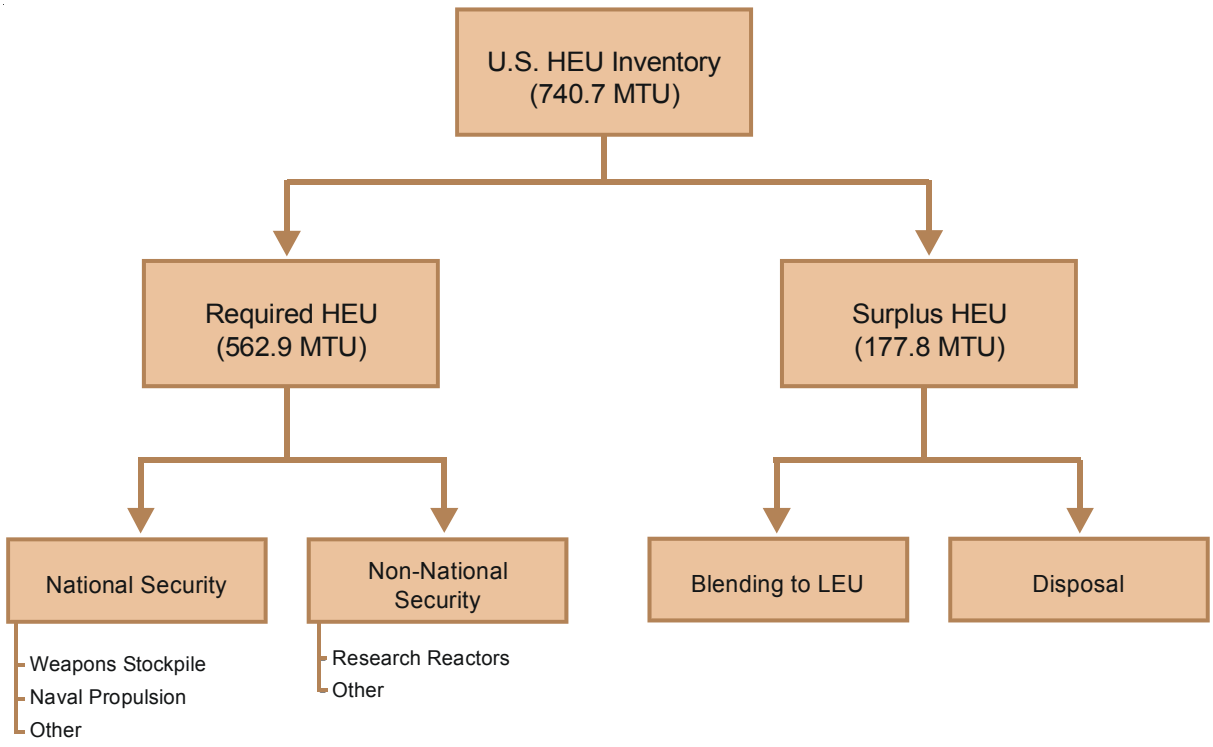
Other Sites with Small HEU Holdings

The remaining **8.3** MTU is located at other DOE sites as well as commercial facilities. This HEU material is in the form of reactor fuel plates, pure and impure oxides, solutions, calibration standards, sources, spent fuel, and other items. Site inventories range from gram quantities to approximately 1.6 MTU at the Oak Ridge National Laboratory.

HEU Programmatic Requirements

From a programmatic perspective, the U.S. HEU inventory can be divided into two categories—required HEU and surplus HEU. As shown in **Figure 3-1,** a total of **562.9** MTU is required HEU and a total of **177.8** MTU is surplus HEU. Required HEU is defined in this report as material that is currently in active use or planned future use for weapons and nonweapons programs. Surplus HEU is no longer required by the DOE and is planned for disposition either through blending or disposal operations.

Figure 3-1 U.S. HEU Inventory Categories as of September 30, 1996



REQUIRED HEU

As of September 30, 1996, the total quantity of required HEU in the U.S. HEU inventory was **562.9** MTU **(Table 3-2).** The required HEU is needed to support national security and non-national security programs.

Required HEU Inventory

Location	*MTU*
Y-12 Plant, Pantex Plant & Department of Defense	548.8
Idaho National Engineering & Environmental Laboratory	5.0
Rocky Flats Environmental Technology Site	3.8
Los Alamos National Laboratory	2.9
Other	2.4
Total	562.9

NATIONAL SECURITY

National security programs include the nuclear weapons stockpile, the Naval Nuclear Propulsion Program, and other national security programs.

NUCLEAR WEAPONS STOCKPILE

The U.S. nuclear weapons stockpile, America's strategic nuclear deterrent, along with appropriate defensive capabilities will remain at the core of U.S. national security. On August 11, 1995, President Clinton stated, "As part of our national strategy, the United States must and will retain strategic nuclear forces sufficient to deter any future hostile foreign leadership with access to strategic nuclear forces from action against our vital interests and to convince it that seeking a nuclear advantage would be futile."

As a result of this policy, HEU is required for nuclear weapons as part of the Stockpile Stewardship Program and includes research and development and surveillance activities to assure the long-term reliability of the stockpile.

NAVAL NUCLEAR PROPULSION PROGRAM

All U.S. Navy nuclear powered warships currently use reactors fueled by HEU. Unlike commercial power reactors, which are incrementally refueled, naval reactor cores are completely replaced when the operation of a reactor becomes inefficient. At the end of a core life, the core is removed from the ship and sent to the Expended Core Facility (ECF) at INEEL for examination.

Since the U.S. has ceased production of HEU, the future source of HEU for naval reactors will come from weapons returns and existing inventories. Based on current available inventory of material not in cores, uranium from weapons returns will be needed in the near future to continue to build naval cores. This process of turning former nuclear weapons into naval cores supports

the U.S. nonproliferation policy, since this material will eventually become spent naval fuel, which will not be available for future weapons use.

OTHER NATIONAL SECURITY

HEU is also required to support other national security programs including the Advanced Test Reactor operations at INEEL, future naval reactor requirements, and strategic reserves of HEU.

NON-NATIONAL SECURITY

HEU is required to support fuel fabrication for DOE non-weapons research reactors (e.g., High Flux Isotope Reactor, High Flux Beam Reactor, and the Brookhaven Medical Research Reactor), and the Department of Commerce's National Institute of Standards and Technology research reactor. These reactors are planned to operate for a minimum of ten more years. In addition, HEU is needed to support the DOE's University Reactor Fuel Assistance Program for fuel in university reactors (e.g., University of Missouri at Rolla reactor).

Table 3-2 Location of Required HEU Inventory as of September 30, 1996

Location	20 to <90% U-235		≥90% U-235		Total	
	MTU	MTU-235	MTU	MTU-235	MTU	MTU-235
Y-12 Plant, Pantex Plant & Department of Defense[a]					**548.8**	**498.3**
Idaho National Engineering and Environmental Laboratory	2.5	1.7	2.5	2.3	**5.0**	**4.0**
Rocky Flats Environmental Technology Site			3.8	3.6	**3.8**	**3.6**
Los Alamos National Laboratory	0.1	0.1	2.9	2.7	**2.9**	**2.7**
Sandia National Laboratory	0.1	0.1	0.4	0.4	**0.5**	**0.5**
Other	0.3	0.2	1.6	1.5	**1.9**	**1.7**
Total					**562.9**	**510.8**

Note: Totals may not add due to rounding.

a For purposes of national security, the HEU inventory for the Y-12 Plant, the Pantex Plant and the Department of Defense is a total combined quantity. As part of the Department of Defense inventory, the Naval Nuclear Propulsion Program includes HEU in nuclear-powered submarines, surface ships, and training platforms. In addition, this category includes the BWX Technologies Naval Nuclear Fuel Division facility, the Knolls Atomic Power Laboratory, the Bettis Atomic Power Laboratory, and the Expended Core Facility at the Idaho National Engineering and Environmental Laboratory. For purposes of national security, only the total quantities of uranium and uranium-235 are provided since the quantities in each assay range remain classified.

SURPLUS HEU

Surplus HEU Inventory (as of September 30, 1996)

Location	*MTU*
Y-12 Plant, Pantex Plant & Department of Defense	102.8
Idaho National Engineering & Environmental Laboratory	22.4
Savannah River Site	22.2
Portsmouth Gaseous Diffusion Plant	21.7
Rocky Flats Environmental Technology Site	2.2
K-25 Site	1.5
Oak Ridge National Laboratory	1.6
Other	3.4
Total	177.8

Over the years, the U.S. inventory has been used primarily for nuclear weapons production and other defense-related missions. With the end of the Cold War and resulting diminished strategic military threat, opportunities presented themselves for the DOE to redirect its HEU priorities from weapons production activities to HEU disposition activities. With the reduction in nuclear weapons, significant quantities of HEU became surplus 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 HEU 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, DOE and DoD performed an in-depth review of the fissile material required to support the nuclear weapons program and other national security needs. In December 1994, **174.3** MTU of HEU was declared surplus to national defense needs. In addition, the Secretary of Energy announced on December 20, 1994, that plutonium and weapons-usable HEU that was recovered during the cleanup 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, 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." The 200 tons of fissile material referred to by the President includes plutonium as well as HEU.

Information about the location, form, and quantity of the **174.3** MTU was released at the February 6, 1996, DOE Openness Press Conference. This release was based on the September 1995 HEU inventory. **Table 3-3** updates the location, form, and quantity of surplus HEU from **174.3** to **177.8** MTU. This revised quantity is based on the September 30, 1996, inventory.

As can be seen from Table 3-3, the amount of HEU that is surplus to national security has increased by 3.5 MTU. The location, quantities, and form of HEU in the U.S. inventory and, in particular, the quantity surplus to national security needs continues to be very dynamic. Reactor burnup, discards to waste, and the blending of HEU to LEU are continually reducing the HEU inventory. At the same time, the surplus inventory has increased with the receipt of HEU from foreign countries and changing DOE programmatic requirements. The location and forms of HEU have changed as a result of ongoing DOE facility and site cleanup, materials stabilization, and nonproliferation activities.

Table 3-3 Location of Surplus HEU Inventory as of September 30, 1996

Location	Metal	Oxides	Unirradiated Fuel	Irradiated Fuel	Other Forms	Total	
						MTU	MTU-235
Y-12 Plant, Pantex Plant and Department of Defense	84.2	6.4	10.1	0.1	2.0	**102.8**	**59.1**
Idaho National Engineering and Environmental Laboratory	0.8	1.8	0.8	18.5	0.4	**22.4**	**15.3**
Savannah River Site	6.1	0.5	5.8	8.3	1.4	**22.2**	**14.6**
Portsmouth Gaseous Diffusion Plant		7.3			14.4	**21.7**	**14.1**
Rocky Flats Environmental Technology Site	2.1		0.1			**2.2**	**2.0**
K-25 Site					1.5	**1.5**	**0.8**
Oak Ridge National Laboratory		1.0		0.6		**1.6**	**1.3**
Los Alamos National Laboratory		0.3			0.3	**0.6**	**0.5**
Hanford Site		0.1	0.1	0.2	0.1	**0.5**	**0.2**
Brookhaven National Laboratory				0.3		**0.3**	**0.2**
Sandia National Laboratory		0.1		0.1		**0.2**	**0.1**
Other				0.8	1.0	**1.8**	**1.3**
Total MTU	**93.2**	**17.6**	**17.0**	**28.9**	**21.1**	**177.8**	**109.5**
Total MTU-235	**56.9**	**9.4**	**8.7**	**19.3**	**15.2**		

Notes:

1 Quantities are in metric tons of uranium (MTU) and metric tons of uranium-235 (MTU-235).

2 Totals may not add due to rounding.

3 Information is based on the September 30, 1996, HEU inventory.

Relative to surplus HEU, the mission of the DOE Office of Fissile Materials Disposition is to support nonproliferation objectives making the material nonweapons-capable. In the Record of Decision for the Disposition of Surplus Highly Enriched Uranium issued on July 29, 1996, DOE decided to convert the surplus HEU into a nonweapons-capable material by down blending the HEU to LEU. The LEU will subsequently be provided to the commercial nuclear reactor industry as a source of fuel (in an effort to maximize the economic benefit of the material), or if that is not possible, be disposed of as low-level radioactive waste (DOE 1997).

SECTION 4
HISTORICAL MATERIAL BALANCE

This section provides information on the elements used in constructing the historical material balance. Also provided is a discussion on the data limitations incurred during the data-gathering phase of this report. Due to data limitations, the material balance has been calculated in terms of uranium-235, the fissile isotope of uranium used in nuclear weapons.

ELEMENTS OF THE MATERIAL BALANCE

The historical material balance is comprised of five primary elements: acquisitions, removals, classified transactions, calculated inventory, and actual inventory. Acquisitions and removals are broken down further into material balance categories. Acquisitions contain three material balance categories and removals contain seven. Additional information on acquisitions and removals is provided in Sections 5 and 6, respectively.

The methodology used to determine the calculated U.S. HEU inventory is to subtract the total quantity of removals from the total quantity of acquisitions and classified transactions for a given period. The calculated inventory is then compared to the actual inventory at the end of the given period.

Methodology

Summarize Acquisition Quantities
- ✓ Production from uranium enrichment processes
- ✓ Production from blending
- ✓ Receipts from foreign countries

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

Determine Calculated Inventory by Subtracting Removals from Acquisitions and Classified Transactions

Compare and Analyze Calculated Inventory with Actual Inventory

ACQUISITIONS

Acquisitions increase the U.S. HEU inventory. From 1945 through September 30, 1996, the U.S. acquired a total of **864.4** MTU-235 contained in HEU. The three material balance categories that comprise acquisitions are as follows:

- **Production from uranium enrichment processes** includes HEU produced from electromagnetic separation and gaseous diffusion processes. The Y-12 Plant calutrons produced HEU from electromagnetic separation, whereas the Oak Ridge and Portsmouth Gaseous Diffusion Plants produced HEU from gaseous diffusion.
- **Production from blending** occurs when HEU is mixed with either depleted, natural, or LEU to form a new HEU product. This new HEU product will have an assay lower than

the original HEU, and the uranium-235 in the non-HEU blend stock will be added to the HEU inventory. Production from blending occurred primarily at the Y-12 Plant.

- **Receipts from foreign countries** includes the receipt of HEU from foreign countries primarily under Agreements for Cooperation for the Peaceful Uses of Atomic Energy. Also included is the receipt of HEU from the former Soviet Republic of Kazakhstan.

Removals

Removals decrease the U.S. HEU inventory. From 1945 through September 30, 1996, the U.S. b(5) removed a total of <deleted> contained in HEU. The seven material balance categories that comprise removals are as follows:

- **Refeed at enrichment plants** is the reintroduction of HEU, which has been previously produced as a finished product, back into the enrichment process. HEU was removed from the inventory and refed into the Y-12 Plant calutrons and the Oak Ridge and the Portsmouth Gaseous Diffusion Plants. This removal is necessary so that quantities of HEU produced are not double-counted.
- **Nuclear tests and wartime detonations** include the expenditure of HEU in 1,054 U.S. nuclear tests and one wartime detonation from 1945 through 1992. Since 1992, the U.S. has not conducted any nuclear weapons tests.
- **Fission and transmutations** account for HEU consumed by nuclear irradiation as a result of exposure in a reactor. The largest consumers of HEU were the Savannah River Site production reactors and the Naval Nuclear Propulsion Program reactors.
- **Normal operating losses** account for HEU in waste, which is determined to be technically or economically unrecoverable. Quantities of HEU in spent fuel and HEU expended in weapons testing activities are not considered normal operating losses.
- **Transfers to foreign countries** include the transfer of HEU to foreign countries under two types of Agreements for Cooperation: (1) peaceful uses of atomic energy, and (2) mutual defense purposes.
- **Down blending** removals occur when HEU is mixed with either depleted, natural, or LEU to form a new product that is not HEU (less than 20 percent uranium-235). The uranium-235 in the HEU blend stock is thereby removed from the HEU inventory. Down blending of HEU occurred primarily at the Y-12 Plant.
- **Inventory differences** are the differences between the quantity of nuclear material on hand at a facility, according to each facility's accounting records system, and the quantity measured during a physical inventory. Inventory differences can be positive or negative. In this report, inventory differences are treated as a removal from the inventory since the cumulative inventory difference for all U.S. facilities is a positive quantity, which is an apparent loss of material.

Classified Transactions

Classified transactions are those transactions that remain classified for national security purposes. From 1945 through September 30, 1996, a total of <deleted> was acquired through classified transactions. b(5)

Calculated Inventory

As shown in **Table 4-1,** the U.S. acquired a total of 864.4 MTU-235 in HEU from 1945 through September 30, 1996. During the same period, <deleted> in HEU were removed from the U.S. inventory, resulting in a calculated inventory of 620.3 MTU-235 contained in HEU. The 620.3 quantity includes <deleted> of transactions that remain classified. b(5) b(5)

Table 4-1 Historical Material Balance of Uranium-235 in HEU

Material Balance Category		MTU-235	
Acquisitions	Production from Uranium Enrichment Processes	859.2	
	Production from Blending	0.3	
	Receipts from Foreign Countries	4.9	
	Total Acquisitions	**864.4**	
Removals	Refeed at Enrichment Plants	114.2	
	Nuclear Tests, Wartime Detonations, and Naval Reactor Use	31.9	
	Fission and Transmutations	56.2	
	Normal Operating Losses	4.9	
	Transfers to Foreign Countries	<deleted>	b(5)
	Down Blending	1.5	
	Inventory Differences	3.2	
	Total Removals	<deleted>	b(5)
Totals	Total Acquisitions	864.4	
	Minus Total Removals	<deleted>	b(5)
	Plus Classified Transactions	<deleted>	b(5)
	Equals the Calculated U.S. HEU Inventory	**620.3**	

Actual U.S. HEU Inventory as of September 30, 1996	MTU-235
	620.3

Actual Inventory

As discussed in Section 3 of this report, the actual U.S. HEU inventory as of September 30, 1996, was **740.7** MTU containing **620.3** MTU-235.

Inventory Analyses and Data Limitations

An accurate material balance in terms of uranium was not possible due to the data limitations described below. However, a material balance in terms of uranium-235 was accomplished yielding a calculated inventory (**620.3** MTU-235) that equaled the actual inventory (**620.3** MTU-235). It should be noted that even though a balance in terms of uranium-235 was obtained, some uncertainty remains due to data limitations.

b(5)
b(5)

Historical Material Balance (in terms of uranium-235)

	MTU-235
Total Acquisitions	864.4
Total Removals	<deleted>
Classified Transactions	<deleted>
Calculated Inventory	**620.3**
Actual Inventory	**620.3**

If a material balance was performed using just the total uranium data, the calculated U.S. HEU inventory would be **731.1** MTU compared to an actual U.S. HEU inventory of **740.7** MTU. This results in a variance of **9.6** MTU between the inventories. This variance can best be explained through the blending of depleted, normal, and LEU with HEU at the Y-12 Plant. Quantities gained by blending at the Oak Ridge Y-12 Plant prior to 1976 were not available and, therefore, were not included in the material balance. While omission of the quantities blended would have a minimal effect on the uranium-235 balance because of the small amount of uranium-235 in LEU, it could significantly understate the total uranium produced from blending.

In addition to incomplete blending data, other data limitations were encountered during the preparation of this report. Some of the data were extracted from historical sources originally compiled for reasons other than for HEU accountability. As a result, some judgments were necessary in interpreting and adapting the information to satisfy the requirements of the historical material balance. In addition, some data associated with inventory differences were available only in terms of uranium-235.

The information in this report is based on the evaluation of available records and represents the Department's best judgment. The information contained in this report may be updated or revised in the future should additional or more detailed data become available.

SECTION 5
ACQUISITIONS

The total HEU acquisitions for the period between 1945 and September 30, 1996, were **1,055.4** MTU containing **864.4** MTU-235. For the purpose of this report, total HEU acquisitions consist of the following:

- Production from uranium enrichment processes
- Production from blending LEU to HEU
- Receipts from foreign countries

U.S. production from uranium enrichment processes accounts for approximately 99 percent of all acquisitions with a total of **1,045.4** MTU. Approximately **3.1** MTU was produced from blending, and **6.9** MTU was received from foreign countries.

U.S. HEU PRODUCTION

From 1945 through 1996, a total of **1,045.4** MTU containing **859.2** MTU-235 was produced in the United States at three facilities utilizing two different production technologies. Total U.S. HEU production is provided in **Table 5-1** with annual production presented in four distinct ranges of uranium-235 percentages (in kilograms) along with total kilograms of uranium and uranium-235.

U.S. HEU Production

Location	*MTU*
Y-12 Plant Calutrons	1.4
Oak Ridge Gaseous Diffusion Plant	491.8
Portsmouth Gaseous Diffusion Plant	552.2
Total	1,045.4

Figure 5-1 shows that the majority of HEU was produced from 1956 through 1964. During these years, the Oak Ridge and Portsmouth Gaseous Diffusion Plants produced HEU concurrently. This period accounts for approximately 70 percent of the total amount of HEU produced by the U.S. Site details are discussed later in this section.

Shown in **Figure 5-2** are the quantities of HEU produced by assay range.

- Approximately 19 percent of the total HEU produced was enriched in the assay range greater than or equal to 96 percent. All of this HEU was produced at the Portsmouth Gaseous Diffusion Plant. The average assay of this material is approximately 97 percent.
- The largest quantity of HEU produced was in the assay range from 90 percent to less than 96 percent enriched. This material accounted for approximately 58 percent of the total quantity of HEU produced and was used in nuclear weapons, Savannah River Site production reactors, military reactors, research reactors, and space propulsion reactors. The average assay of this HEU is approximately 93 percent.

- HEU enriched in the assay range from 20 to less than 90 percent accounts for the remaining quantity of HEU produced.

Openness Press Conference

At the June 27, 1994, Openness Press Conference, the DOE released 994 metric tons as an estimate of HEU produced in the U.S. between 1945 and 1992 (DOE 1994a). This report updates the June 1994 production estimate from 994 to 1,045 metric tons HEU. Several factors account for the 51 metric ton increase in production. First, the 994 quantity relied on readily available existing reports that proved to be incomplete. In support of the June 1994 Openness Press Conference, there was insufficient time to research historical production reports, reconcile data to site accountability records, or to review plant operating records. In addition, the June 1994 production quantity did not recognize or adjust for changes in definitions, terminology, and reporting that have occurred over the last 50 years. Furthermore, the June 1994 quantity did not include:

- HEU produced in the Y-12 Plant calutrons,
- HEU produced below 90 percent uranium-235 at the Oak Ridge Gaseous Diffusion Plant from 1945 to 1954, and
- HEU produced at the Portsmouth Gaseous Diffusion Plant after July 1991.

Most importantly, the June 1994 release did not include a material balance, and, therefore, these early oversights were not discovered until the preparation of the current material balance contained in this report.

Table 5-1 Total U.S. HEU Production

Year	Percent U-235[a]								Totals[a]	
	20 to <70%		70 to <90%		90 to <96%		≥96%			
	U	U-235	U	U-235	U	U-235	U	U-235	U	U-235
1945[b]	1,529	391	--	--	--	--	--	--	1,529	391
1946[b]	3,127	905	73	61	603	571	--	--	3,804	1,538
1947	118	36	--	--	1,746	1,637	--	--	1,864	1,673
1948	--	--	--	--	1,391	1,296	--	--	1,391	1,296
1949	25	14	87	65	1,582	1,473	--	--	1,694	1,552
1950	370	158	10	9	1,687	1,570	--	--	2,068	1,737
1951	--	--	--	--	1,091	1,016	--	--	1,091	1,016
1952	110	35	12	10	4,163	3,877	--	--	4,284	3,923
1953	--	--	1	1	7,261	6,765	--	--	7,262	6,766
1954	1,379	518	--	--	14,302	13,333	--	--	15,681	13,851
1955	16,812	6,600	--	--	17,364	16,209	--	--	34,176	22,809
1956	26,362	9,983	2,991	2,380	30,707	28,641	--	--	60,060	41,004
1957	21,520	8,073	72	64	43,357	40,454	--	--	64,950	48,591
1958	15,663	5,874	-13	-12	61,715	57,612	--	--	77,364	63,475
1959	37,142	13,353	68	59	64,686	60,632	--	--	101,896	74,045
1960	23,364	8,354	150	134	72,312	68,068	--	--	95,826	76,557
1961	9,454	3,455	132	117	79,015	73,702	--	--	88,601	77,274
1962	16,451	6,267	450	404	74,589	69,533	521	508	92,012	76,712
1963	19,738	8,423	7,538	5,328	58,261	54,357	--	--	85,537	68,109
1964	10,125	5,262	10,246	7,289	32,228	30,046	11,967	11,652	64,566	54,248
1965	1,828	643	233	209	12,808	11,930	6,484	6,333	21,353	19,115
1966	753	224	165	148	6,382	5,945	4,578	4,471	11,879	10,788
1967	2,375	752	260	234	2,314	2,156	5,710	5,576	10,660	8,718
1968	2,302	1,187	200	180	2,340	2,180	3,455	3,374	8,297	6,921
1969	2,613	1,302	600	533	5,697	5,306	8,270	8,076	17,181	15,217
1970	1,250	519	100	78	264	240	5,167	5,046	6,782	5,884
1971	1,041	248	109	98	94	85	4,108	4,009	5,352	4,440
1972	83	24	142	127	1,932	1,796	7,788	7,605	9,945	9,552
1973	44	10	18	16	2,239	2,081	8,562	8,361	10,862	10,467
1974	404	128	--	--	626	583	7,818	7,634	8,848	8,345
1975	46	14	1	1	1,260	1,174	7,323	7,152	8,631	8,341
1976	1,049	472	102	74	218	203	12,885	12,582	14,254	13,331
1977	39	11	--	--	555	517	11,850	11,565	12,443	12,092
1978	4	2	84	70	1	1	9,541	9,284	9,631	9,356
1979	825	496	54	38	227	211	4,777	4,648	5,883	5,392
1980	28	9	2	1	275	256	2,317	2,254	2,621	2,521
1981	66	27	7	6	28	26	4,983	4,849	5,084	4,908
1982	55	22	11	9	681	635	12,297	11,965	13,044	12,630
1983	104	41	31	24	2	1	8,958	8,716	9,095	8,783
1984	113	38	-3	-1	-16	-15	5,837	5,680	5,931	5,702
1985	166	55	-15	-10	34	32	5,902	5,744	6,088	5,821
1986	40	6	29	21	331	307	3,778	3,675	4,177	4,010
1987	143	58	28	21	5	4	5,056	4,912	5,231	4,995
1988	55	21	21	17	7	7	7,395	7,191	7,478	7,237
1989	32	13	15	13	8	7	9,071	8,817	9,125	8,849
1990	182	83	8	7	63	59	5,929	5,740	6,183	5,888
1991	-26	-18	40	31	499	476	1,581	1,527	2,093	2,017
1992	1	--	101	88	1,105	1,032	177	170	1,384	1,290
1993[c]	30	16	-1	-1	--	--	-2	-3	27	12
1994[c]	15	3	--	--	1	1	--	--	16	5
1995[c]	60	24	6	5	--	--	1	1	67	29
1996[c]	77	13	3	2	4	3	1	1	85	19
Total	**219,087**	**84,144**	**24,171**	**17,949**	**608,044**	**568,031**	**194,085**	**189,115**	**1,045,387**	**859,242**

Note: Totals may not add due to rounding.

a Quantities are in kilograms.

b Calutron production for 1945 is combined with production for 1946 and included only in the data for 1946.

c HEU production was suspended in 1992. Quantities reported for 1993 through 1996 reflect the removal of residual holdup.

Figure 5-1 U.S. HEU Production by Year

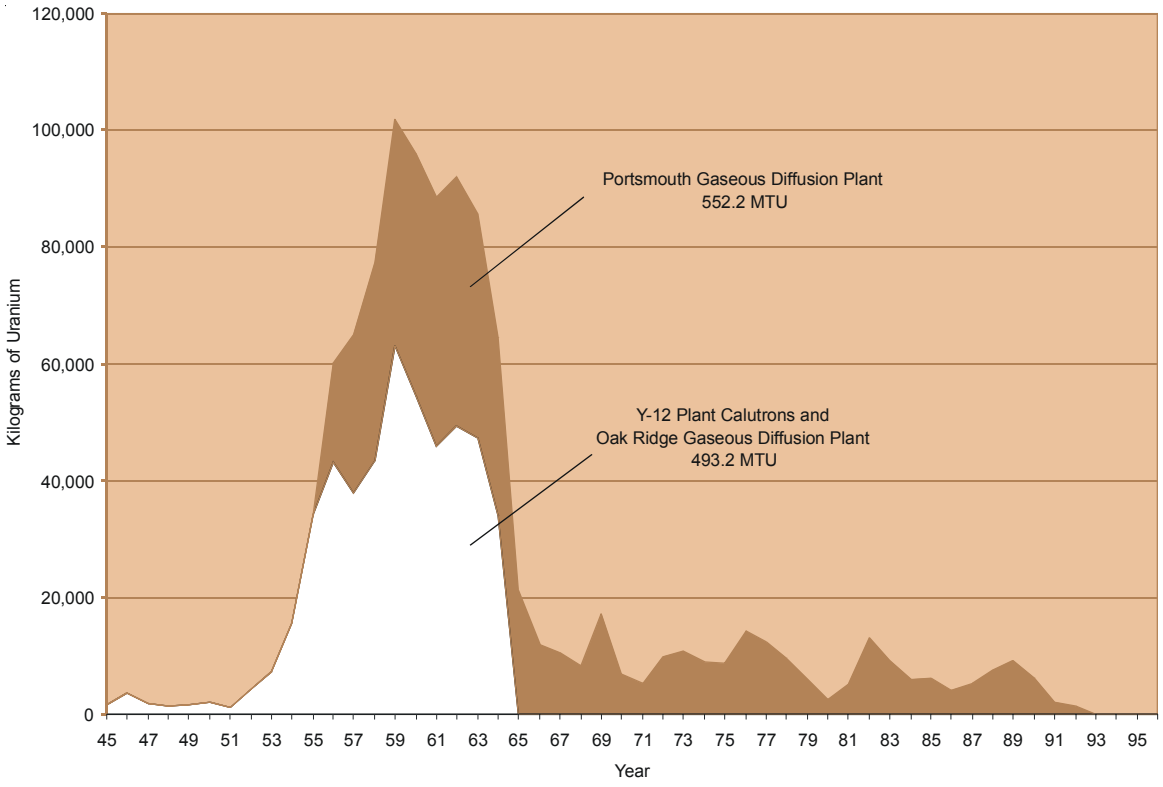
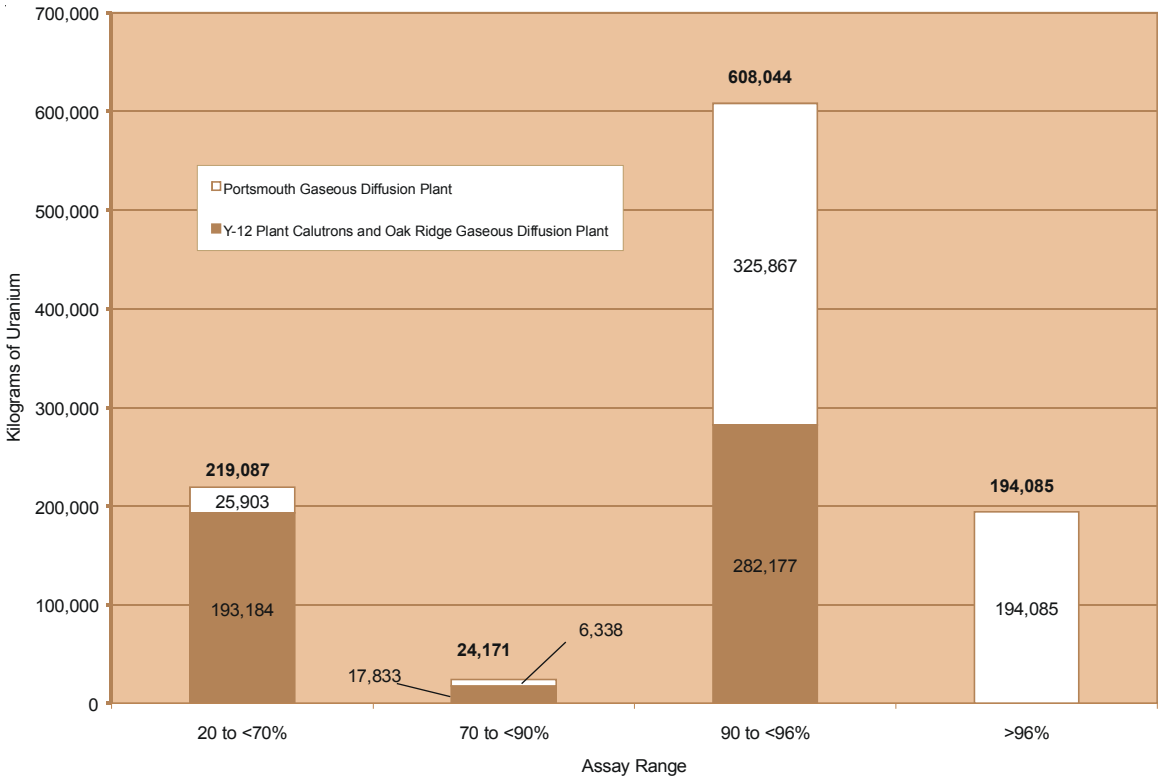


Figure 5-2 U.S. HEU Production by Assay



Y-12 Plant Calutrons

The Y-12 Plant calutrons produced **1.4** MTU containing **1.2** MTU-235 from 1945 through 1947 using the electromagnetic separation process. HEU production from the Y-12 Plant calutrons is provided in **Table 5-2** and is presented in four distinct ranges of uranium-235 percentages (in kilograms) along with total kilograms of uranium and uranium-235.

HEU Production at the Y-12 Plant Calutrons

- ✓ Located in Oak Ridge, Tennessee, the Y-12 Plant calutrons produced the **first quantities of HEU in the U.S**.
- ✓ Using the electromagnetic separation process, a total of **1.4** MTU containing **1.2** MTU-235 was produced from 1945 through 1947.

General Site History

Site selection for the production of HEU was accomplished in the fall of 1942 when the U.S. Army Corps of Engineers' Manhattan Engineer District, under the direction of General Leslie R. Groves, purchased 54,000 acres of land near the towns of Knoxville and Clinton, Tennessee. A portion of the site became the Oak Ridge Reservation with a primary mission to produce uranium-235 on a scale sufficient to support production of atomic weapons. Proposed technologies for accomplishing this objective included: gaseous diffusion; thermal diffusion; centrifuge separation; and electromagnetic separation. Additionally, the process had to be implemented quickly enough to enable the United States to produce an atomic weapon ahead of Germany. The site chosen for the electromagnetic separation process, called the Y-12 site, was about 825 acres. Groundbreaking for the construction of the huge electromagnetic complex took place on February 18, 1943.

The electromagnetic separation process was, like many World War II projects, based on a simple concept. The process used a device called a calutron. Calutrons use magnetic fields to separate a stream of ions (atoms carrying electrical charges). The different masses of the isotopes give each a different radius of curvature in a magnetic field, causing the stream to divide into separate streams. Ninety-six calutrons were to be grouped into racetracks, named for their oval shape. The major items required for efficient calutron operation were well-designed magnets and associated power supplies, high-voltage triodes for close current control, a special high-voltage, high-current x-ray cable, and large vacuum systems. Also needed were huge quantities of copper (or other electrical conductors) to be fabricated into large coils that would produce the magnetic fields in the calutrons. As a result of a wartime shortage of copper, the Army borrowed almost 14,600 tons of pure silver from the U.S. Treasury as a substitute for copper.

In August 1943, the first racetrack began to operate successfully but soon failed as a result of a leaky vacuum, shorted coils, and warped tanks from the powerful magnet. By April 1944, four alpha racetracks were functioning, including the repaired first racetrack.

During 1944, the alpha calutrons continued to be improved while a second generation of calutrons, called beta, was being built. The beta calutrons further enriched the uranium produced in the alpha calutrons and accepted enriched uranium feed from the gaseous diffusion and thermal diffusion separation processes. Since the beta calutrons used only enriched uranium as feed, they processed proportionally less material. As a result, beta calutron beams did not have to be as broad or as large as those in alpha calutrons.

The first beta units were tested at Oak Ridge in late February 1944 but were soon redesigned to overcome technical problems in recovering the precious enriched uranium scattered throughout the calutron. Ultimately, nine alpha tracks and six beta tracks operated at Oak Ridge. Some of the uranium-235 produced in the beta calutrons was sent by train to the Los Alamos National Laboratory, where the material was fabricated as part of the "Little Boy" atomic weapon and detonated in World War II.

Table 5-2 HEU Production at the Y-12 Plant Calutrons

Year	Percent U-235[a]								Totals[a]	
	20 to <70%		70 to <90%		90 to <96%		≥96%			
	U	U-235	U	U-235	U	U-235	U	U-235	U	U-235
1946	238	63	73	61	603	571	--	--	915	695
1947	--	--	--	--	482	456	--	--	482	456
Total	**238**	**63**	**73**	**61**	**1,085**	**1,027**	**--**	**--**	**1,396**	**1,151**

Note: Totals may not add due to rounding.

[a] Quantities are in kilograms.

[b] Includes HEU produced in 1945 and 1946.

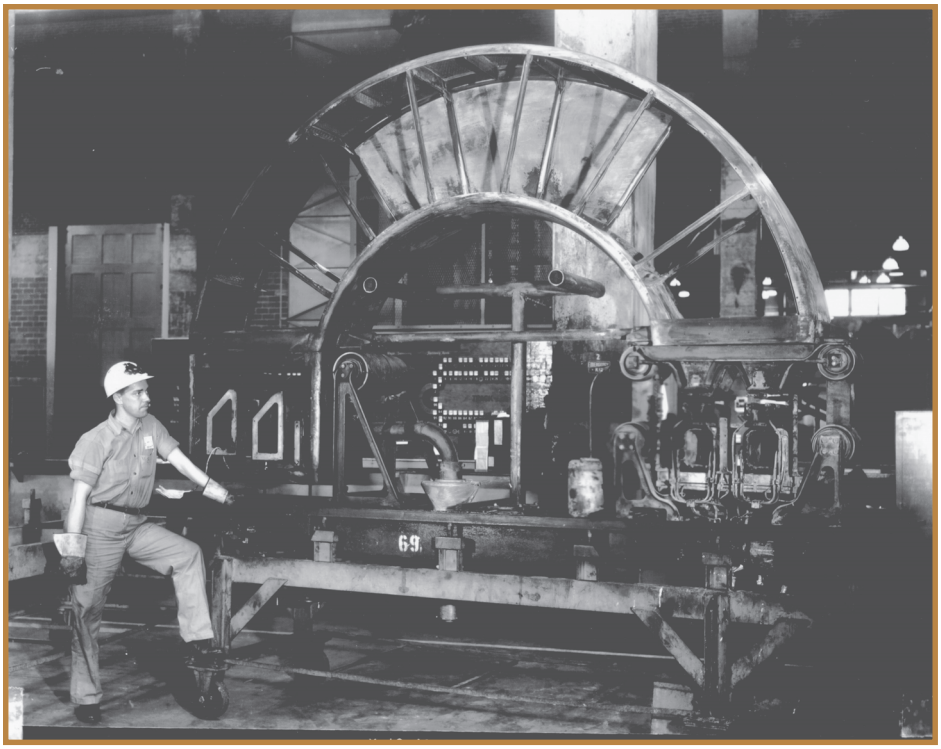
The major advantages of the calutron process were a very low loss of uranium-235 and the ability to reach very high enrichments in a simple, highly efficient step. The major constraint on electromagnetic separation efficiency was the recycling, handling, and chemical separation of enriched uranium deposited on the walls of the calutrons themselves and just about everything else in the process buildings. Because of these factors, calutrons used an inordinate amount of manpower.

The Y-12 Plant calutrons remained the mainstay of the U.S. uranium enrichment effort through 1947, when the HEU production capability was terminated in favor of the more cost-effective gaseous diffusion process.

Current Status

As of the date of this report, only one racetrack of calutrons is preserved at Oak Ridge. It is maintained and operated for the production and sale of stable isotopes that are important to industry, medicine, and scientific research.

Using the electromagnetic separation process, the "alpha" calutrons at the Y-12 Plant produced enriched uranium that was fed to the "beta" calutrons for further enrichment. Pictured is the Y-12 Plant Alpha 1 racetrack.



A total of nine "alpha" and six "beta" racetracks produced enriched uranium at the Y-12 Plant from 1943 through 1947. Pictured is the Alpha Type 1 "D" Unit removed for maintenance.

Oak Ridge Gaseous Diffusion Plant

From 1945 through 1964, the Oak Ridge Gaseous Diffusion Plant produced **491.8** MTU containing **348.9** MTU-235. HEU production from the Oak Ridge Gaseous Diffusion Plant is provided in **Table 5-3** and is presented in four distinct ranges of uranium-235 percentages (in kilograms) along with total kilograms of uranium and uranium-235.

HEU Production at the Oak Ridge Gaseous Diffusion Plant

- ✓ Located in Oak Ridge, Tennessee, the Oak Ridge Gaseous Diffusion Plant **was the first gaseous diffusion plant to produce HEU**.
- ✓ A total of **491.8** MTU containing **348.9** MTU-235 was produced from 1945 through 1964.
- ✓ The Oak Ridge Gaseous Diffusion Plant continued to produce LEU until 1985 when it was placed in standby status.

General Site History

The Oak Ridge Gaseous Diffusion Plant was the first gaseous diffusion plant to perform large-scale enrichment of uranium-235. It was selected in September 1942 because of its comparatively isolated location and the availability of electrical power (from the Tennessee Valley Authority) and water. Construction started in 1943 with the first process building designated as K-25. The first shipment of enriched uranium from K-25 was made in 1945, and a subsequent process building addition, K-27, was placed in full operation in February 1946.

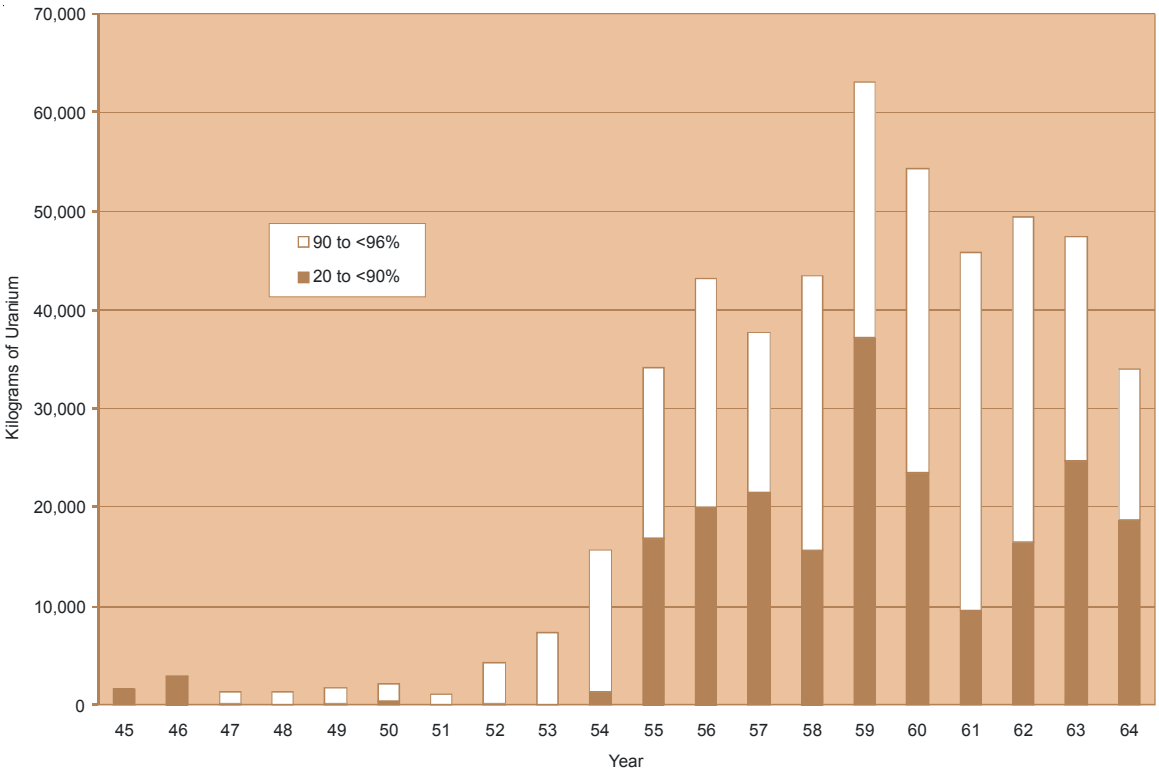
Increasing production demands and concerns over the possibility of sabotage prompted AEC to approve an additional building for Oak Ridge, K-29, in March 1949. With the outbreak of the Korean War in June 1950, less than a year after the first Russian nuclear detonation, additional production capacity was required. As a result, buildings K-31 and K-33 were approved for construction. Once constructed, this five-building complex was commonly referred to as the Oak Ridge Gaseous Diffusion Plant (ORGDP).

By the mid-1950s, all five of the process buildings were interconnected to form one long continuous cascade of approximately 5,000 stages capable of furnishing a "top product" of 93.15 percent uranium-235. The K-25 building operated at the top of the plant cascade and received uranium hexafluoride at approximately 20 percent enriched from the K-27 building. This material was further enriched to above 90 percent at K-25. By 1964, defense needs for HEU had been satisfied, and the first two buildings, K-25 and K-27, were shut down and placed in standby. The remaining buildings continued to produce LEU with a maximum enrichment of about 5 percent uranium-235, adequate for civilian nuclear power plants. These LEU operations continued until 1985, when the remaining process buildings were placed on standby. In December 1987, buildings K-29, K-31, and K-33 and the associated enrichment operations buildings were officially shut down.

Current Status

The Oak Ridge Gaseous Diffusion Plant is today known as the East Tennessee Technology Park (previously K-25 Site). The mission of the plant includes environmental restoration, waste management, technology development and demonstration, education and training, and technology transfer for the DOE, other agencies, and the public.

Table 5-3 HEU Production at the Oak Ridge Gaseous Diffusion Plant

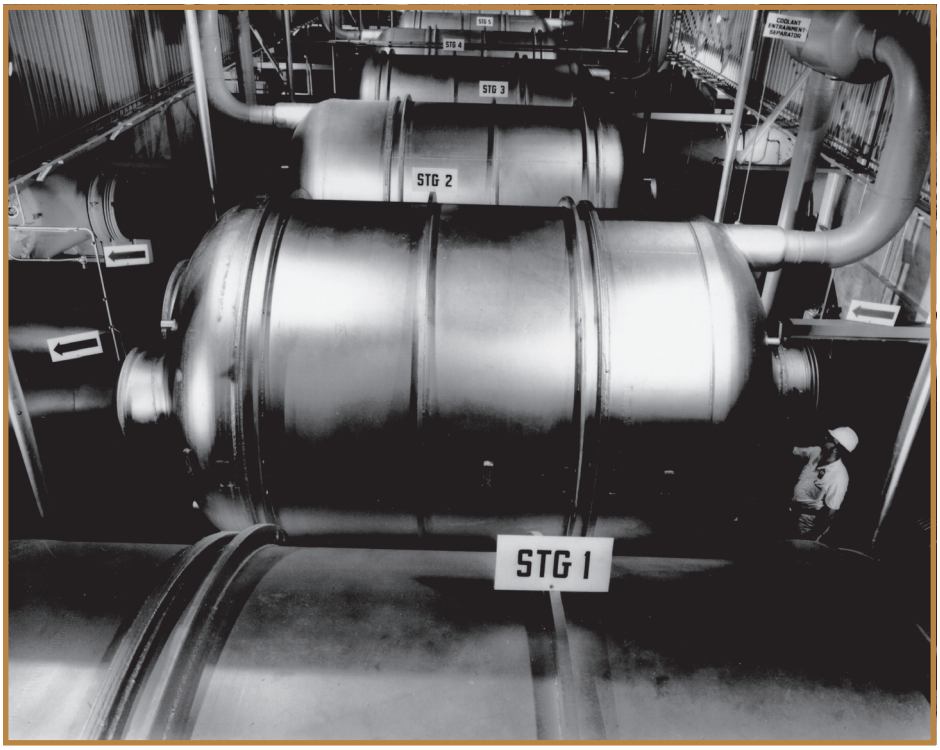


Year	Percent U-235 [a]								Totals [a]	
	20 to <70%		70 to <90%		90 to <96%		≥96%			
	U	U-235	U	U-235	U	U-235	U	U-235	U	U-235
1945	1,529	391	--	--	--	--	--	--	1,529	391
1946	2,889	842	--	--	--	--	--	--	2,889	842
1947	118	36	--	--	1,264	1,181	--	--	1,383	1,218
1948	--	--	--	--	1,391	1,296	--	--	1,391	1,296
1949	25	14	87	65	1,582	1,473	--	--	1,694	1,552
1950	370	158	10	9	1,687	1,570	--	--	2,068	1,737
1951	--	--	--	--	1,091	1,016	--	--	1,091	1,016
1952	110	35	12	10	4,163	3,877	--	--	4,284	3,923
1953	--	--	1	1	7,261	6,765	--	--	7,262	6,766
1954	1,379	518	--	--	14,302	13,333	--	--	15,681	13,851
1955	16,812	6,600	--	--	17,364	16,209	--	--	34,176	22,809
1956	20,001	7,493	6	6	23,124	21,565	--	--	43,131	29,064
1957	21,520	8,073	15	13	16,231	15,144	--	--	37,767	23,231
1958	15,663	5,874	10	8	27,712	25,867	--	--	43,384	31,750
1959	37,142	13,353	68	59	25,860	24,236	--	--	63,070	37,649
1960	23,353	8,352	136	122	30,833	29,007	--	--	54,322	37,482
1961	9,396	3,436	111	100	36,358	33,912	--	--	45,865	37,447
1962	16,008	6,005	450	404	32,976	30,740	--	--	49,434	37,149
1963	17,211	7,656	7,527	5,318	22,616	21,095	--	--	47,354	34,070
1964	9,419	4,790	9,325	6,643	15,277	14,240	--	--	34,021	25,673
Total	**192,946**	**73,628**	**17,760**	**12,758**	**281,092**	**262,528**	--	--	**491,797**	**348,915**

Note: Totals may not add due to rounding.

[a] Quantities are in kilograms.

The Oak Ridge Gaseous Diffusion Plant was the first gaseous diffusion plant to produce HEU. Ultimately, there were five process buildings at the plant that were interconnected to form one long, continuous cascade.



To enrich uranium using the gaseous diffusion process, uranium hexafluoride gas must be cycled and recycled through various stages of equipment, such as the arrangement at the Oak Ridge Gaseous Diffusion Plant (ORGDP). By the mid-1950s, the ORGDP had approximately 5,000 stages capable of furnishing a top product of 93 percent uranium-235.

Paducah Gaseous Diffusion Plant

The Paducah Gaseous Diffusion Plant produced LEU for weapons production beginning in the early 1950s. No HEU was produced at Paducah; however, the plant was constructed to operate in conjunction with the Oak Ridge Gaseous Diffusion Plant.

General Site History

The Paducah Gaseous Diffusion Plant, located on a 750-acre site near Paducah, Kentucky, was the second gaseous diffusion plant to be constructed. Prior to the outbreak of the Korean War, the entire U.S. gaseous diffusion capacity was concentrated at Oak Ridge. Additional gaseous diffusion complexes were located at sites other than Oak Ridge to increase production and enhance security through dispersion.

Paducah Gaseous Diffusion Plant

- ✓ Located near Paducah, Kentucky, it was the **second gaseous diffusion plant built**.
- ✓ **No HEU was produced** at the Paducah Gaseous Diffusion Plant. Only LEU was produced.
- ✓ Paducah currently produces LEU for the commercial nuclear power industry.

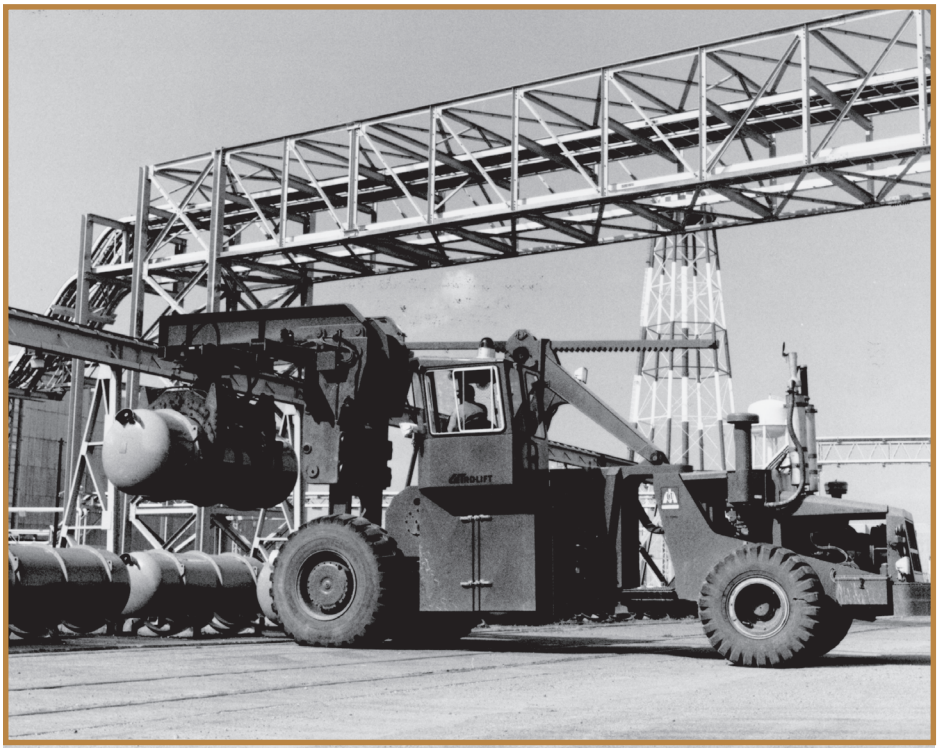
Construction of the Paducah Gaseous Diffusion Plant began in 1951, and production of LEU began in 1952 before construction was completed. The plant was constructed in two steps. The first step consisted of two process buildings, C-331 and C-333, with a total of 880 stages and ground coverage of about 36 acres. The second step consisted of another two process buildings, C-335 and C-337, duplicating the first two buildings.

Paducah produced an intermediate enriched product that was fed to the Oak Ridge and Portsmouth Gaseous Diffusion Plants for further enrichment. The nominal product enrichment of Paducah is limited to 2 percent uranium-235.

Current Status

In October 1992, the Energy Policy Act of 1992 was passed creating the United States Enrichment Corporation (USEC). This corporation, which officially began operations on July 1, 1993, is responsible for all uranium enrichment activities in the United States. As part of these activities, Paducah enriches uranium for commercial customers, primarily nuclear power utilities.

The Paducah Gaseous Diffusion Plant began producing LEU in 1952. Even though HEU was never produced at Paducah, the LEU product was shipped as feed material to the Oak Ridge and Portsmouth Gaseous Diffusion Plants.



Pictured is a uranium hexafluoride cylinder handler at the Paducah Gaseous Diffusion Plant. This piece of equipment is used to handle 4-foot diameter, 10- and 14-ton uranium hexafluoride cylinders.

PORTSMOUTH GASEOUS DIFFUSION PLANT

The Portsmouth Gaseous Diffusion Plant produced **552.2** MTU containing **509.2** MTU-235 from 1956 through 1992, when HEU production was terminated. HEU production from the Portsmouth Gaseous Diffusion Plant is provided in **Figure 5-3** and **Table 5-4**. Data in Table 5-4 is presented in four distinct ranges of uranium-235 percentages (in kilograms) along with total kilograms of uranium and uranium-235.

HEU Production at the Portsmouth Gaseous Diffusion Plant

- ✓ Located near Portsmouth, Ohio, the Portsmouth Gaseous Diffusion Plant **was the largest producer of HEU.**
- ✓ A total of **552.2** MTU containing **509.2** MTU-235 was produced from 1956 through 1992.
- ✓ Portsmouth currently produces LEU for the commercial nuclear power industry.

GENERAL SITE HISTORY

The Portsmouth Gaseous Diffusion Plant was the last gaseous diffusion plant constructed. Construction of the plant began in 1952, and the first process building, designated as X-330, started production in September 1954. The last two process buildings, designated as X-333 and X-326, were placed in full operation in November 1955 and February 1956, respectively. By the mid-1950s, all three process buildings were interconnected to form one long continuous cascade of approximately 4,000 stages capable of furnishing a "top product" of 97.65 percent uranium-235. Because of the length of the cascade, a large amount of uranium is contained within the process piping and equipment of the various stages. While a small portion of this uranium is HEU, it is not counted as part of HEU production or as part of the U.S. HEU inventory until it has been withdrawn from the cascades. This amount can vary depending on how the cascades are being operated and the desired product. For example, in September 1990, the "uranium in cascades" was approximately 328.0 MTU containing 4.4 MTU-235.

Until the mid-1960s, the plant produced HEU for nuclear weapons, the Naval Nuclear Propulsion Program, and other defense needs. With defense needs satisfied, the U.S. ceased the production of HEU for weapons in 1964. After 1964, the U.S. continued to make HEU at Portsmouth for naval, space and research reactors. As commercial nuclear power reactor programs expanded in the 1970s and defense requirements dropped, an increasing portion of the plant's production was a low assay product in the range of 2 to 5 percent uranium-235.

In November 1991, the DOE announced that production of HEU at Portsmouth would be suspended. The decision was later modified to indicate that production of HEU would be permanently shut down. The process equipment in the X-326 building was modified to produce LEU. At the same time, a comprehensive program was initiated to perform chemical treatments on cells in X-326 to remove residual HEU holdup in process equipment. All of the gas phase HEU

in the cascade was removed by February 1993. Top enrichment is now approximately 5 to 6 percent uranium-235. As the solid HEU holdup is recovered, it is refed to the operating cascade where it is blended with LEU to yield the desired LEU product.

Current Status

In October 1992, the Energy Policy Act of 1992 was passed creating USEC. In accordance with this Act, the diffusion cascade and support facilities at the plant have been leased to USEC. This corporation, which officially began operations on July 1, 1993, is responsible for all uranium enrichment activities in the U.S. As part of these activities, Portsmouth enriches uranium for commercial customers, primarily nuclear power utilities.

Figure 5-3 HEU Production at the Portsmouth Gaseous Diffusion Plant

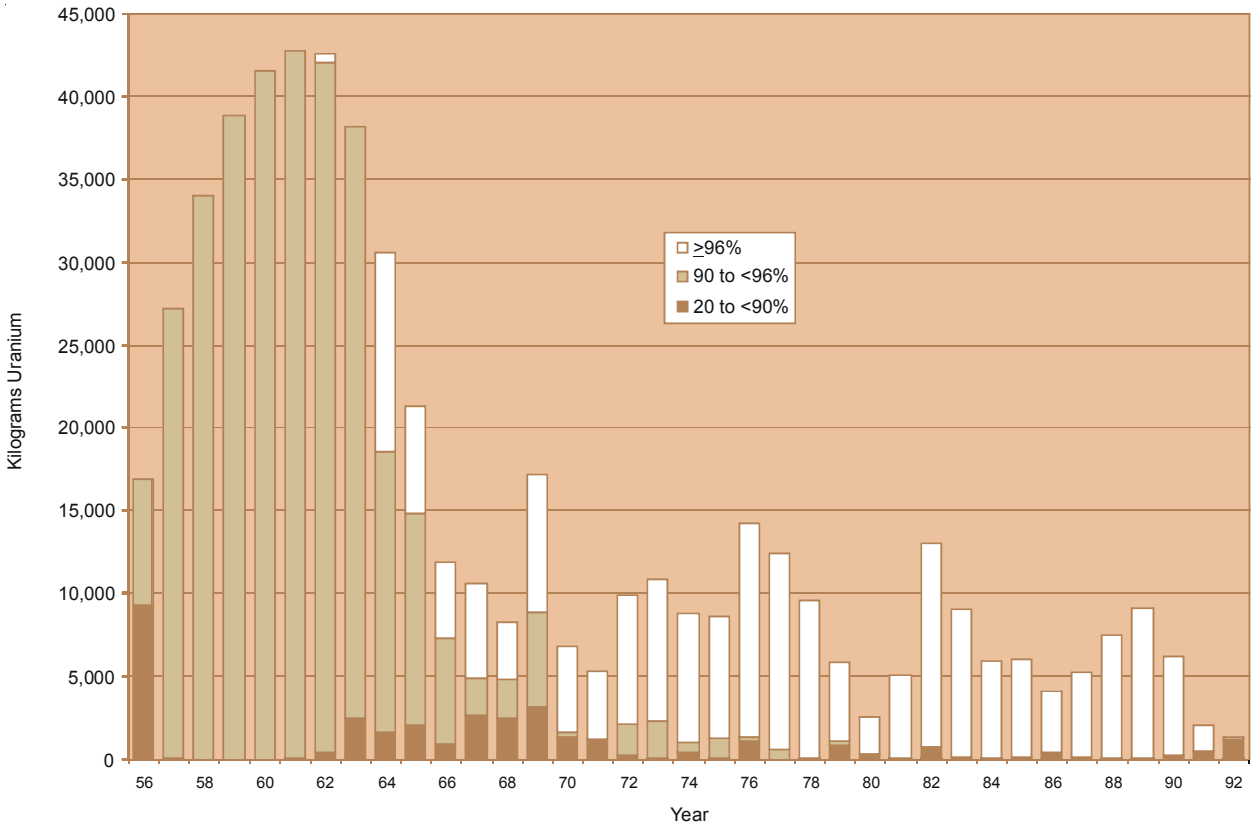


Table 5-4 HEU Production at the Portsmouth Gaseous Diffusion Plant

Year	Percent U-235[a]								Totals[a]	
	20 to <70%		70 to <90%		90 to <96%		≥96%			
	U	U-235	U	U-235	U	U-235	U	U-235	U	U-235
1956	6,361	2,490	2,985	2,374	7,583	7,076	–	–	16,929	11,940
1957	–	–	57	51	27,126	25,310	–	–	27,183	25,360
1958	–	–	-23	-20	34,003	31,745	–	–	33,980	31,725
1959	–	–	–	–	38,826	36,396	–	–	38,826	36,396
1960	11	2	14	12	41,479	39,061	–	–	41,504	39,075
1961	58	19	21	17	42,657	39,790	–	–	42,736	39,827
1962	443	262	–	–	41,613	38,793	521	508	42,578	39,563
1963	2,527	767	11	10	35,645	33,262	–	–	38,183	34,039
1964	706	472	921	646	16,951	15,806	11,967	11,652	30,545	28,575
1965	1,828	643	233	209	12,808	11,930	6,484	6,333	21,353	19,115
1966	753	224	165	148	6,382	5,945	4,578	4,471	11,879	10,788
1967	2,375	752	260	234	2,314	2,156	5,710	5,576	10,660	8,718
1968	2,302	1,187	200	180	2,340	2,180	3,455	3,374	8,297	6,921
1969	2,613	1,302	600	533	5,697	5,306	8,270	8,076	17,181	15,217
1970	1,250	519	100	78	264	240	5,167	5,046	6,782	5,884
1971	1,041	248	109	98	94	85	4,108	4,009	5,352	4,440
1972	83	24	142	127	1,932	1,796	7,788	7,605	9,945	9,552
1973	44	10	18	16	2,239	2,081	8,562	8,361	10,862	10,467
1974	404	128	–	–	626	583	7,818	7,634	8,848	8,345
1975	46	14	1	1	1,260	1,174	7,323	7,152	8,631	8,341
1976	1,049	472	102	74	218	203	12,885	12,582	14,254	13,331
1977	39	11	–	–	555	517	11,850	11,565	12,443	12,092
1978	4	2	84	70	1	1	9,541	9,284	9,631	9,356
1979	825	496	54	38	227	211	4,777	4,648	5,883	5,392
1980	28	9	2	1	275	256	2,317	2,254	2,621	2,521
1981	66	27	7	6	28	26	4,983	4,849	5,084	4,908
1982	55	22	11	9	681	635	12,297	11,965	13,044	12,630
1983	104	41	31	24	2	1	8,958	8,716	9,095	8,783
1984	113	38	-3	-1	-16	-15	5,837	5,680	5,931	5,702
1985	166	55	-15	-10	34	32	5,902	5,744	6,088	5,821
1986	40	6	29	21	331	307	3,778	3,675	4,177	4,010
1987	143	58	28	21	5	4	5,056	4,912	5,231	4,995
1988	55	21	21	17	7	7	7,395	7,191	7,478	7,237
1989	32	13	15	13	8	7	9,071	8,817	9,125	8,849
1990	182	83	8	7	63	59	5,929	5,740	6,183	5,888
1991	-26	-18	40	31	499	476	1,581	1,527	2,093	2,017
1992[b]	1	–	101	88	1,105	1,032	177	170	1,384	1,290
1993[b]	30	16	-1	-1	–	–	-2	-3	27	12
1994[b]	15	3	–	–	1	1	–	–	16	5
1995[b]	60	24	6	5	–	–	1	1	67	29
1996[b]	77	13	3	2	4	3	1	1	85	19
Total	**25,903**	**10,454**	**6,338**	**5,129**	**325,867**	**304,478**	**194,085**	**189,115**	**552,193**	**509,176**

[a] Quantities are in kilograms.

[b] HEU production was suspended in 1992. Quantities reported for 1993 through 1996 are not a result of HEU production. These quantities reflect the removal of holdup during cleanup of the cascades.

The Portsmouth Gaseous Diffusion Plant was the largest producer of HEU. By the mid-1950s, all three of the process buildings at Portsmouth were interconnected to form one long continuous cascade of approximately 4,000 stages capable of furnishing a "top product" of 97.65 percent uranium-235.

Pictured is a storage yard of cylinders at the Portsmouth Gaseous Diffusion Plant. The cylinders contain cascade tails material with a uranium-235 content between 0.3 and 0.55 percent.

Production from Blending

Through September 30, 1996, a total quantity of **3.1** MTU containing **0.3** MTU-235 was produced from blending LEU to HEU. Production from blending occurred primarily at the Oak Ridge Y-12 Plant, the Oak Ridge Gaseous Diffusion Plant, and the Portsmouth Gaseous Diffusion Plant. It is important to note that these values may be somewhat understated since data for fiscal year 1977 and all fiscal years prior to 1976 were not available for the Oak Ridge Y-12 Plant.

For the purpose of this report, HEU production from blending occurs when HEU is mixed with either depleted, natural, or LEU to form a new product. The resulting product will be the average of all of the materials mixed. If the resulting mixture has an isotopic concentration of 20 percent or greater uranium-235, the quantity of the depleted, natural, or LEU used in the blending operation is added to the HEU inventory as production. However, if the new mixture has an isotopic concentration of less than 20 percent uranium-235, the HEU used in the blending operation is removed from the HEU inventory as down blending. Quantities removed from the inventory as a result of down blending are provided in Section 6.

Production from Blending

- ✓ **Total Production** – **3.1** MTU (3,058 kilograms) containing **0.3** MTU-235 (261 kilograms). This is the amount of LEU blended to HEU.
- ✓ **Primary Blending Sites** – Oak Ridge Y-12 Plant, Oak Ridge Gaseous Diffusion Plant, and Portsmouth Gaseous Diffusion Plant.

- ✓ **Example:** If 1 kilogram of LEU at a 10 percent enrichment is mixed with 1 kilogram of HEU at a 90 percent enrichment, the resultant mixture will contain 2 kilograms of HEU at an enrichment of 50 percent.

Receipts from Foreign Countries

- ✓ **Total Receipts** – **6.9** MTU containing **4.9** MTU-235.

- ✓ **Return of U.S.-Origin HEU** – Approximately **6.3** MTU containing **4.3** MTU-235 was received in accordance with Agreements for Cooperation for the Peaceful Uses of Atomic Energy.
- ✓ **Kazakhstan: Project Sapphire –** A total of **0.65** MTU containing **0.58** MTU-235 was obtained from the former Soviet Union.

HEU Receipts from Foreign Countries

From 1958 through 1996, the U.S. received **6.9** MTU containing **4.9** MTU-235 from foreign countries. **Figure 5-4** provides the annual quantities of HEU received by the U.S. from foreign countries through September 30, 1996. **Tables 5-5** and **5-6** provide the location and quantities of HEU returned to the U.S. from Euratom and non-Euratom countries.

RETURN OF U.S.-ORIGIN HEU

A total of **6.3** MTU containing **4.3** MTU-235 was received from foreign countries in accordance with Agreements for Cooperation for the Peaceful Uses of Atomic Energy, primarily Euratom countries, Canada, Japan, and South Africa. Most of this material was of U.S.-origin in the form of spent nuclear fuel.

The acceptance of spent nuclear fuel from foreign countries was originally authorized by the Atomic Energy Act of 1954, as amended, and the NNPA. The Atoms for Peace Program provided the framework for these activities. Under this program, nuclear fuel was sold or leased for use in foreign power, research, and experimental reactors. The details of these shipments are provided in Section 6, Removals.

The Atoms for Peace Program also allowed for the subsequent return of this material for reprocessing in the U.S. In July 1963, the first shipment of irradiated (spent) reactor fuel was received from abroad for reprocessing at the Idaho Chemical Processing Plant in Idaho Falls, Idaho. The fuel had been leased to Sweden in 1961 for use in the materials testing and research reactor, "R-2," near Stockholm. In 1964, the U.S. offered to accept the delivery of highly enriched spent fuel from foreign research reactors for chemical processing at the Savannah River Site. Previously, such shipments were restricted to the Idaho Chemical Processing Plant.

Reducing the threat of the proliferation of nuclear weapons is one of the foremost goals of the United States. Proper management of spent nuclear fuel from foreign research reactors is essential to achieving these goals since much of the fuel contains HEU, which could be used in simple nuclear weapons.

The concern over appropriate management of foreign research reactor spent nuclear fuel was reiterated in the Presidential Directive on Nonproliferation and Export Controls, issued by President Clinton on September 27, 1993. In particular, the Presidential Directive included steps to accelerate the return of U.S.-origin spent fuels from foreign research reactors.

Figure 5-4 HEU Received from Foreign Countries

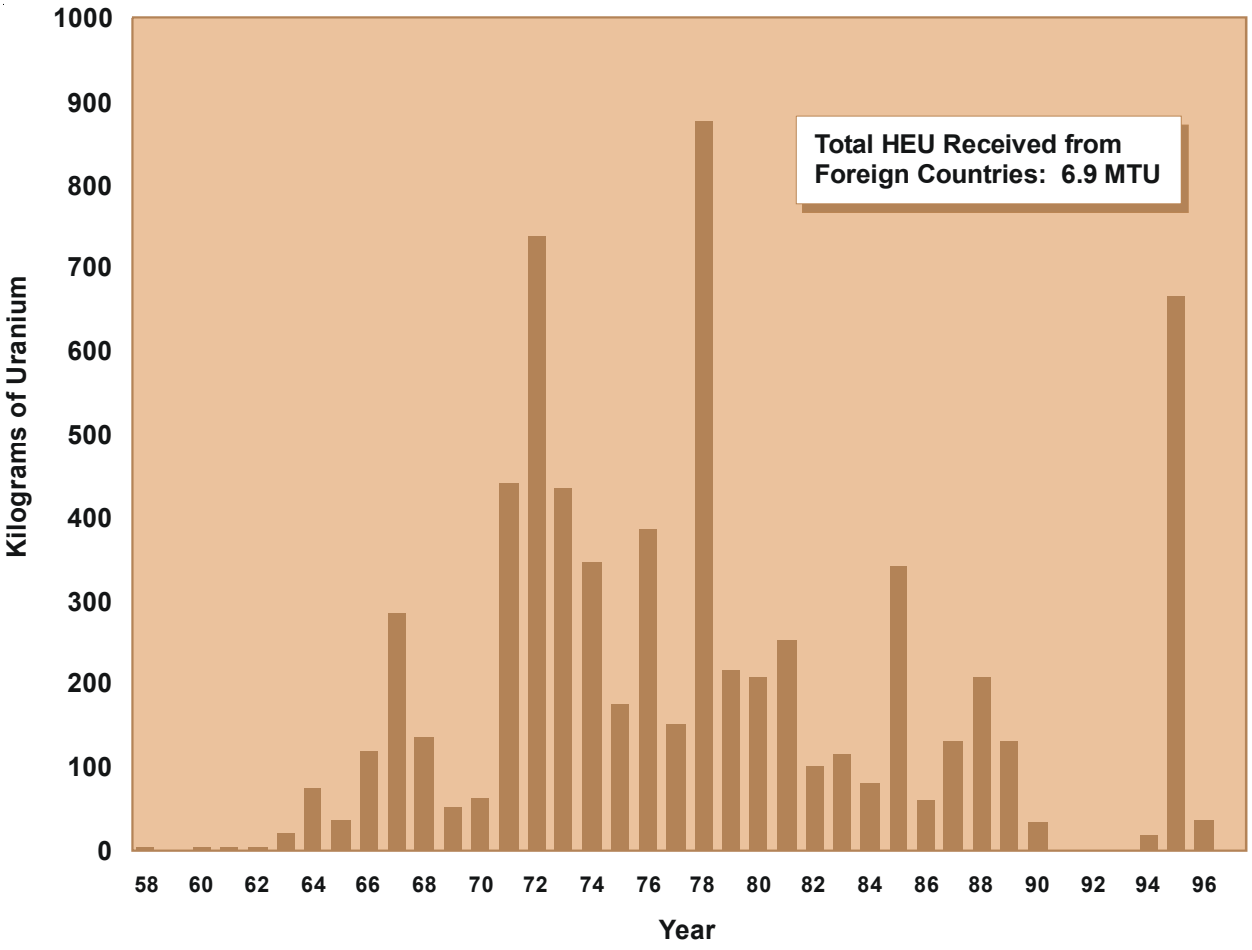
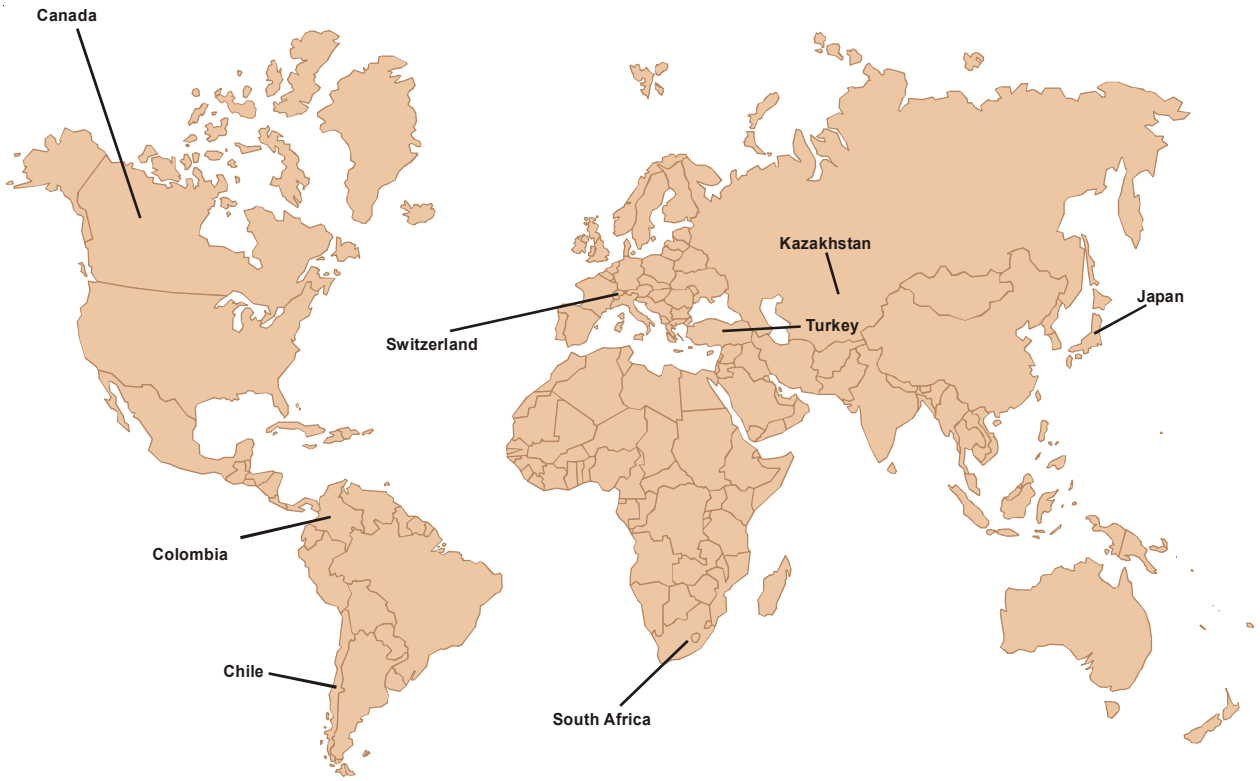


Table 5-5 HEU Received from Euratom Countries

Country	Percent U-235[a]				Totals[a]	
	20 to <90%		≥90%			
	U	U-235	U	U-235	U	U-235
Austria	11	7			11	7
Belgium	500	390	3	2	503	392
Denmark	72	51			72	51
France	2,767	2,015	35	32	2,802	2,047
Germany	940	348	75	70	1,015	418
Greece	9	8			9	8
Italy	75	61			75	61
Netherlands	223	172			223	172
Spain	7	6			7	6
Sweden	306	230			306	230
United Kingdom	150	118			150	118
Total	**5,060**	**3,406**	**113**	**105**	**5,173**	**3,512**

[a] Quantities are in kilograms.

Table 5-6 HEU Received from Non-Euratom Countries



Country	Percent U-235[a]				Totals[a]	
	20 to <90%		³ 90%			
	U	U-235	U	U-235	U	U-235
Canada	651	441	51	48	702	489
Chile	4	2			4	2
Colombia			3	3	3	3
Japan	342	299			342	299
Kazakhstan	568	506	84	76	652	581
South Africa	34	26			34	26
Switzerland	18	12			18	12
Turkey	5	4			5	4
Others	1	1			1	1
Total	**1,623**	**1,291**	**138**	**127**	**1,761**	**1,417**

[a] Quantities are in kilograms.

KAZAKHSTAN-"PROJECT SAPPHIRE"

In November 1994, in response to the President's Nonproliferation and Export Control Policy, the DOE acquired approximately **652** kilograms of HEU from the former Soviet Republic of Kazakhstan. The purchase was conducted as a classified operation under the code name "Project Sapphire."

When the U.S. acquired the HEU from the Republic of Kazakhstan, in consultation with the Russian Federation, the purpose of both governments was to prevent this HEU from falling into the hands of those who might use it to produce nuclear weapons. Central to this action was the need to ensure understanding and confidence that the material would not be used in the United States' nuclear arsenal. Therefore, it was important to blend the Kazakhstan-origin HEU to a nonweapons-usable form that would ultimately result in the peaceful use of this material as fuel for commercial nuclear reactors. In this manner, the U.S. hoped to encourage other nations to reduce their stockpiles of weapons-usable fissile materials and to advance global nonproliferation goals.

The Kazakhstan material was received and placed in safe, secure, interim storage at the Oak Ridge Y-12 Plant. In May 1995, the DOE conducted an environmental assessment to determine the disposition of the HEU. Based upon the analyses in the environmental assessment, the DOE awarded a contract to Babcock and Wilcox in Lynchburg, Virginia, to blend the Kazakhstan-origin HEU to LEU (DOE 1995a).

Conversion of this HEU to LEU was also in direct response to President Clinton's Nonproliferation and Export Control Policy, which mandates that the United States will:

- Seek to eliminate, where possible, the accumulation of stockpiles of HEU; and
- Pursue the purchase of HEU from the former Soviet Union and other countries and the conversion of that HEU to peaceful use as reactor fuel.

Kazakhstan HEU was packaged into 55-gallon "6M" shipping containers by DOE personnel for shipment to the U.S.

Kazakhstan HEU was then loaded onto a U.S. Air Force C-5 Galaxy Aircraft at the UST-Kamenogorsk airport in Kazakhstan. The material was then transported to the Oak Ridge Y-12 Plant for safekeeping.

Established in 1943, the Oak Ridge Y-12 Plant's mission includes the purification and processing of HEU into useable products or forms for use in the U.S. as well as foreign countries. These processes result in normal operating losses, blending, and inventory differences.

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SECTION 6
REMOVALS

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

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

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

REFEED AT THE ENRICHMENT PLANTS

Refeed at Enrichment Plants

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

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

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

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

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

Table 6-1 Total HEU Refed at the Enrichment Plants

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

[a] Quantities are in kilograms.

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

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

[a] Quantities are in kilograms.

[b] Includes HEU cumulative production through 1946.

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

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

[a] Quantities are in kilograms.

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

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

[a] Quantities are in kilograms.

NUCLEAR TESTS AND WARTIME DETONATIONS

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

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

U.S. Nuclear Tests and Wartime Detonations

- ✓ The U.S. conducted a total of **1,054** nuclear weapons tests and peaceful nuclear explosions beginning in July 16, 1945, with the first U.S. nuclear weapon test, code named "Trinity." Of the **1,054** tests conducted, **1,030** were conducted solely by the U.S. and **24** were conducted jointly with the United Kingdom.
- ✓ In August 1945, the U.S. detonated **two** nuclear weapons over Japan in World War II. The first bomb, "Little Boy," was dropped on Hiroshima on August 6, 1945 and was a uranium gun-type weapon. The second, "Fat Man," was dropped on Nagasaki on August 9,1945 and was an implosion-type weapon with a plutonium pit. These nuclear weapons were intended to end World War II as quickly as possible.

PURPOSE OF U.S. NUCLEAR TESTS

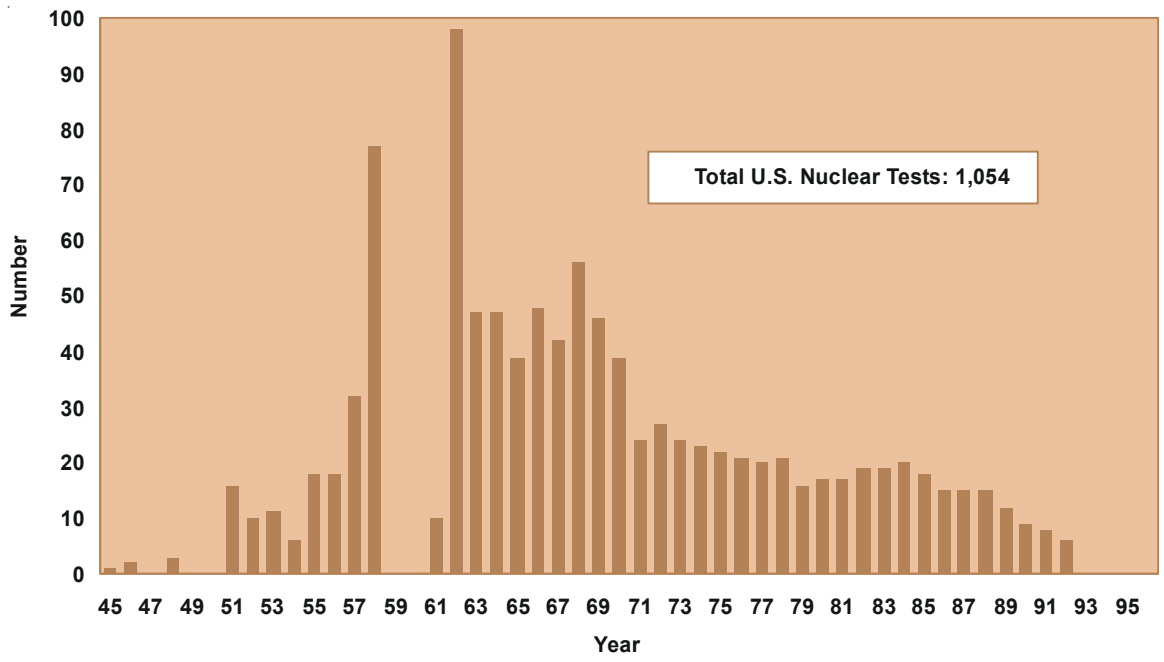
The United States performed its nuclear tests for several reasons. The following paragraphs define the seven different purposes for these detonations.

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

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

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

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



Notes:

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

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

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

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

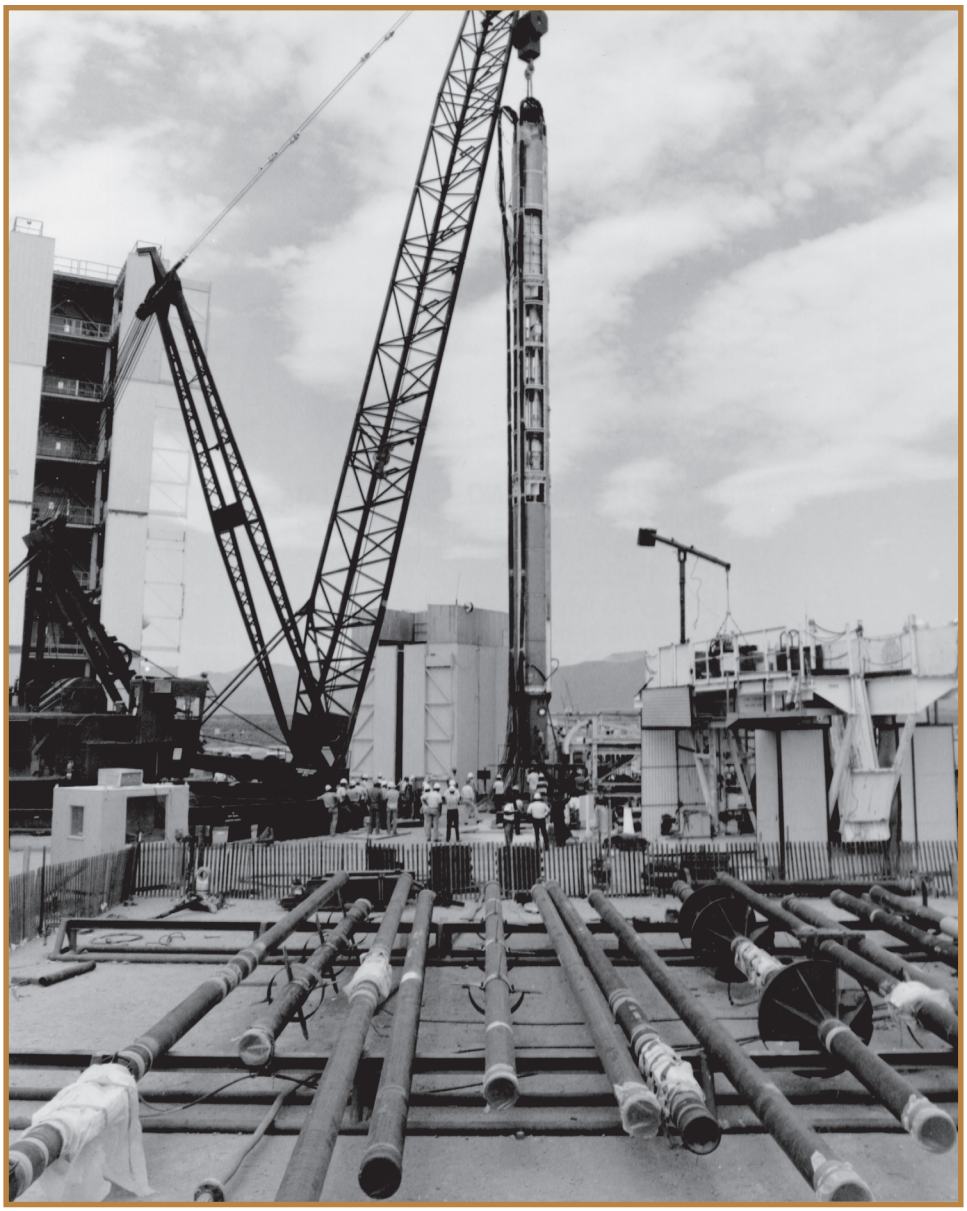
Nuclear Testing Sites

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

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

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

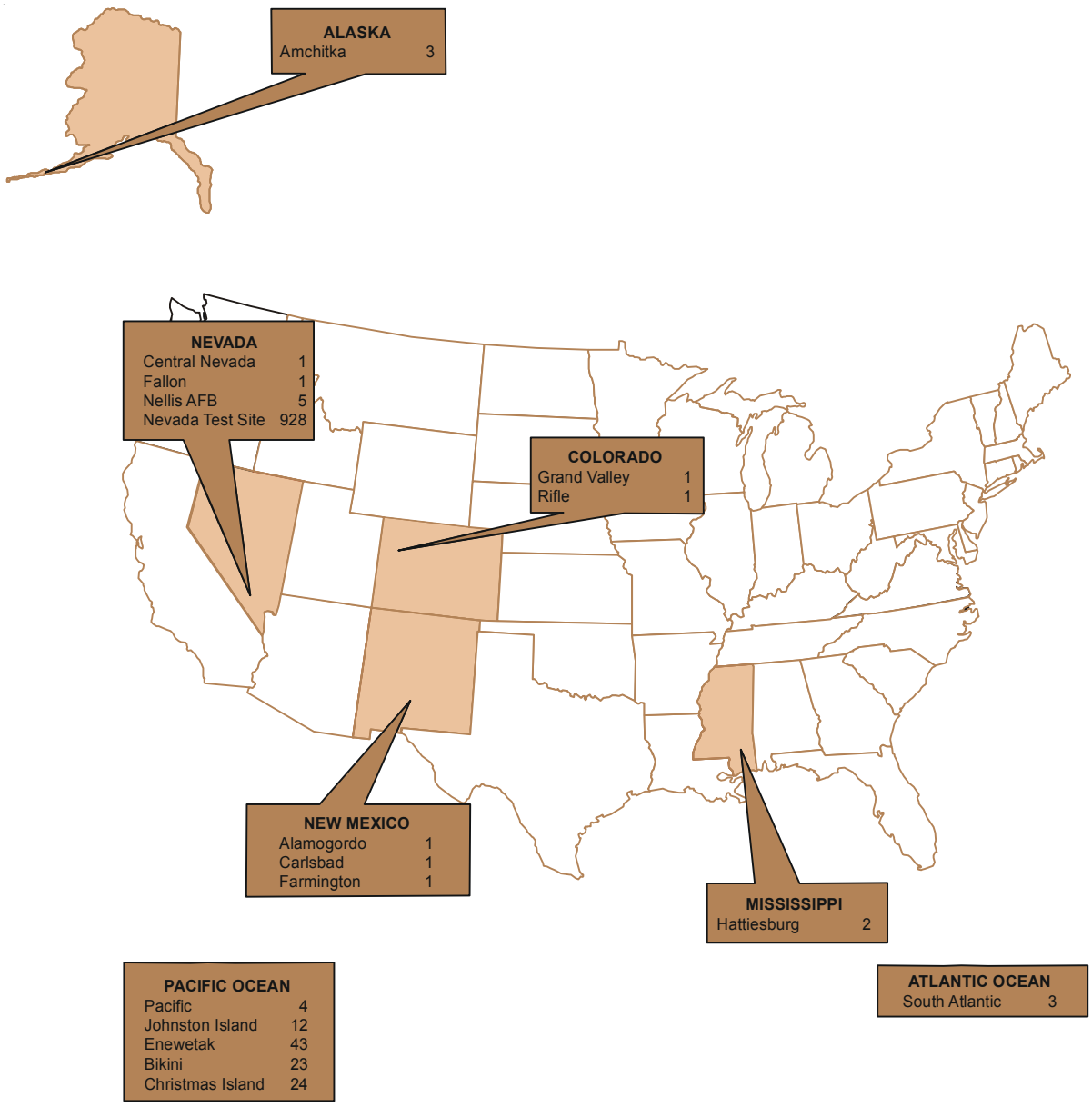
- Colorado - Two nuclear tests were conducted in Colorado, one each at Grand Valley and Rifle. Both tests were part of Project Plowshare. Shot Rulison was conducted in Grand Valley on September 10, 1969, and Rio Blanco in Rifle on May 17, 1973.
- Mississippi - Two nuclear tests were conducted in Hattiesburg,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



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

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

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



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

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

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

FISSION AND TRANSMUTATIONS

Fission and Transmutations

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

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

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

NUCLEAR MATERIALS PRODUCTION

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

NAVAL NUCLEAR PROPULSION PROGRAM

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

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

Other Government and Commercial Reactors

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

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

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

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

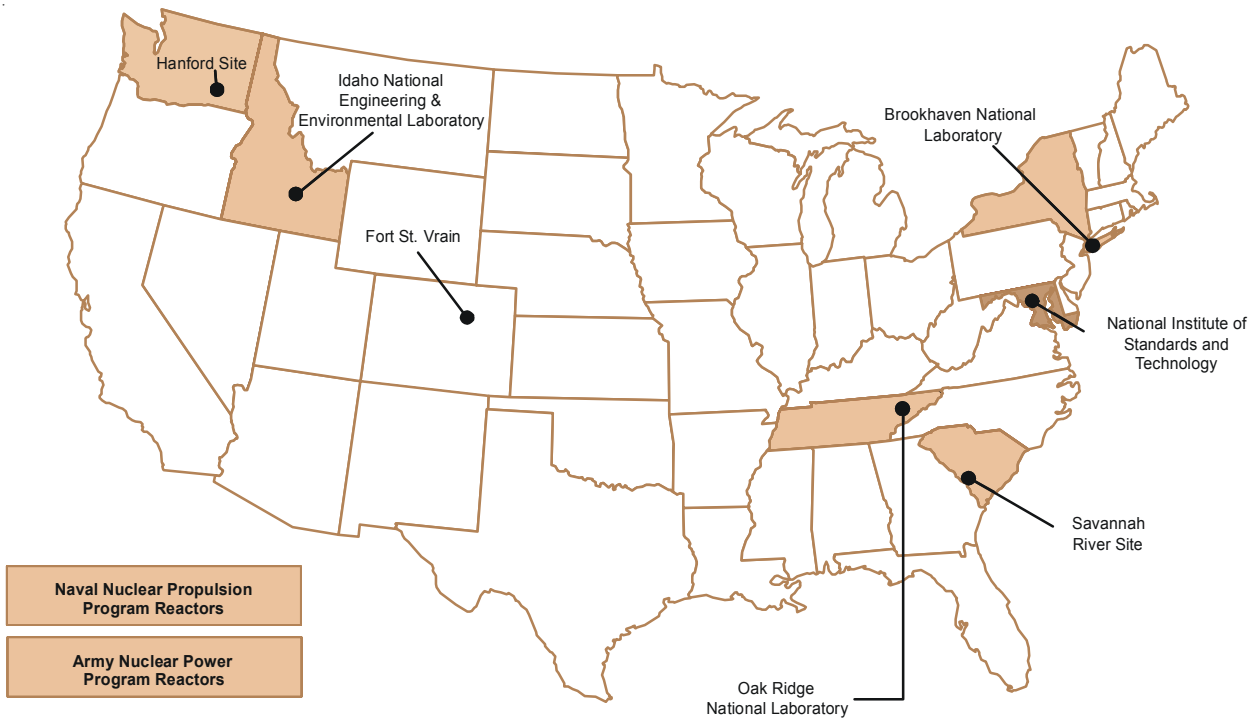
  Research and development was also conducted at other locations. For example, the National Institute of Standards and Technology (NIST) research reactor in Gaithersburg, Maryland, focuses on the establishment of measurements and standards. The NIST reactor uses HEU to provide a neutron source for industry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

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

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

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

Table 6-5 Cumulative HEU Fission and Transmutations



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

Notes:

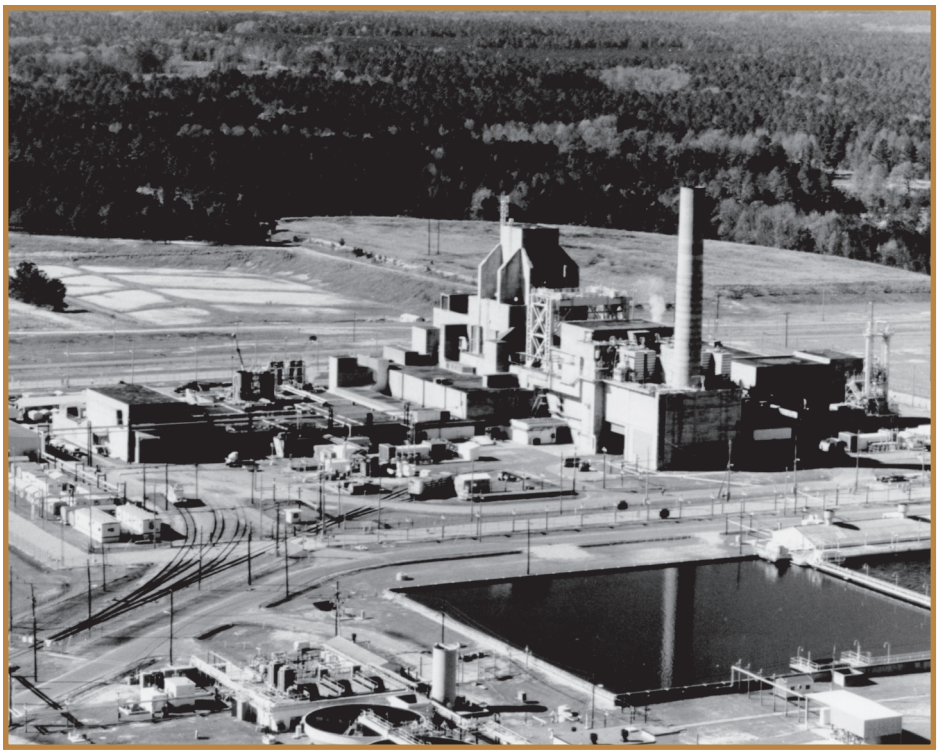
1 Idaho National Engineering and Environmental Laboratory reactors include the Advanced Test Reactor, Engineering Test Reactor, Experimental Breeder Reactor II, and Materials Test Reactor.

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

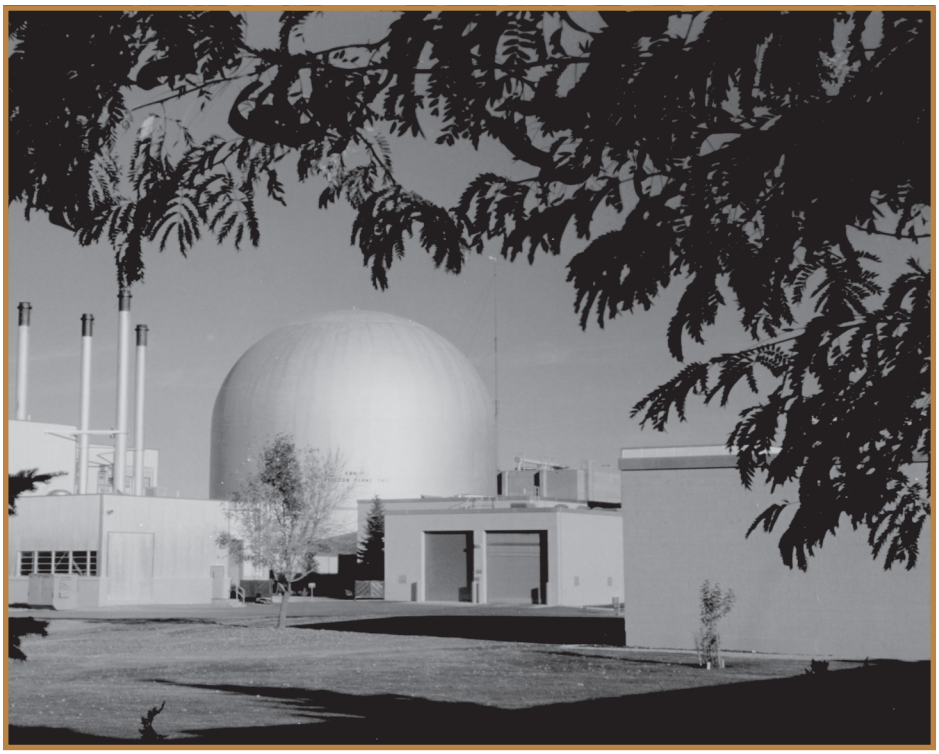
3 Brookhaven National Laboratory reactors include the High Flux Beam Reactor.

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

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



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



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

Normal Operating Losses

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

Normal Operating Losses

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

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

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

Department of Energy Sites

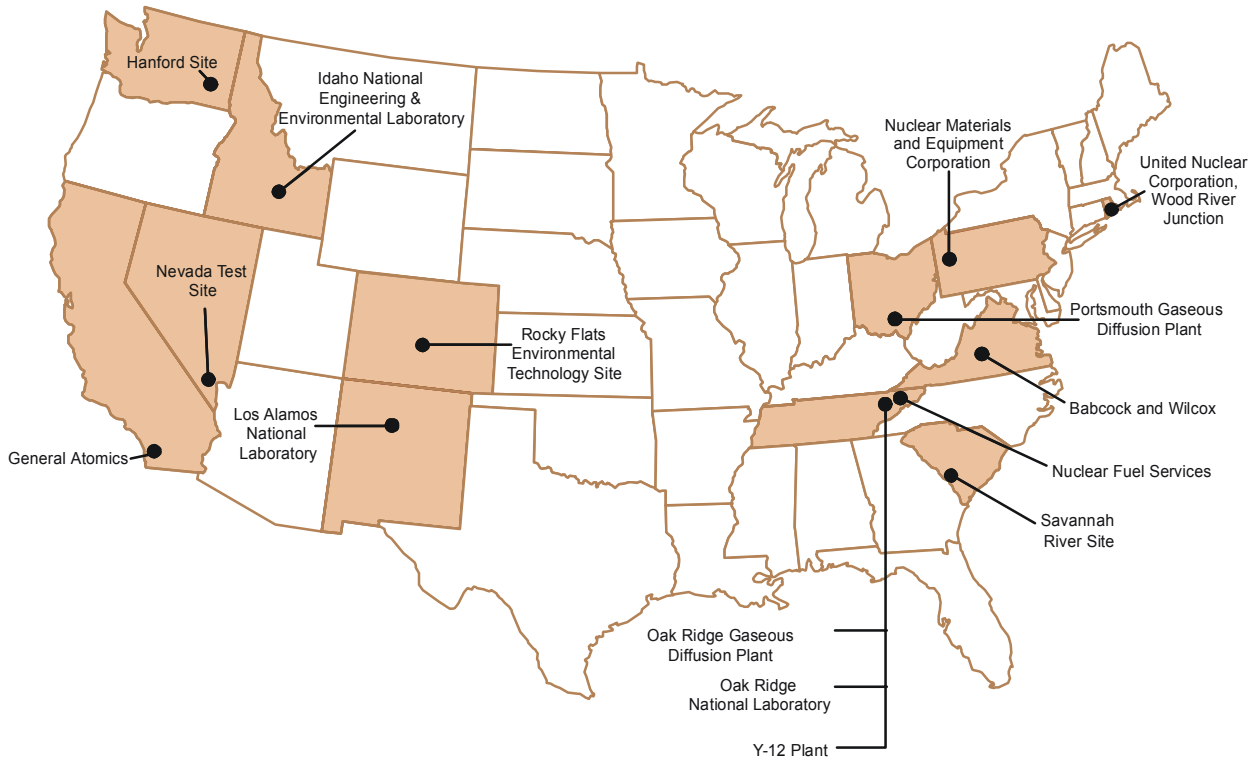
DOE sites removed a total of **3.2** MTU containing **2.4** MTU-235 as normal operating losses. The sites with the largest quantities of HEU removed as normal operating losses are the Y-12 Plant (**1.4** MTU), the Savannah River Site (**0.5** MTU), and the Idaho National Engineering and Environmental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

Commercial Sites

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

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

Table 6-6 Cumulative HEU Normal Operating Losses



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

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

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

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

HEU Transfers to Foreign Countries

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

Transfers to Foreign Countries

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

Peaceful Uses of Atomic Energy

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

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

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

The export quantities shown in Tables 6-7 and 6-8 reflect the amount of HEU exported from the U.S. to a foreign country of first destination. First destination does not necessarily mean that the receiving country was the ultimate destination for the HEU, only that it was the first foreign

receipt for the material. For example, HEU sent to France for fabrication into reactor fuel for a reactor in Switzerland is counted as a delivery to France, not to Switzerland. Therefore, U.S. HEU exports minus imports do not necessarily equal inventories for individual countries. Examples of this are as follows:

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

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

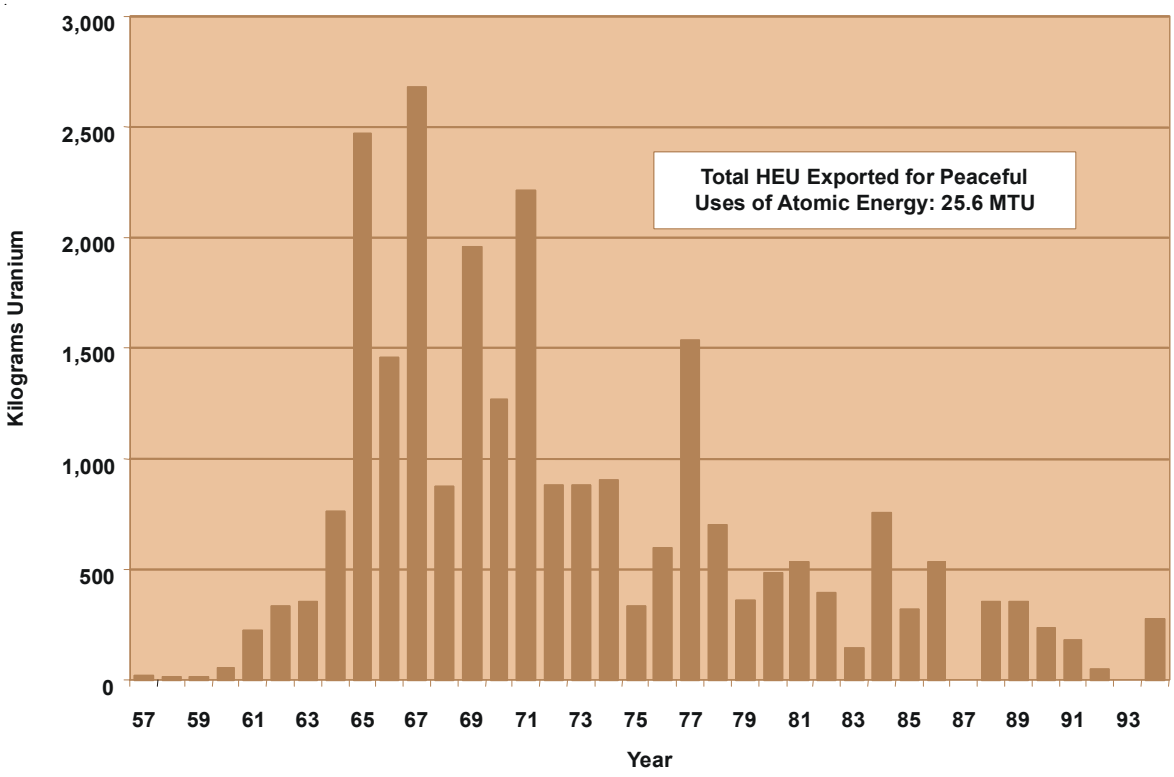


Table 6-7 U.S. HEU Exported to Euratom Countries for Peaceful Uses of Atomic Energy

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

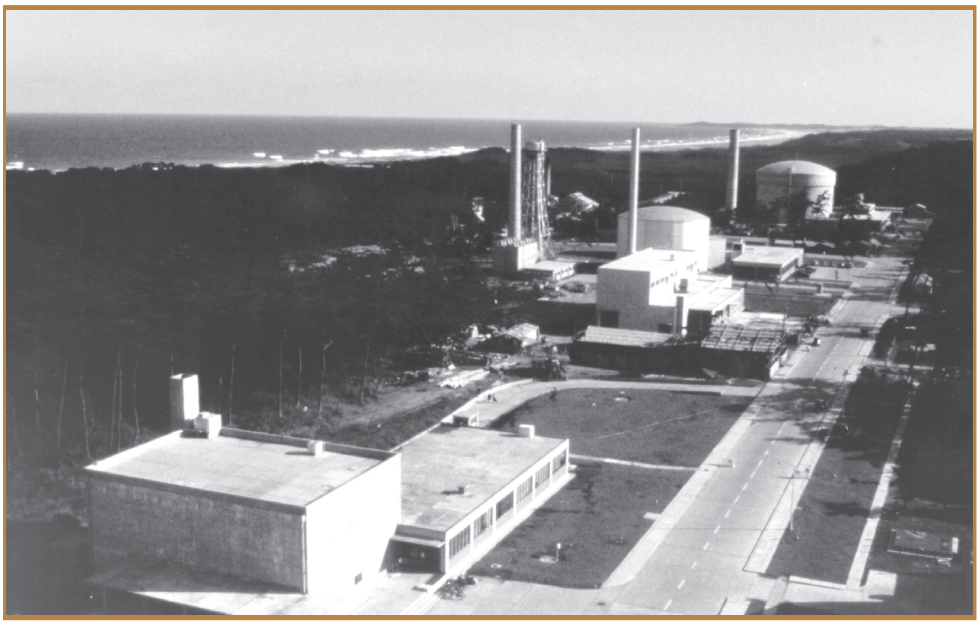
[a] Quantities are in kilograms.

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

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

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

[a] Quantities are in kilograms.



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

Mutual Defense Agreements

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

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

Down Blending

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

HEU Down Blending

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

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

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

Research and Development Activities

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

Reduction of Weapons-Usable Fissile Material

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

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

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

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

INVENTORY DIFFERENCES

Inventory Differences

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

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

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

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

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

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

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

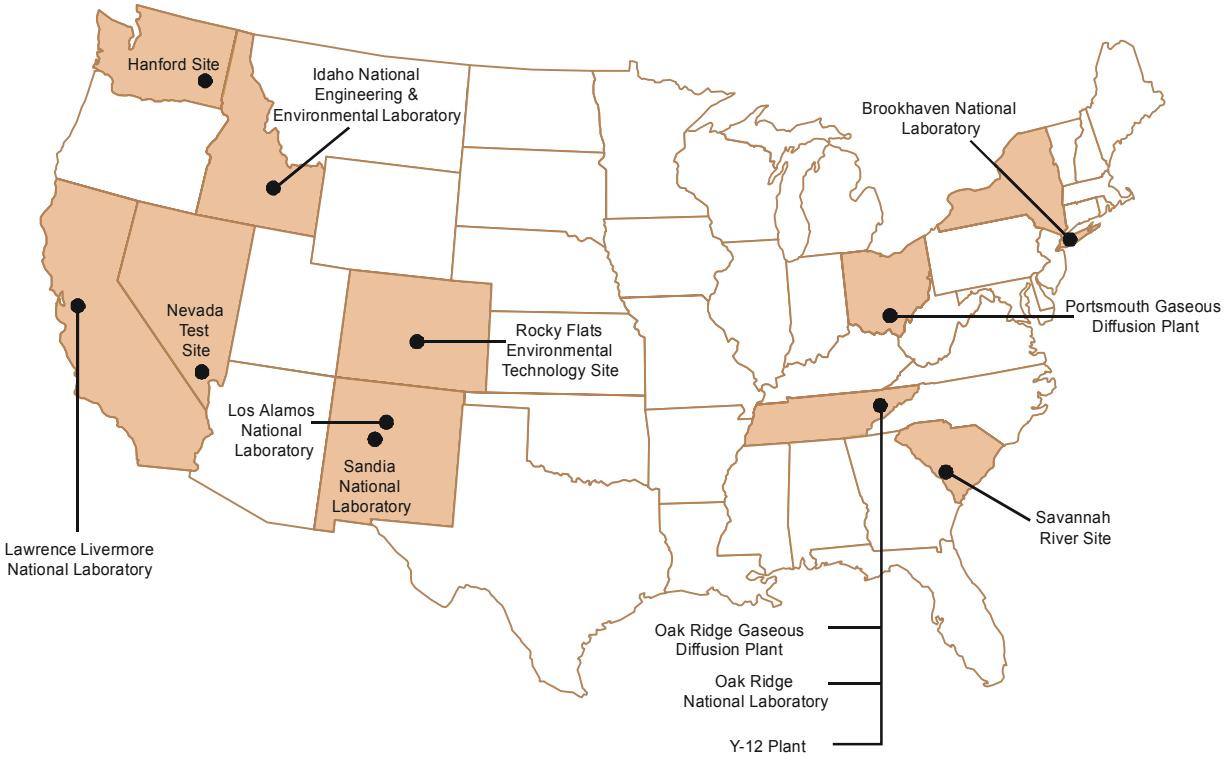
As part of the inventory difference evaluation, other security events are reviewed to ensure that inventory differences are not linked to breaches of physical security or insider acts. If there is no evidence of security breaches, then inventory differences are less likely to be caused by malevolent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

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

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

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

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



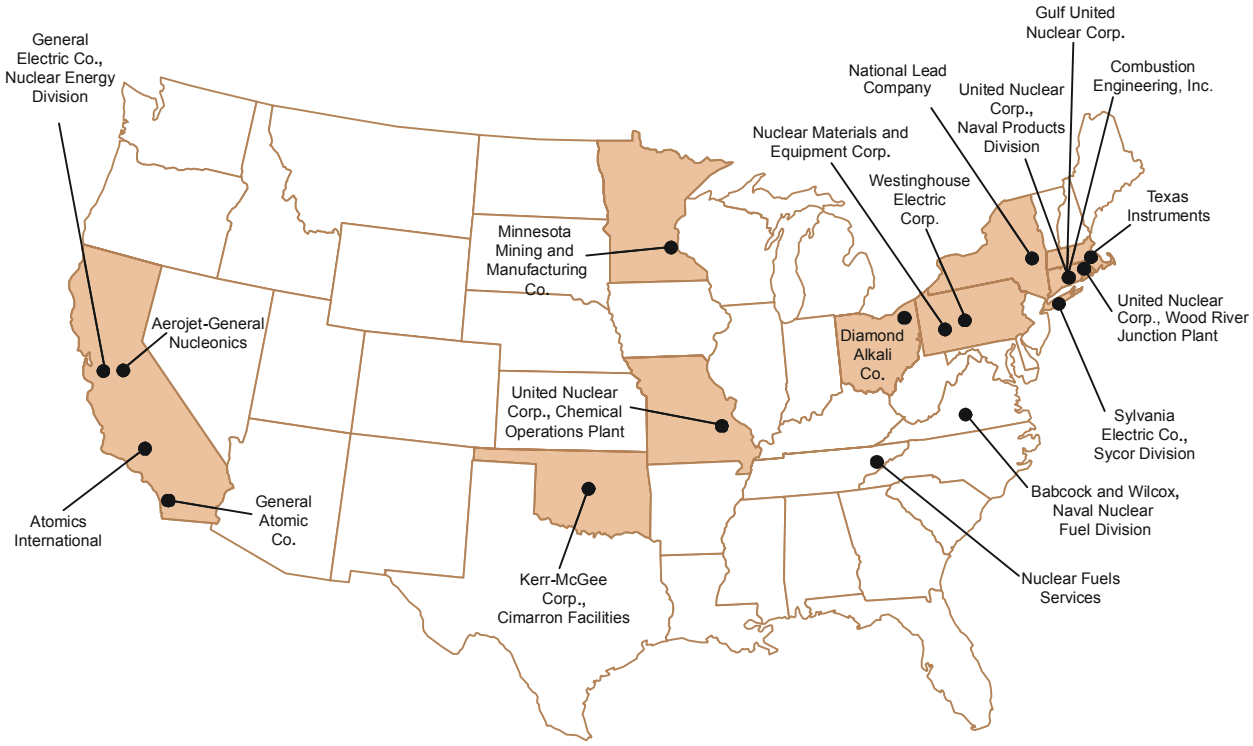
Site	kg U-235
Brookhaven National Laboratory	-4
Hanford Site	11
Idaho National Engineering and Environmental Laboratory	-11
Lawrence Livermore National Laboratory	1
Los Alamos National Laboratory	116
Oak Ridge Gaseous Diffusion Plant	113
Oak Ridge National Laboratory	6
Nevada Test Site	17
Portsmouth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

Notes:

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

2 Quantities are rounded to the nearest kilogram.

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



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

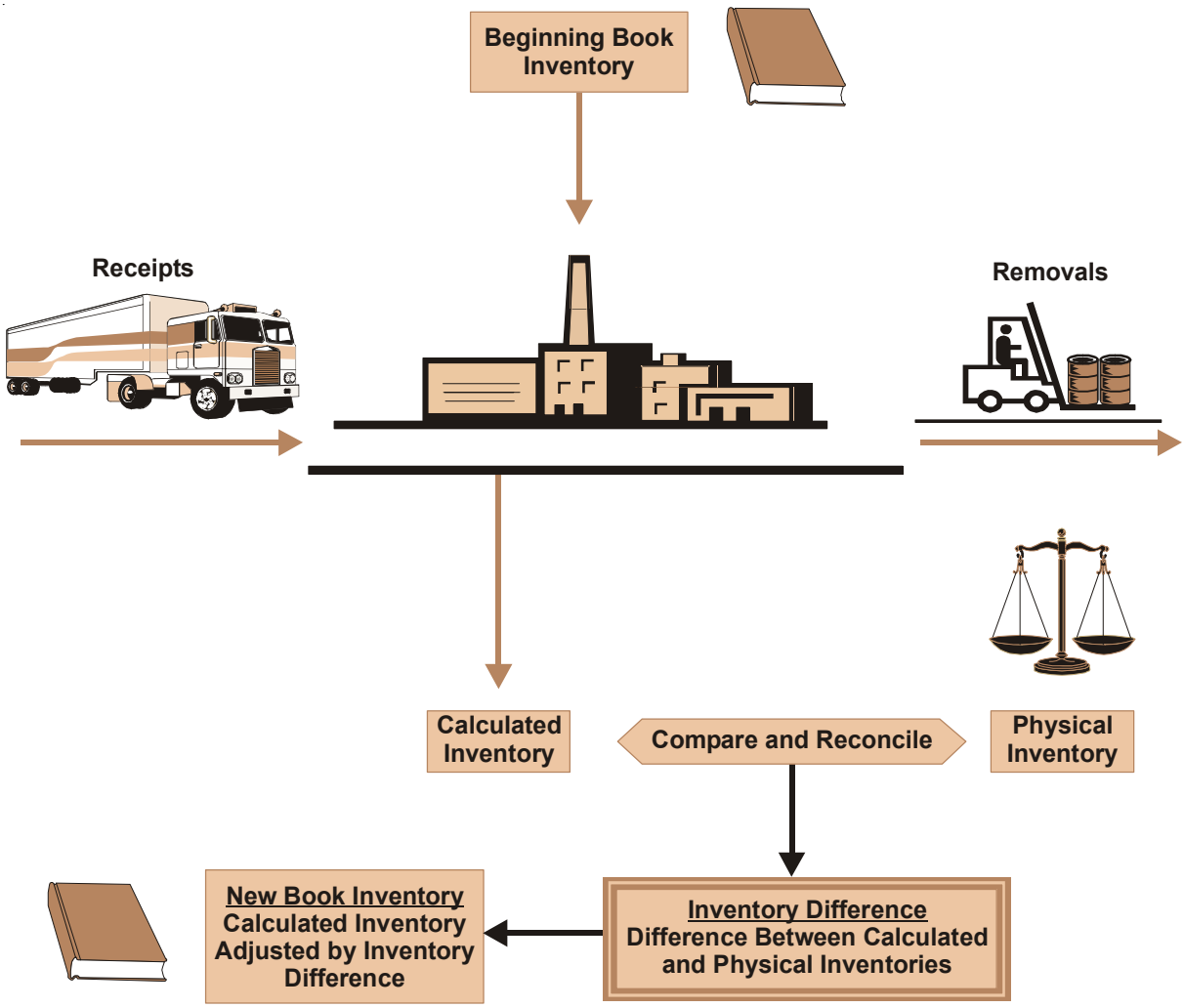
Notes:

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

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

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

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

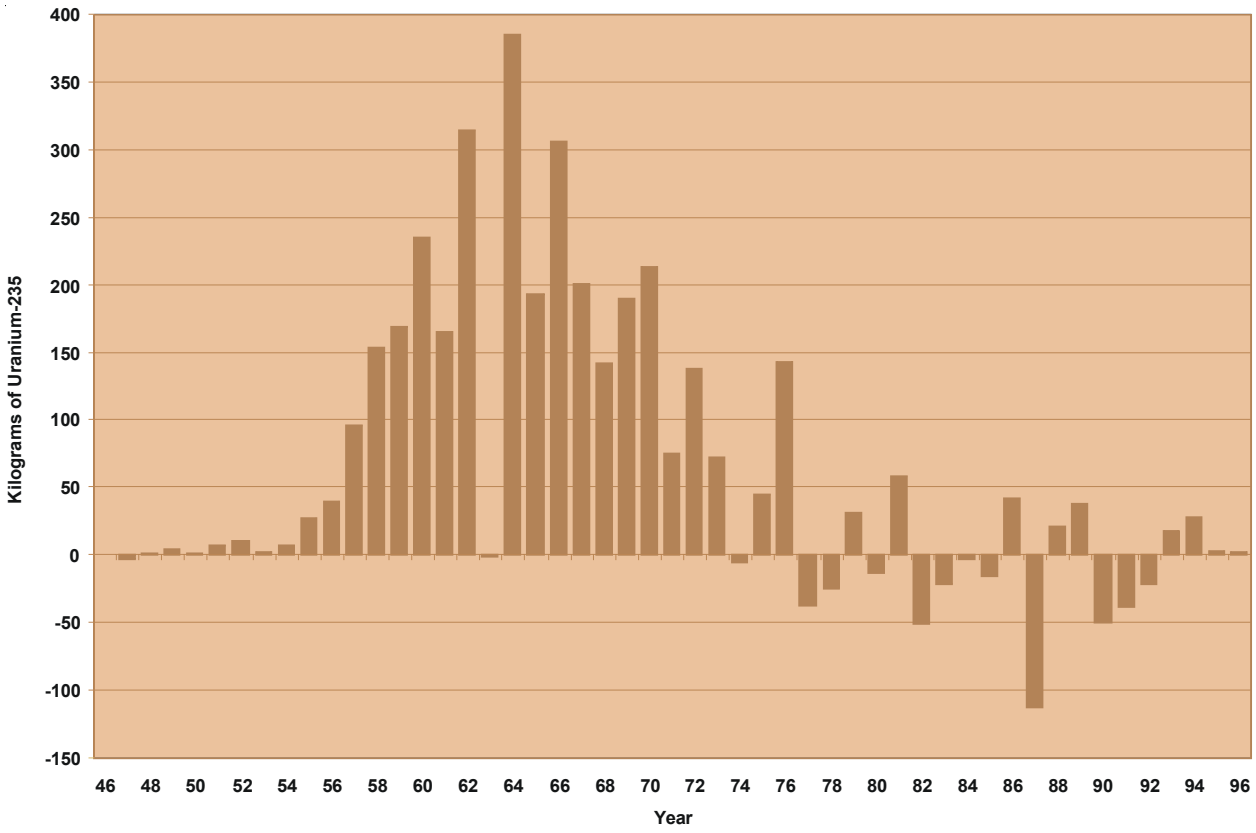


Notes:

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

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

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



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APPENDICES

The Y-12 Plant was established in 1943 as part of the Manhattan Project with a mission to separate uranium-235 from natural uranium using the electromagnetic separation process. Pictured is a view of the Y-12 Plant looking east in 1944.

The Los Alamos National Laboratory was established as a nuclear weapons design laboratory as part of the Manhattan Project in 1943. Pictured is an aerial view of the Laboratory.

APPENDIX A
CHRONOLOGY OF SIGNIFICANT NUCLEAR EVENTS

1930s

1938 Otto Hahn and Fritz Strassmann discover the process of fission in uranium.

1939 Albert Einstein writes President Franklin D. Roosevelt, alerting the President to the importance of research on chain reactions and the possibility that research might lead to developing powerful bombs.

1940s

1940 Alfred Nier completes isotopic separation of uranium-235 and uranium-238 using electromagnetic methods.

1942 President Roosevelt approves production of the atomic bomb, the Manhattan Engineer District is established in New York City, and scientists led by Enrico Fermi achieve the first self-sustained nuclear chain reaction.

1943 Construction starts on the Y-12 Plant and Oak Ridge Gaseous Diffusion Plant in Oak Ridge, Tennessee. Los Alamos National Laboratory is established as a nuclear weapons design laboratory in Los Alamos, New Mexico.

1944 First electromagnetic uranium separation operations begin at the Y-12 Plant.

1945 U.S. conducts first nuclear weapon test, code named "Trinity." First unit of the Oak Ridge Gaseous Diffusion Plant begins initial operation and the first uranium bomb, called "Little Boy," is dropped on Hiroshima. Sandia National Laboratory is established as a nuclear weapons design laboratory in Albuquerque, New Mexico.

1946 President Truman signs the Atomic Energy Act of 1946 to ensure that the development of nuclear energy is conducted in a manner consistent with the security of the United States.

1947 In accordance with the Atomic Energy Act of 1946, all atomic energy activities are transferred from the Manhattan Engineer District to the newly created Atomic Energy Commission (AEC). Brookhaven National Laboratory is established in Upton, New York. Knolls Atomic Power Laboratory is established to conduct research and development for the design and operation of naval nuclear propulsion plants.

1948 The U.S. Navy creates the new Nuclear Power Branch within the Bureau of Ships for the purpose of establishing the Naval Nuclear Propulsion Program.

1949 The Idaho National Engineering and Environmental Laboratory is established near Idaho Falls, Idaho, as the National Reactor Testing Station to provide an isolated location where prototype nuclear reactors could be designed, built, and tested.

1950s

1950 Expansion program to develop thermonuclear weapons is announced by President Truman.

1951 Construction starts on the Paducah Gaseous Diffusion Plant in Kentucky. Nevada Test Site is established near Las Vegas, Nevada, with a primary mission to ensure the safety

and reliability of the Nation's nuclear weapons stockpile. AEC begins rehabilitating the Pantex Plant near Amarillo, Texas, for nuclear weapons operations. Rocky Flats Plant is established near Golden, Colorado, for nuclear weapon component fabrication.

1952 Construction starts on the Portsmouth Gaseous Diffusion Plant in Ohio. Lawrence Livermore National Laboratory is established as a nuclear weapons design laboratory near Livermore, California.

1953 First unit of the Paducah Gaseous Diffusion Plant begins operation and construction is completed of the first pressurized-water naval nuclear propulsion plant.

1954 First unit of the Portsmouth Gaseous Diffusion Plant begins operation and the Atomic Energy Act of 1946 is amended to authorize distribution of special nuclear (enriched uranium and plutonium) materials for domestic and foreign programs.

1955 U.S.S. *Nautilus* (SSN 571), first nuclear powered submarine, becomes operational.

1956 Project Rover is initiated to determine feasibility of utilizing nuclear energy for rocket vehicle propulsion.

1957 The International Atomic Energy Agency (IAEA) is established.

1960s

1963 The Portsmouth Gaseous Diffusion Plant starts producing very highly enriched uranium for naval reactors.

1964 Curtailment in the production of enriched uranium and plutonium is announced by President Johnson. Four reactors (one at Savannah River and three at Hanford) were to be shut down. K-25 and K-27 buildings were shut down at the K-25 Site, while the K-29, K-31 and K-33 buildings continued to operate, producing low enriched uranium.

1968 The B-Reactor at Hanford and the L-Reactor at Savannah River are shut down. The Hanford F and H Reactors, formerly in standby mode, were abandoned for future production use.

1970s

1970 Nuclear Nonproliferation Treaty (NPT) entered into force.

1971 The KE reactor at Hanford is shut down.

1975 Energy Reorganization Act of 1974 abolishes the Atomic Energy Commission and creates the Energy Research and Development Administration (ERDA).

1977 ERDA and NRC release a comprehensive report on strategic special nuclear material inventory differences. The Department of Energy Organization Act creates the Department of Energy (DOE) to develop a strong national energy program to meet future energy needs.

1978 Nuclear Non-Proliferation Act of 1978 is enacted.

1980s

1985 K-25 Site placed in standby mode.

1987 K-25 Site placed in shutdown mode.

1988 C, K, L and P-reactors at Savannah River are shut down.

1990s

1992 Production of HEU is terminated. Public Law 102-486 is enacted to establish the U.S. Enrichment Corporation (USEC) to lease/run the Paducah and Portsmouth Gaseous Diffusion Plants. The last U.S. nuclear weapons test, called "Divider," is conducted at the Nevada Test Site. Presidents Bush and Yeltsin announce plans to reduce the U.S. and former Soviet strategic arsenals.

1993 K-Reactor at the Savannah River Site is restarted and shut down. President Clinton signs Presidential Directive on Nonproliferation and Exports Controls to accelerate the return of U.S.-origin spent nuclear fuel. On December 7, 1993, the first Openness Press Conference is held with a primary focus on the plutonium inventory and weapon test information.

1994 June 27, 1994 - Openness Press Conference held. Primary focus is on classified issues, nuclear material inventories and additional weapons testing information. U.S. acquires HEU from the former Soviet Republic of Kazakhstan under the code name "Project Sapphire."

1995 President Clinton declares 200 metric tons of HEU and plutonium as excess to national security needs.

1996 February 6, 1996 - Openness Press Conference held. The DOE releases a report on plutonium inventories entitled *Plutonium: The First 50 Years*, and a report on fundamental classification policy review; updated Departmental declassification efforts; and releases the location, form, and quantity of plutonium and HEU declared surplus to national security needs.

In the 1960s and 1970s, several commercial companies were involved in processing and fabricating HEU. The United Nuclear Corporation Recovery Systems facility, located in Wood River Junction, Rhode Island, was engaged primarily in processing scrap material to recover enriched uranium. Processing operations continued until 1980, when United Nuclear Corporation terminated operations and initiated decommissioning.

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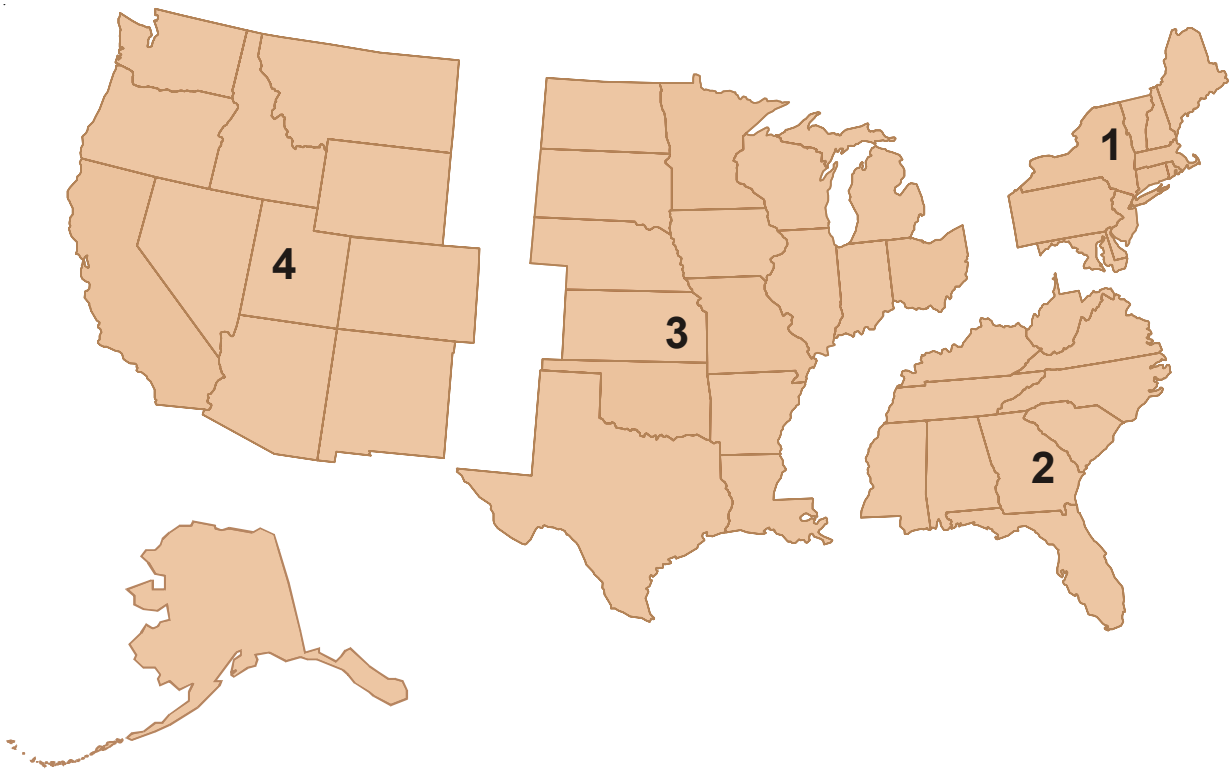
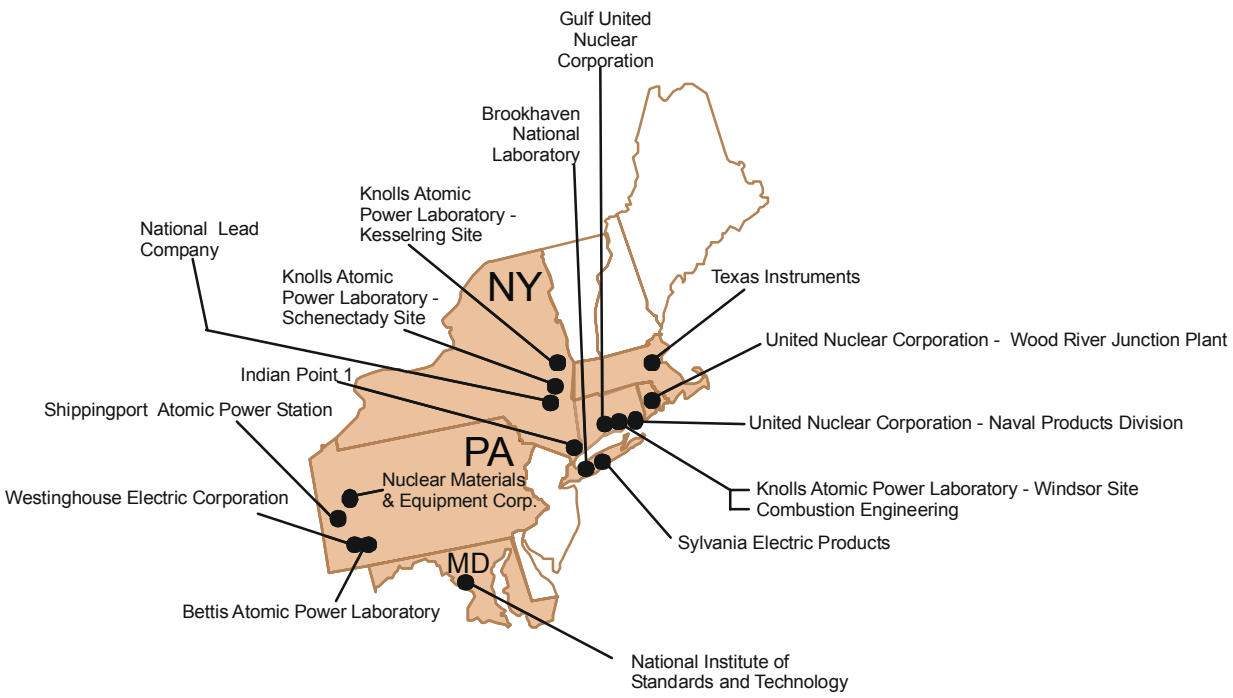
APPENDIX B
SITES DISCUSSED IN THIS REPORT

This appendix lists the sites discussed in this report that contributed to the production and utilization of highly enriched uranium (HEU). Sites are grouped into four geographical regions: (1) northeast, (2) southeast, (3) midwest, and (4) west. Within each region, sites are listed in alphabetical order along with location and a brief description of activities in support of HEU production and utilization.

The intent of this appendix is not to provide information on the final disposition of each site or on the environmental legacy remaining at each site. Such information is outside of the scope of this HEU report. However, when such information was available, it was included in this appendix.



NORTHEAST



BETTIS ATOMIC POWER LABORATORY

The Bettis Atomic Power Laboratory, established in 1948 near Pittsburgh, Pennsylvania, is engaged solely in research and development for design and operation of naval nuclear propulsion plants. Bettis operates the Naval Reactors Facility at the Idaho National Engineering and Environmental Laboratory. These facilities used HEU fuel in the design, construction, and testing of prototype reactors for the Naval Nuclear Propulsion Program.

BROOKHAVEN NATIONAL LABORATORY

The Brookhaven National Laboratory was established in 1947 in Upton, New York. The facilities at Brookhaven have been used primarily for research and training. The Brookhaven Medical Research Reactor, a light-water cooled, tank-type reactor, uses HEU as fuel. It reached initial criticality in 1959 and is used for medical purposes. The High Flux Beam Reactor at Brookhaven, which has been shut down, is a heavy water reactor that used HEU as fuel. It reached criticality in October 1965 and has been used for studies in chemistry, physics, materials science, medicine, and biology.

Combustion Engineering

Combustion Engineering, located in Windsor, Connecticut, began designing a submarine nuclear power plant facility for the AEC in 1955, which ultimately led to the manufacture, assembly, testing, and operation of the S1C Prototype Reactor Facility. Work for the AEC also included the fabrication of HEU fuel elements for the reactor facility. These activities continued through 1967.

Gulf United Nuclear Corporation

Gulf United Nuclear Corporation, located in New Haven, Connecticut, fabricated uranium fuel from the late 1960s to the mid-1970s. In 1976, the site was decommissioned.

Indian Point 1

The Indian Point Nuclear Power Station, Unit #1, was a pressurized water reactor, owned and operated by the Consolidated Edison Company. It began operation in 1962 and was located on the Hudson River in Buchanan, New York, approximately 35 miles north of New York City. The first reactor core used HEU and thorium fuel and was subsequently reprocessed at the Nuclear Fuel Services facility in West Valley, New York, in 1969. In 1974, Indian Point 1 was permanently shut down.

Knolls Atomic Power Laboratory

The Knolls Atomic Power Laboratory (KAPL), established in 1947, is engaged solely in research and development for the design and operation of naval nuclear propulsion plants. The KAPL has sites at Windsor, Connecticut (known as the KAPL - Windsor Site); and Niskayuna (known as the KAPL - Schenectady Site) and West Milton (known as the KAPL - Kesselring Site), New York. These facilities used HEU fuel in the design, construction, and testing of prototype reactors for the Naval Nuclear Propulsion Program.

National Institute of Standards and Technology

The National Institute of Standards and Technology (NIST), formerly known as the National Bureau of Standards, is located in Gaithersburg, Maryland, and has a research reactor owned by the U.S. Department of Commerce. Since the 1960s, this research reactor has focused on research activities directed towards the establishment of measurements and standards. The NIST research reactor uses HEU fuel enriched to 93 percent uranium-235 and provides a neutron source for industry researchers and scientists.

National Lead Company

The National Lead Company, located in Albany, New York, began manufacturing uranium products in the 1950s. Work at the site included production of uranium metal, oxides and compounds from uranium hexafluoride, fabrication of uranium fuels, and chemical processing of nonirradiated uranium scrap. HEU activities at the site continued through the early 1970s. As of the date of this report, the site is undergoing environmental restoration.

Nuclear Materials and Equipment Corporation

The Nuclear Materials and Equipment Corporation (NUMEC) began operation of the uranium fuel fabrication plant, in Apollo, Pennsylvania, in 1957. From 1967 to 1971, the Atlantic Richfield Company was the operator. In 1971, the Babcock and Wilcox (B&W) Company became the owner of the site. The primary operation at the facility was the chemical conversion of both low- and highly enriched uranium hexafluoride (UF_6) gas into uranium dioxide (UO_2) and other uranium materials for use by the Government and nuclear power industry. On April 15, 1997, the U.S. Nuclear Regulatory Commission (NRC) announced its release of the Apollo site and its removal from the NRC Site Decommissioning Management Plan.

Shippingport Atomic Power Station

The Shippingport Atomic Power Station, located in Shippingport, Pennsylvania, was the first large-scale nuclear power electrical generating plant in the United States. This plant achieved criticality and began full power operation in December 1957. Shippingport was a pressurized water reactor that used HEU as fuel. The primary objective of the Shippingport plant was to advance reactor technology and develop information useful in the design and operation of nuclear power plants. Owned by DOE, the plant was shut down on October 1, 1982, and decommissioning was completed in December 1989.

Sylvania Electric Products

The Sylvania Electric Products, Sycor Division, was located in Hicksville, New York. Sylvania fabricated uranium fuels from the mid-1950s to the mid-1960s.

Texas Instruments

Texas Instruments, Inc., originally established in 1952 as Metal and Controls, Inc., was located in Attleboro, Massachusetts. In 1959, Metal and Controls, Inc. merged with Texas Instruments. From 1952 through 1965, Texas Instruments fabricated uranium fuel elements for the Naval Nuclear Propulsion Program. During the period 1965 through 1981, the Texas Instruments facility fabricated fuel for the High Flux Isotope Reactor at ORNL and other Government-owned research reactors. The facility began cleanup of uranium contamination in 1981, after operational activities ceased. Decontamination and decommissioning was concluded at the facility in February 1997, and the NRC license has since been terminated.

United Nuclear Corporation, Naval Products Division

The United Nuclear Corporation (UNC) Naval Products Division began fabricating reactor fuel elements in the 1950s for the Naval Nuclear Propulsion Program at the Montville, Connecticut, facility. This facility was authorized for the fabrication and inspection of unclad fuel components, incapsulation of the fuel into corrosion-resistant materials, and the assemblage of these into larger components or into reactor cores. In 1990, UNC began performing decontamination and decommissioning activities while concurrently completing work on existing contracts.

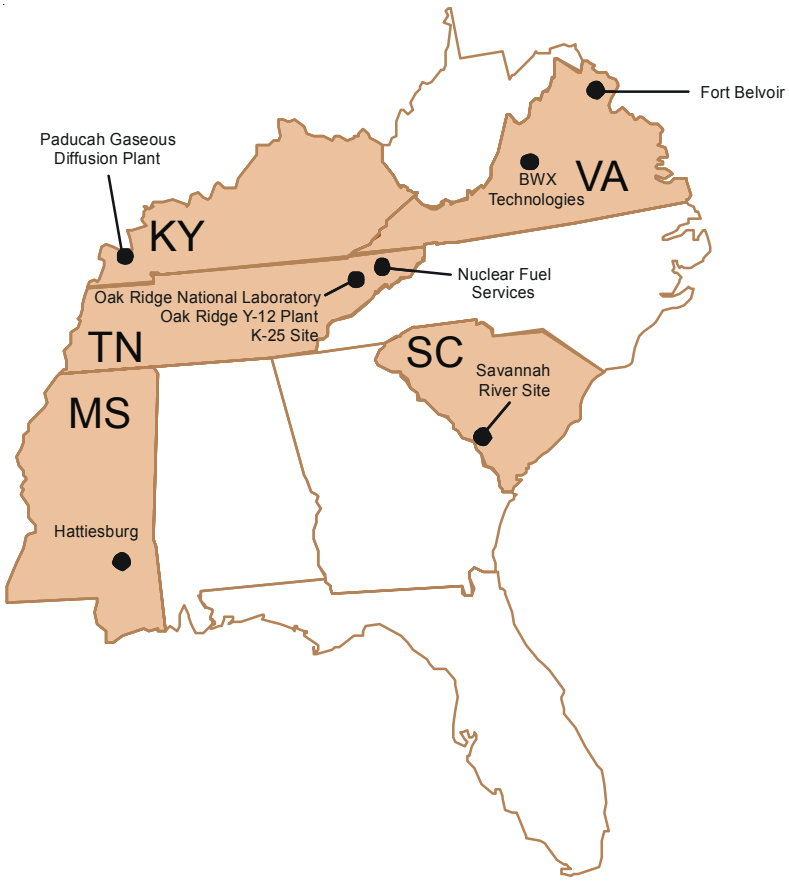
United Nuclear Corporation, Wood River Junction Plant

The UNC Recovery Systems facility, located in Wood River Junction, Rhode Island, began processing scrap material in 1964 to recover enriched uranium. This material consisted primarily of nonirradiated uranium; however, some slightly irradiated fuel from zero power reactors was also processed. Uranium-235 enrichments in the scrap material ranged from a few percent to greater than 90 percent. Processing operations continued until 1980, when UNC terminated operations and initiated decommissioning. Decommissioning was completed, and the license was terminated in September 1995.

Westinghouse Electric Corporation

The Westinghouse Electric Corporation is located in the Pittsburgh, Pennsylvania area. From the mid-1950s to the late 1960s, Westinghouse was involved in several projects that utilized HEU, including the Naval Nuclear Propulsion Program and the Nuclear Engine for Rocket Vehicle Application (NERVA) program. The company designed reactor cores and fabricated fuel elements for naval reactors. The Astronuclear Laboratory of Westinghouse was involved in developing nuclear rocket engine technology as part of the NERVA program, which ended in 1971.

SOUTHEAST



BWX TECHNOLOGIES

BWX Technologies, Inc. (BWXT), formerly the Babcock and Wilcox (B&W) Company, Naval Nuclear Fuel Division (NNFD) facility is located approximately five miles east of Lynchburg, Virginia. Beginning in 1956 and continuing through today, BWXT NNFD has been manufacturing enriched uranium nuclear reactor fuel for research purposes and naval propulsion reactors. The fuel production cycle at this facility begins with either uranium metal or oxide (or uranium in a form provided by a fuel vendor) and ends up with fuel elements and/or reactor cores for use by the customer.

FORT BELVOIR

Fort Belvoir, located in Springfield, Virginia, was the headquarters of the Army Nuclear Power Program (ANPP). This program was initiated in 1954, and during its lifetime, it designed, constructed, operated, and deactivated nine nuclear power plants as described in Appendix D of this report. By 1977, due to changing military requirements and funding limitations, major program

activities ceased when the last ANPP facility was deactivated. Oversight responsibility for deactivated ANPP facilities rests with the U.S. Army Nuclear and Chemical Agency (USANCA) located at Ft. Belvoir.

Hattiesburg, Mississippi

In October 1964 and December 1966, two underground nuclear tests were conducted in Hattiesburg, Mississippi, to evaluate the seismic response of salt deposits to nuclear explosives. The first test, named Project Salmon, had a yield of 5.3 kilotons and was part of the Vela Uniform Program. The second test, named Project Sterling, had a yield of 380 tons and was also part of the Vela Uniform.

K-25 Site

The K-25 Site is located approximately eight miles west of Oak Ridge, Tennessee. It was established in 1943 and was originally known as the Oak Ridge Gaseous Diffusion Plant. The K-25 Site was the first of three gaseous diffusion plants built to perform large-scale separation and enrichment of uranium, and one of two to supply HEU for nuclear weapons. Operations ceased in 1985, and the site was permanently shut down in 1987. The site currently is a center for applied technology and operates waste treatment and storage facilities under the DOE environmental management program.

Nuclear Fuel Services

The Nuclear Fuel Services, Inc. (NFS) facility is approximately 0.5 miles southwest Erwin, Tennessee. Beginning in the early 1960s, this facility manufactured HEU for DOE, the Naval Nuclear Propulsion Program, and other customers, and recovered enriched uranium from process scrap. The basic processing services consisted of recovery and purification of uranium from heterogeneous scrap materials generated both onsite and from offsite customers. The facility is still operating.

Oak Ridge National Laboratory

The Oak Ridge National Laboratory (ORNL), originally known as Clinton Laboratories, was established in 1943 to pioneer a method for producing and separating plutonium. The High Flux Isotope Reactor at ORNL achieved initial criticality in 1965 and utilized 93 percent HEU. The Oak Ridge Research Reactor at ORNL, which also used HEU fuel, achieved initial criticality in 1958 and was shut down in 1987. Today, the multiprogram laboratory is responsible for the development

of new energy sources, technologies and materials, and for advancing knowledge in the biological, computational, environmental, radiochemical, physical, and social sciences.

Paducah Gaseous Diffusion Plant

The Paducah Gaseous Diffusion Plant, near Paducah, Kentucky, was established in 1951 and was the second gaseous diffusion plant constructed. It produced massive quantities of uranium enriched to about 1.0 percent uranium-235 (low enriched uranium). This material was shipped from Paducah to the Portsmouth Gaseous Diffusion Plant and the K-25 Site for further enrichment. In 1993, management of the Paducah Plant was transferred to the United States Enrichment Corporation (USEC). USEC was created by Congress in the Energy Policy Act of 1992 in an attempt to transform DOE's uranium enrichment enterprise into a profitable business. As part of this activity, the Paducah Gaseous Diffusion Plant produces enriched uranium for civilian power reactors.

Savannah River Site

The Savannah River Site (SRS), formerly known as the Savannah River Plant, is located near Aiken, South Carolina. SRS was established in 1950 to produce nuclear materials (primarily plutonium and tritium) for national defense. The major nuclear facilities at SRS include fuel and target fabrication facilities, nuclear material production reactors, chemical separation plants used for recovery of plutonium and uranium isotopes, a uranium fuel processing area, and the Savannah River Technology Center, which provides process support. During times of full operation, HEU was shipped from the Y-12 Plant to SRS where it was fabricated into fuel for the production reactors. Residual HEU was recovered from fission products and recycled.

Y-12 Plant

Located in Oak Ridge, Tennessee, the Y-12 Plant was established in 1943 as part of the Manhattan Project. The site's first mission was the separation of uranium-235 from natural uranium using electromagnetic separation. The Y-12 Plant is the primary receiver, processor, and interim storage site of HEU, where material from disassembled warheads is shipped from the weapons stockpile to the Plant. Additionally, the Y-12 Plant continues to maintain the capability to fabricate materials (i.e., HEU) into components, inspect and certify the components, and produce weapons subassemblies from the components. The Y-12 Plant also performs some stockpile surveillance activities to ensure reliability of the nuclear weapons stockpile.

MIDWEST

ARGONNE NATIONAL LABORATORY - EAST

Argonne National Laboratory - East was established in 1946 near Chicago, Illinois. The laboratory conducts many missions, including basic research in energy and environmental technologies, computing and communications, biotechnology, and manufacturing technology. Argonne also conducts nuclear chemistry research and conducts small-scale demonstrations of advanced technology systems.

DIAMOND ALKALI COMPANY

Diamond Alkali Company (also known as Diamond Magnesium Company) was located in Painesville, Ohio. In the early to mid-1960s, Diamond Alkali processed uranium-coated particles

from uranium hexafluoride. As of September 1996, the site was owned by the Uniroyal Chemical Company and was undergoing environmental restoration.

Elk River Reactor

The Elk River Reactor, located in Elk River, Minnesota, was a 58-megawatt thermal boiling water reactor that used HEU fuel and was operated by the Rural Cooperative Power Association. The operating license was issued in 1962, and the plant was shut down in 1968. In 1974, the reactor was dismantled and removed from the site.

Enrico Fermi Atomic Power Plant, Unit 1

The Enrico Fermi Atomic Power Plant, Unit 1, also known as Fermi I, is located in Lagoona Beach, Michigan. Fermi I is a 200-megawatt thermal sodium-cooled fast reactor. Its operating license was granted in 1963, and the plant was shut down in 1972.

Feed Materials Production Center (Fernald)

The Feed Materials Production Center (currently known as the Fernald Environmental Management Project), is located 18 miles northwest of Cincinnati, Ohio. The site was established in 1951 to produce uranium metal. The mission at Fernald includes the removal or dispositioning of all site materials, decommissioning and decontaminating all site buildings and facilities, and returning the site to public use.

Iowa Army Ordnance Plant

The Iowa Army Ordnance Plant, in Burlington, Iowa, was established in 1947 primarily as a weapons assembly facility. This facility also manufactured high-explosive components for nuclear weapons from 1947 to 1975. In 1975, functions at the Burlington plant were transferred to the Pantex Plant, which remains the DOE's sole facility for weapon assembly, modification and dismantlement to the present day.

Kerr-McGee Corporation

The Kerr-McGee Corporation facility is located near Crescent, Oklahoma. This facility was operational from 1966 to 1975 and was operated by subsidiaries of Kerr-McGee Industries, Inc.

under an AEC license. There were two plants operating under NRC licenses: a Mixed Oxide Fuel Fabrication Plant and a Uranium Plant, which produced enriched uranium fuel. As of September 1996, this facility was included as part of the Nuclear Regulatory Commission (NRC) Site Decommissioning Management Plan and was in the final stages of decommissioning.

Minnesota Mining and Manufacturing

Minnesota Mining and Manufacturing (3M), located in St. Paul, Minnesota, fabricated uranium fuel elements in the early to mid-1960s. As of September 1996, this site was included as part of the NRC Site Decommissioning Management Plan and was undergoing decommissioning activities.

Pantex Plant

The Pantex Plant (formerly known as the Pantex Army Ordnance Plant), in Amarillo, Texas, was first used by the U.S. Army for loading conventional ammunition shells and bombs from 1942 to 1945. In 1951, the AEC began rehabilitating the plant for nuclear weapons operations. In the past, the Pantex Plant was primarily responsible for the fabrication of nonnuclear high-explosive components for nuclear weapons and for the assembly and final delivery of nuclear warheads to the Department of Defense. The Pantex Plant's mission includes the fabrication of chemical high explosives for nuclear weapons; assembly, disassembly, maintenance, and surveillance of nuclear weapons in the stockpile; dismantlement of nuclear weapons being retired from the stockpile; and interim storage of plutonium components from dismantled weapons. Weapons activities involve the handling (but not processing) of uranium, plutonium, and tritium compounds, as well as a variety of nonradioactive hazardous or toxic chemicals.

Portsmouth Gaseous Diffusion Plant

The Portsmouth Gaseous Diffusion Plant is located approximately 20 miles north of Portsmouth, Ohio, and approximately 4 miles southwest of Piketon, Ohio. The Plant was established in 1951 and was the last of the three gaseous diffusion plants constructed to enrich uranium. The primary mission of the site was to produce HEU for use in nuclear weapons. In the 1960s, it began serving the commercial nuclear power industry. In 1964, Portsmouth ceased producing HEU directly for nuclear weapons. From 1964 until production of HEU was terminated in 1992, the HEU produced at Portsmouth was provided for the Naval Nuclear Production Program. In 1993, management of the Portsmouth Gaseous Diffusion Plant was transferred to the USEC. USEC was created by Congress in the Energy Policy Act of 1992 in an attempt to transform DOE's uranium enrichment

enterprise into a profitable business. As part of this activity, the Portsmouth Gaseous Diffusion Plant produces enriched uranium for civilian power reactors.

United Nuclear Corporation, Chemical Operations Plant

The United Nuclear Corporation Chemical Operations Plant was built in 1956 and is located in Hematite, Missouri. Processing capabilities included conversion of uranium (in gaseous form) to uranium compounds and uranium metal, operation of a small scrap recovery facility, and blending of uranium compounds in the formation of pellets in a product form. All operations involving HEU were closed in 1974, and the facility was decontaminated. As of September 1996, the Plant was operating as an LEU facility.

Weldon Spring, Missouri

The Weldon Spring Plant is about 30 miles west of St. Louis, Missouri, and consists of a chemical plant and a quarry. Located on the site of a former Army ordnance production facility, Weldon Spring operated from 1956 to 1966 to sample and refine uranium ore for the AEC and manufacture production reactor fuel. The site is currently known as the Weldon Spring Site Remedial Action Project and is undergoing environmental restoration.

WEST

AEROJET-GENERAL NUCLEONICS

Aerojet-General Nucleonics, a subsidiary of the Aerojet-General Corporation, is located in San Ramon, California. From the late 1950s to the early 1970s, Aerojet-General Nucleonics was the prime contractor involved in developing nuclear rocket engine technology as part of the NERVA program, which ended in 1971.

AMCHITKA ISLAND TEST SITE

In October 1965, October 1969, and November 1971, three underground nuclear tests were conducted at the Amchitka Island Test Site in Alaska. The first test, named Project Long Shot, had a yield of approximately 80 kilotons and was part of the Vela Uniform Program. The second test,

named Project Milrow, had a yield of one megaton and was a weapons-related test. The third test, named Project Cannikin, had yield of less than five megatons and was also a weapons-related test. As of the date of this report, the site is undergoing environmental restoration.

Atomics International

Atomics International (a subsidiary of North American Aviation, Inc.) operated the Liquid Metal Engineering Center (LMEC), located in Canoga Park, California, as part of the AEC's sodium breeder program. Beginning in 1966, Atomics International utilized HEU in conducting research primarily related to the development of sodium-cooled nuclear power plants and space power systems and as fuel for Training, Research, Isotope, General Atomics (TRIGA) reactors. In 1978, LMEC was renamed as Energy Technology Engineering Center and was operated by Rockwell International. As of the date of this report, this facility has been decommissioned.

Carlsbad, New Mexico

The Project Gnome test was conducted in bedded salt approximately 31 miles southeast of Carlsbad, New Mexico, in December 1961. The purpose of the test was to determine the effects and products of a nuclear explosion in a salt medium. This underground nuclear detonation had a yield of 3 kilotons and was part of the Plowshare Program. As of the date of this report, the site is undergoing environmental restoration.

Central Nevada Test Area, Nevada

In January 1968, a subsurface nuclear test, named Project Faultless, was conducted at the Central Nevada Test Area. Project Faultless was detonated to determine the suitability of the area for additional testing. The site was decommissioned in 1973 and is currently undergoing environmental restoration.

Fallon, Nevada

In October 1963, an underground nuclear test, named Project Shoal, was conducted at Fallon, Nevada. Project Shoal was designed to determine the behavior and characteristics of seismic signals generated by nuclear detonations and to differentiate them from seismic signals generated by earthquakes. This detonation had a yield of 12 kilotons and was part of the Vela Uniform Program. As of the date of this report, the site is undergoing environmental restoration.

Farmington, New Mexico

The Gasbuggy Site, located approximately 55 miles east of Farmington, New Mexico, was the location of a single subsurface nuclear test in December 1967. The purpose of the test was to determine whether or not nuclear explosions would stimulate release of natural gas not recoverable by conventional methods. This detonation had a yield of 29 kilotons and was part of the Plowshare Program. As of the date of this report, the site is undergoing environmental restoration.

Fort St. Vrain Nuclear Generating Station

The Fort St. Vrain Nuclear Generating Station, operated by the Public Services Company of Colorado, is a high-temperature, gas-cooled reactor located in Platteville, Colorado. Fort St. Vrain first produced power in December 1976 with a capacity of 342 megawatts and used HEU fuel enriched to approximately 93.15 percent. In August 1989, the Fort St. Vrain reactor was shut down and subsequently decommissioned.

General Atomic Company

Beginning in 1959, the General Atomic Company operated a facility in San Diego, California, that developed and fabricated nuclear fuel for TRIGA reactors, the AEC's Space Nuclear Propulsion Program and gas-cooled reactors, including Fort St. Vrain. This facility had HEU for blending of fuel material, and extrusion and finishing of fuel elements. In 1996, General Atomic began decommissioning the site.

General Electric Company

The General Electric Company, Nuclear Energy Division, was located in San Jose, California. From the late 1950s to the mid-1970s, General Electric fabricated uranium fuel elements for use as reactor fuel and for research and development.

Hanford Site

The Hanford Site is located in southeastern Washington State just north of Richland. The site was established in early 1943 as part of the Manhattan Project with a purpose of building the first full-size reactors for the production of plutonium for nuclear weapons. Although defense production was a primary mission, the site now focuses on environmental restoration and waste management and related scientific and environmental research. As of September 1996, Hanford stored small quantities of HEU.

Idaho National Engineering and Environmental Laboratory

The Idaho National Engineering and Environmental Laboratory (INEEL) was established in 1949 as the National Reactor Testing Station with a purpose of providing an isolated location where prototype nuclear reactors could be designed, built, and tested. It is located near Idaho Falls, Idaho and is comprised of the INEEL and the Argonne National Laboratory - West (ANL-W). Over 52 research and test reactors at the INEEL have been used through the years to test reactor systems, fuel and target designs, and overall reactor safety. Facilities at INEEL that have used HEU include the Advanced Test Reactor, Engineering Test Reactor, Experimental Breeder Reactor II, Idaho Chemical Processing Plant, Materials Testing Reactor, and the Naval Reactor Facility. The Experimental Breeder Reactor II is located on the ANL-W portion of the INEEL site and was used to demonstrate the Integral Fast Reactor concept. The Idaho Chemical Processing Plant reprocessed spent reactor fuels in order to recover enriched uranium and other materials.

Lawrence Livermore National Laboratory

The Lawrence Livermore National Laboratory (LLNL) was established in 1952 as a nuclear weapons design laboratory and was formerly known as the Lawrence Radiation Laboratory. Its facilities are near Livermore, California. LLNL is a multidisciplinary research and engineering facility engaged in a variety of programs for DOE and other Government agencies. LLNL maintains research, design, development, testing (including nuclear testing), surveillance, assessment, and certification capabilities in support of the Stockpile Stewardship and Management Program.

Los Alamos National Laboratory

The Los Alamos National Laboratory (LANL) was established as a nuclear weapons design laboratory in 1943 and was formerly known as the Los Alamos Scientific Laboratory. Its facilities are located about 25 miles northwest of Santa Fe, New Mexico. LANL is a multidisciplinary research and engineering facility engaged in a variety of programs for DOE and other Government agencies. LANL maintains research, design, development, testing (including nuclear testing), surveillance, assessment, and certification capabilities in support of the Stockpile Stewardship and Management Program. Since the end of the Cold War, LANL has conducted pit surveillance and has manufactured some nonnuclear components due to termination of the nuclear weapons mission at other DOE sites.

Nellis Air Force Base

Nellis Air Force Base is located approximately 8 miles north of Las Vegas, Nevada, and covers more than 11,000 acres. The primary mission at Nellis is to advance the training of combat aircrews. Additionally, the Air Force conducts follow-on operational testing and tactics development and evaluation using the latest weapons systems. From 1957 through 1963, five nuclear tests were conducted at Nellis. Of these, four were storage transportation tests and one was a safety experiment.

Nevada Test Site

The Nevada Test Site (NTS) is about 65 miles northwest of the city of Las Vegas. The primary mission of NTS is to ensure the safety and reliability of the Nation's nuclear weapons stockpile. The first nuclear test at NTS was conducted in January 1951, with the last nuclear test occurring September 1992. Since the signing of the *Threshold Test Ban Treaty* in 1974, NTS has been the only U.S. site used for nuclear weapons testing. Today, the site retains the capability to resume testing, if authorized.

Rifle, Colorado

The AEC conducted the Rulison and Rio Blanco tests under the Plowshare Program to increase natural gas production from low-permeability sandstone. The Project Rulison detonation took place in September 1969 in a sandstone formation near Rifle, Colorado, and consisted of a yield of 40 kilotons. In May 1973, the Project Rio Blanco test, which was located approximately 36 miles northwest of Rifle, consisted of the nearly simultaneous detonation of three 33-kiloton devices.

Rocky Flats Environmental Technology Site

The Rocky Flats Environmental Technology Site (RFETS), formerly known as the Rocky Flats Plant, is near Golden, Colorado. Established in 1951, RFETS was one of the major nuclear weapons component fabrication sites. It began manufacturing HEU, plutonium, and depleted uranium pit parts in 1952. Ceasing nuclear component production in 1990, RFETS is no longer part of the DOE nuclear weapons complex. With the discontinuation of nuclear component production, the RFETS mission now focuses on special nuclear materials stabilization, and deactivation and decommissioning of facilities.

Sandia National Laboratories

Sandia National Laboratories (SNL) was established in 1945 as a nuclear weapons design laboratory. SNL has facilities in three locations: Albuquerque, New Mexico; Livermore, California; and Tonopah, Nevada. SNL is a multidisciplinary research and engineering facility engaged in a variety of programs for DOE and other Government agencies. SNL maintains research, design, development, testing (including nuclear testing), surveillance, assessment, and certification capabilities in support of the nuclear weapons Stockpile Stewardship and Management Program.

United Nuclear Homestake Site

The United Nuclear Homestake Site was a uranium milling facility located near Grants, New Mexico. The site was established in 1957 by the Phillips Petroleum Company and was later operated by the United Nuclear Corporation and the Homestake Mining Company. Work at the site included the milling of uranium ore into U_3O_8, and the extraction of uranium from mine water using an ion exchange system. As of September 1996, the site was undergoing environmental restoration.

White Sands Missile Range

The White Sands Missile Range is located near Alamogordo, New Mexico. On July 16, 1945, the first U.S. nuclear weapons test, code-named Trinity, was detonated at White Sands to test the feasibility of using nuclear weapons in warfare. The Trinity test was detonated above ground and had a yield of 21 kilotons.

APPENDIX C
U.S. HEU SPENT NUCLEAR FUEL INVENTORY

This appendix provides information on the location and quantity of spent nuclear fuel and other reactor irradiated nuclear materials containing highly enriched uranium (HEU) in storage at DOE facilities throughout the United States (U.S.) as of September 30, 1996. These quantities (summarized in Table C-1) are included as part of the overall U.S. HEU inventory (see Table 3-1). HEU in spent nuclear fuel is not weapons-usable unless it is reprocessed. While natural as well as low enriched uranium can be used as a reactor fuel, spent fuel produced from these materials is beyond the scope of this report.

BACKGROUND

When a reactor is operated, uranium atoms in the fuel undergo a process known as fission, where atoms are split and create energy. Fission also creates radioactive waste products (fission products) inside the fuel elements. After a time, but before all the uranium atoms are consumed, the radioactive fission products build up, causing inefficient use of the fuel. At this point, fuel elements are considered "spent" and are removed from the reactor, and new fuel elements are installed. When removed from a reactor, spent fuel elements are intensely radioactive due to the fission product content. To allow time for some of the radioactivity to die down, spent fuel is stored, usually under water, for several months, a step known as decay cooling.

Once the decay cooling step is complete, the valuable unused uranium can be recovered from the spent fuel and used in new fuel elements. The recovery sequence begins when the fuel assemblies are loaded into heavily shielded transfer casks and shipped to a fuel reprocessing plant. The recovery of uranium from spent fuel involves a series of operations, most of which are conducted by remote control in equipment installed behind massive concrete shielding walls. To obtain purified uranium, the spent fuel is dissolved in acid and the uranium is extracted from the resulting solution and purified.

The purified uranium product, uranyl nitrate, is essentially free of all fission products and other impurities. The uranyl nitrate solution may be converted to hexafluoride and recycled through the enrichment process to restore its uranium-235 concentration to the pre-irradiation level, or it may be converted to uranium dioxide and blended with material of higher uranium-235 content and ultimately remanufactured into reactor fuel.

Spent Fuel Reprocessing

Spent fuel containing HEU has been processed in the U.S. since 1953, primarily at DOE facilities in Idaho and South Carolina. In addition, small quantities of HEU spent fuel were processed at the Nuclear Fuel Services facility in West Valley, New York, in 1968. In 1992, the DOE ceased processing HEU spent fuel at Idaho. Savannah River has a defined mission to dispose of spent nuclear fuel and other reactor irradiated nuclear materials through processing.

Spent Fuel Storage

As a consequence of past policies, the DOE is storing large numbers of spent nuclear fuel and other reactor irradiated nuclear materials. DOE facilities that were designed, constructed, and operated to store spent nuclear fuel and other reactor irradiated nuclear materials for relatively short periods of time now store these materials pending disposition decisions.

In 1993, to ensure that the extended storage of these materials is safe, the DOE conducted an assessment of the environmental, safety, and health vulnerabilities associated with the storage of spent nuclear fuel and other reactor irradiated nuclear materials. Information on the results of the assessment are summarized in the DOE report, *Spent Fuel Working Group Report on Inventory and Storage of the Department's Spent Nuclear Fuel and Other Reactor Irradiated Nuclear Materials and Their Environmental, Safety and Health Vulnerabilities* (DOE 1993b).

As shown in **Table C-1**, approximately 82 percent of the HEU in spent nuclear fuel in the U.S. is stored at the Idaho National Engineering and Environmental Laboratory and the Savannah River Site. The remaining 18 percent is stored at eight other sites.

Idaho National Engineering and Environmental Laboratory

As shown in **Table C-2**, approximately **19.3** metric tons of uranium (MTU) in spent nuclear fuel is stored at the Idaho National Engineering and Environmental Laboratory (INEEL). Most of the spent fuel at INEEL is from naval propulsion and other government reactors and is stored primarily at the Idaho Chemical Processing Plant (ICPP). INEEL has also received spent fuel from university reactors and commercial reactors, as well as foreign research reactors that used U.S.-origin HEU. From 1953 to 1992, the ICPP processed spent nuclear fuel; in 1992, DOE ceased processing operations.

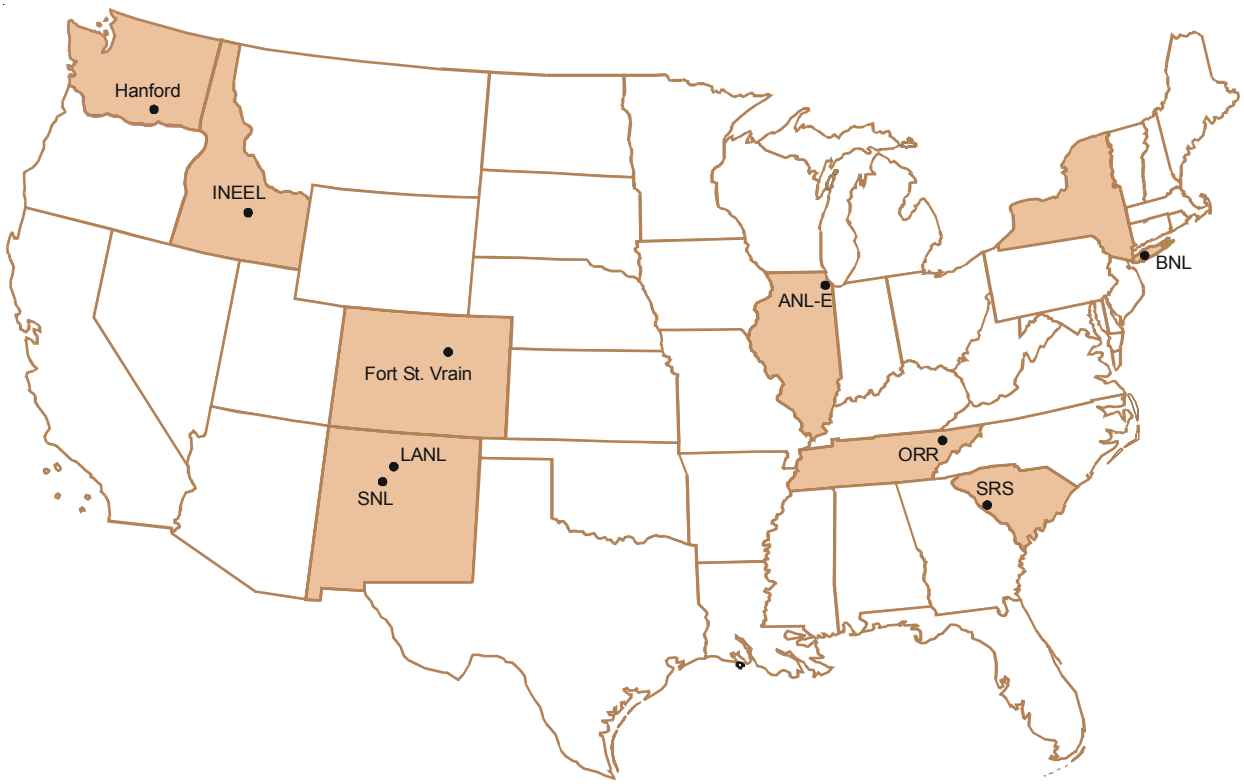
Savannah River Site

The Savannah River Site (SRS) has about **8.3** MTU in spent nuclear fuel, mostly from SRS production reactors. The remaining fuel is from foreign research, university, commercial, and other government-owned reactors (**Table C-3**). Currently, the SRS is accepting U.S.-origin HEU spent nuclear fuel from foreign research reactors to promote U.S. nuclear weapons nonproliferation policy objectives, by eventually eliminating HEU from civilian commerce worldwide. Foreign spent fuel is sent to the Savannah River Receiving Basin for Off-Site Fuel (RBOF) facility and the L Reactor disassembly basin.

Other DOE Sites

In addition, seven other Department-owned sites and the Naval Nuclear Propulsion Program store spent nuclear fuel and other reactor irradiated nuclear material (**Table C-4**). Site inventories range from 15 kilograms of HEU to approximately 3.6 MTU.

Table C-1 Location and Quantity of HEU in Spent Nuclear Fuel



Storage Site	kg U	kg U-235
Idaho National Engineering & Environmental Laboratory (INEEL)	19,281.4	12,952.6
Savannah River Site (SRS)	8,257.9	5,441.8
Other DOE Sites		
Argonne National Laboratory – East (ANL-E)	16.2	10.4
Brookhaven National Laboratory (BNL)	275.9	222.1
Hanford Site	230.7	63.3
Oak Ridge Reservation (ORR)	695.6	613.6
Sandia National Laboratory (SNL)	523.4	406.8
Miscellaneous Sites	4,475.5	3,436.1
Total HEU Spent Fuel in Storage	**33,756.4**	**23,146.5**

Notes:

1 Information is as of September 30, 1996.

2 Miscellaneous sites include the Los Alamos National Laboratory (LANL), Fort St. Vrain, and the naval reactor spent fuel in the possession of the U.S. Navy.

Table C-2 HEU Spent Fuel at INEEL

	kg U	kg U-235	% U-235
Advanced Test Reactor	1,661.0	1,395.8	84%
ARMF / CFMR	12.9	11.9	92%
Berlin Experimental Reactor (BER-2)	9.2	4.0	44%
Boiling Reactor Experiment V	20.8	19.4	93%
Engineering Test Reactor	9.3	4.9	53%
Enrico Fermi Atomic Power Plant	3,874.3	992.8	26%
Experimental Breeder Reactor - II	3,141.4	1,941.6	62%
Experimental Propulsion Test Reactor	107.7	100.3	93%
Fort St. Vrain Nuclear Generating Station	308.3	167.6	54%
Gas-Cooled Reactor Experiment	2.8	2.1	75%
General Electric Test Reactor	4.4	4.1	92%
Heat Transfer Reactor Experiment	1.1	1.0	93%
High Flux Beam Reactor	63.4	50.7	80%
Oak Ridge Research Reactor	3.3	2.6	80%
Naval Reactors	8,970.7	7,436.8	83%
Pathfinder Atomic PWR Plant	53.4	49.2	92%
Peach Bottom Unit 1	332.4	223.5	67%
Power Burst Facility	5.4	1.5	29%
Shippingport Atomic Power Station (SAPS)	521.7	396.0	76%
Special PWR Excursion Reactor Test	0.6	0.5	93%
Stationary Medical PWR Plant 1A	65.8	56.6	86%
Systems for Nuclear Auxiliary Power	28.8	26.8	93%
Transient Reactor Test	14.9	13.9	93%
TRIGA Reactors (Miscellaneous)	12.8	8.8	69%
University of Missouri – Rolla Reactor	38.0	33.3	87%
University of Washington – Argonaut Reactor	3.9	3.6	93%
Unknown	0.5	0.1	28%
Vallecitos Boiling Water Reactor (BWR)	12.6	2.8	22%
Total HEU Spent Fuel in Storage at INEEL	**19,281.4**	**12,952.2**	**67%**

Notes:

1 Information is as of September 30, 1996.

2 Information does not include naval reactor spent fuel stored at the Expended Core Facility.

Table C-3 HEU Spent Fuel at SRS

Source of Spent Fuel	kg U	kg U-235	% U-235
Argonne Thermal Source Reactor	3.2	3.0	93%
ASTRA	3.6	2.5	68%
Biological Research Reactor (JANUS)	2.8	2.6	93%
Commercial (Miscellaneous)	0.0	0.0	52%
Denmark (DR-3)	2.9	2.2	76%
Dresden – 1 Commercial Power Reactor	41.1	22.3	54%
Elk River Reactor	224.3	186.2	83%
Experimental Boiling Water Reactor	30.7	28.3	92%
Experimental Breeder Reactor – II	2.0	1.6	80%
FMRB	8.2	7.2	88%
FRG-1	4.4	3.6	82%
Gas Cooled Reactor Experiment	61.3	56.6	92%
Georgia Tech Research Reactor	4.5	4.0	90%
Greek Research Reactor	9.3	7.8	84%
Heat Transfer Reactor Experiment	4.0	3.4	85%
Heavy Water Components Test Reactor	39.8	33.8	85%
High Flux Isotope Reactor	23.5	20.3	86%
IAN – R1	3.1	2.8	91%
Japanese Material Test Reactor (JMTR)	16.7	14.8	88%
La Reina, RECH – 1	3.9	2.4	61%
MIT Research Reactor	19.4	16.0	82%
Mobile Low Power PWR Plant No. 1	58.6	54.5	93%
Oak Ridge Research Reactor	21.1	17.1	81%
Ohio State Research Reactor	3.4	3.2	93%
R Haut Flux (RHF) Reactor – France	25.5	20.8	81%
R-2 Research Reactor	16.6	12.0	72%
Rhode Island Nuclear Science Center	8.5	7.7	91%
Saphir – Switzerland	11.5	7.8	68%
Savannah River Site Production Reactors	7,295.5	4,624.4	63%
Sodium Reactor Experiment	156.0	143.4	92%
University of Delft (HOR)	4.0	3.1	77%
University of Missouri Research Reactor Columbia	103.6	90.7	88%
University of Missouri Rolla Reactor	4.8	4.3	90%
University of Virginia Reactor	6.9	6.1	88%
Unknown	0.2	0.2	97%
Vallecitos Boiling Water Reactor	4.0	1.0	25%
Sterling Forrest fuel	28.4	23.9	84%
ANL Mixed Oxide	0.4	0.4	86%
Total	**8,257.7**	**5,442.0**	**66%**

Note: Information is as of September 30, 1996.

Table C-4 Location of HEU Spent Fuel at Other DOE Sites

Location and Source of Spent Fuel	Kg U	Kg U-235	% U-235
Argonne National Laboratory – East			
Chicago Pile 5	1.2	1.1	92%
Experimental Breeder Reactor-II	6.1	3.5	57%
LMFBR Test Fuel	5.3	3.0	57%
Miscellaneous Irradiated Fuel	3.6	2.8	78%
Brookhaven National Laboratory			
Brookhaven Medical Research Reactor	4.9	4.3	88%
High Flux Beam Reactor	271.0	217.8	80%
Hanford Site			
Experimental Breeder Reactor-II	25.9	5.3	20%
FFTF Fuel	1.0	0.4	40%
LMFBR Test Fuel	203.8	57.6	28%
Oak Ridge Reservation			
Bulk Shielding Reactor	6.9	6.2	90%
Health Physics Research Reactor	104.1	96.9	93%
High Flux Isotope Reactor	575.4	501.9	87%
Tower Shielding Reactor No. II	9.2	8.6	93%
Sandia National Laboratory			
Annular Core Research Reactor	125.0	35.7	29%
Sandia Pulsed Reactor-II	139.0	129.4	93%
Sandia Pulsed Reactor-III	259.4	241.7	93%
Miscellaneous Sites (Storage Site in Parentheses)			
Fort St. Vrain (Fort St. Vrain)	822.4	404.5	49%
Naval Reactors (Possession of the U.S. Navy)	3,638.2	3,018.8	83%
Omega West Reactor (Los Alamos National Laboratory)	14.9	12.8	86%
Total	**6,217.3**	**4,752.3**	**76%**

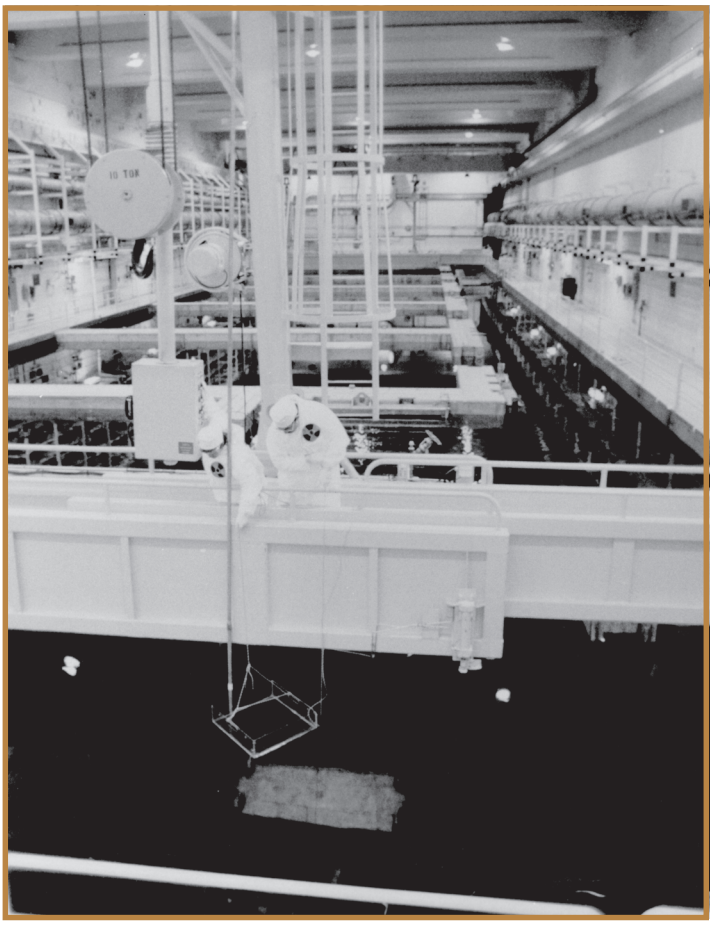
Notes:

1 Information is as of September 30, 1996.

2 The Naval Reactors quantity does not include HEU spent fuel stored at the Knolls Atomic Power Laboratory and the Bettis Atomic Power Laboratory.

The Idaho Chemical Processing Plant at INEEL recovered HEU from spent nuclear reactor fuel elements, mostly from government-owned reactors.

Shown is a view of workers inside the Idaho Chemical Processing Plant.



APPENDIX D
MILITARY REACTORS

NAVAL NUCLEAR PROPULSION PROGRAM

After World War II, the U.S. began to develop nuclear propulsion for the Navy. Admiral Hyman G. Rickover developed the U.S. Naval Nuclear Propulsion Program from the ground up. The initial ship, the U.S.S. *Nautilus* revolutionized naval warfare. Although the concept of using a reactor to produce energy was understood, no one had been successful in applying it. The difficulty was increased because the reactor was to be sent to sea where it had to operate safely and continuously to support Navy missions.

To ensure the high level of reliability needed for shipboard application of nuclear power, the program required its own special discipline, which must be adhered to—a discipline that is in effect to this day. Initially, the program had to develop new materials, design new components, ensure proper fabrication, and instill the new rigorous approach to training sailors for safe reactor operations. Then the new engineering concept had to be fitted inside a submarine pressure hull and designed to operate in the ocean depths. History shows that the program was successful in meeting all of the challenges.

One of the design challenges was to build a small reactor (to fit inside a small submarine hull) yet make it last a long time (refueling a submarine is costly and reduces its availability for fleet support). This reactor must withstand battle shock and rapid changes in power demands. These requirements led to the use of highly enriched uranium (HEU) as the nuclear fuel. As time has passed, the demands for long life and more powerful reactors have increased. These requirements have reinforced the early decisions to use HEU since it is the only way to meet the current military requirements for nuclear powered warships.

In April 1994, the U.S. Navy logged its 100 millionth mile using nuclear powered warships since the *Nautilus* radioed "Underway on nuclear power" on January 17, 1955. This has been accomplished without a nuclear accident, or harm to the public or the environment—a tribute to the thousands of people who design, build, operate, maintain, and dispose of our nuclear-powered warships.

Based on all current projections, there will continue to be a need for HEU for nuclear-powered warship fuel in the future to meet the increasing demands on the U.S. Navy of the 21st Century.

Summary of Naval Nuclear Propulsion Program

The following table summarizes the active Navy Nuclear Propulsion Program as of October 1997.

Table D-1 Summary of the Naval Nuclear Propulsion Program

Vessel Type	Hull Numbers	Number of Vessels
SSN 21 ☐ SEAWOLF	21 (22 & 23 are under construction)	1
SSN 637 ☐ STURGEON	637, 647, 660, 666, 674, 680, 681, 683, 686	9
SSN 640 ☐ BENJAMIN FRANKLIN	642 - converted from an FBM in 1992 645 - converted from an FBM in 1993	2
SSN 671 ☐ NARWHAL	671	1
SSN 688 ☐ LOS ANGELES	688, 690, 691, 697, 698, 699, 700, 701, 703, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773	54
SSBN 726 ☐ OHIO (TRIDENT)	726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743	18
NR 1	Deep Submergence Research Vessel	1
CVN 65 ☐ ENTERPRISE (Aircraft Carrier)	65	1
CVN 68 ☐ NIMITZ (Aircraft Carrier)	68, 69, 70, 71, 72, 73, 74 (75 & 76 are under construction)	7
CGN 36 ☐ CALIFORNIA (Cruiser)	36, 37	2
CGN 38 ☐ VIRGINIA (Cruiser)	40, 41	2
S8G	Trident Prototype Reactor	1
MARF	Modification and Additions to Reactor Facility	1

Commercial Nuclear Power

As part of President Eisenhower's "Atoms for Peace" program, the Naval Nuclear Propulsion Program designed, built, and successfully operated the Nation's first civilian nuclear power plant in Shippingport, Pennsylvania. The Navy freely disseminated the design details, manufacturing specifications, and operation and maintenance procedures to the scientific and engineering community and the public through symposia and the release of over 23,000 technical documents.

The Shippingport Atomic Power Plant (SAPS) established the technology basis for the pressurized water reactor design and core configurations used in commercial reactors throughout the world.

SAPS was operated by the Duquesne Light Company in cooperation with the U.S. Navy and AEC from 1957 until 1982. During that time, the plant was used to train civilian and Navy reactor operators, investigate alternative core designs and serve as a high power research reactor.

In 1965, the AEC investigated alternative light-water breeder reactors (LWBR), which generated more fissionable material than they consumed. In 1977, the SAPS reactor core was loaded with uranium-233 as its "fissile" material, and thorium as the "fertile" material. The LWBR core proved to be very reliable and supplied power to the Pittsburgh area for five years. Extensive end-of-life testing by the Navy confirmed that the LWBR operated as planned. In fact, breeding occurred at a rate higher than predicted, and performance of the core material was excellent.

In 1982, the DOE decommissioned SAPS, removing all radioactive components and returning the site to "park land."

Army Nuclear Power Program

The Army Nuclear Power Program (ANPP) was a joint venture of the Department of Defense (DoD) and the AEC. It was the sole agency for all three military services (Army, Navy, and Air Force) responsible for developing nuclear power systems to meet defense requirements, other than for naval vessel propulsion or for air and space vehicle applications. The ANPP was initiated in 1954; during its lifetime, it designed, constructed, operated, and deactivated nine nuclear power plants as described in this appendix. By 1977, due to changing military requirements and funding limitations, major program activities had ceased when the last ANPP facility was deactivated.

Oversight responsibility for deactivated ANPP facilities rests with the U.S. Army Nuclear and Chemical Agency (USANCA) located at Ft. Belvoir, Virginia. The ANPP is not associated with the DOE, the successor to the AEC, and that the nuclear power plants developed by the ANPP were not licensed by the Nuclear Regulatory Commission (NRC); however, USANCA follows NRC requirements as close as possible.

The ANPP pioneered many technical innovations and produced many achievements during its existence, including:

- Detailed designs for pressurized water reactors (PWR), boiling water reactors (BWR), gas-cooled reactors (GCR), and liquid-metal-cooled reactors (LMCR).
- First nuclear power plant with a containment structure (SM-1 at Ft. Belvoir, Virginia).
- First use of stainless steel for nuclear fuel cladding (SM-1).
- First nuclear power plant to furnish electrical power to a commercial grid (SM-1).

- First in-place reactor vessel annealing within the U.S. (SM-1A at Ft. Greely, Alaska).
- First steam generator replacement within the U.S. (SM-1A).
- First prepackaged nuclear power plant to be installed, operated, and subsequently removed (PM-2A at Camp Century, Greenland).
- First use of nuclear power to desalinate water (PM-3A at McMurdo Sound, Antarctica).
- First land transportable nuclear power plant (ML-1 at the National Reactor Testing Station in Idaho).
- First nuclear powered closed-loop gas turbine cycle (ML-1).

Nuclear Power Plants Constructed and Operated

The two gas cooled reactors in the Army Nuclear Power Program were:

- The Gas Cooled Reactor Experiment (GCRE), located at the National Reactor Testing Station (later renamed the Idaho National Engineering and Environmental Laboratory [INEEL]), was designed by Aerojet General Corporation to test gas cooled reactor behavior, evaluate components, test fuel elements, and obtain technical information. This reactor reached initial criticality in 1959 and was shut down in 1962. Although some spent fuel was retained at INEEL, most was sent to the Savannah River Site (SRS).
- The Mobil Low Power Plant (ML-1), located at INEEL, was designed by Aerojet General Corporation to test an integrated reactor package that was transportable by military semi-trailers, railroad flatcars, and barges. This reactor reached initial criticality March 30, 1961, and was shut down in 1965. The spent fuel from this reactor was sent to SRS.

The following is a list of the six pressurized water reactors in the ANPP:

- The Mobile High Power Plant (MH-1A), located in Virginia, was designed by Martin Marietta Corporation and was installed on a converted Liberty ship named *Sturgis*. It remained moored at Gatun Lake in the Panama Canal from 1968 until 1977. This reactor reached initial criticality January 24, 1967, and was shut down in 1977. This reactor had a total of five cores and used LEU in the range of 4 to 7 percent with a total amount of uranium-235 supplied being 541.4 kg. The spent fuel from this reactor was sent to SRS.
- The Portable Medium Power Plant (PM-1) in Sundance, Wyoming, was designed by the Martin Company and provided electric power to the 731st Radar Squadron of the North American Air Defense Command (NORAD). This Plant reached initial criticality February 25, 1962, and was shut down in 1968. The reactor had two cores with the total amount of uranium-235 supplied being 60.8 kg. PM-1 operated at a uranium-235 enrichment of 93 percent. The spent fuel from the first core was sent to SRS and the fuel from the second core was sent to the Portable Medium Power Plant (PM-3A) located in McMurdo Sound, Antartica.
- The Portable Medium Power Plant (PM-2A) in Camp Century, Greenland, was designed by the American Locomotive Company to demonstrate the ability to assemble a nuclear power plant from prefabricated components in a remote, arctic location. The pressure vessel was subsequently used to investigate neutron embrittlement in carbon steel. This Plant reached initial criticality October 3, 1960, and was shut down 1963-1964. This reactor had one core with the total amount of uranium-235 supplied being 18.2 kg. PM-2A operated

at a uranium-235 enrichment of 93 percent. The spent fuel from this reactor was sent to SRS.

- The Portable Medium Power Plant (PM-3A), located in McMurdo Sound, Antartica, was designed by the Martin Company to provide electric power and steam heating to the Naval Air Facility at McMurdo Sound. This Plant reached initial criticality March 3, 1962, and was shut down in 1972. The reactor had a total of five cores with a total amount of uranium-235 supplied being 121.6 kg. PM-3A operated at a uranium-235 enrichment of 93 percent. The spent fuel from all five reactors was sent to SRS.
- The Stationary Medium Power Plant (SM-1), located at Ft. Belvoir, Virginia, was designed by the American Locomotive Company and was the first reactor developed under the Army Nuclear Power Program. This Plant was used to train Army nuclear plant operators. SM-1 was also the first reactor built with a containment structure. It reached initial criticality on April 8, 1957 and was shut down from 1973-1975. This reactor had a total of three cores with the total amount of uranium-235 supplied being 72.7 kg. SM-1 operated at a uranium-235 enrichment of 93 percent. The spent fuel from the first core was sent to INEEL, and the fuel from the second and third core was sent to SRS.
- The Stationary Medium Power Plant (SM-1A) at Ft. Greely, Alaska, was designed by the American Locomotive Company and was the first field facility developed under the Army Nuclear Power Program. This site was selected to develop construction methods in a remote, arctic location. SM-1A reached initial criticality March 13, 1962 and was shut down in 1972. This reactor had a total of four cores with the total amount of uranium-235 supplied being 117.1 kg. SM-1A operated at a uranium-235 enrichment of 93 percent. The spent fuel from the first and second cores was sent to SRS, and the fuel from the third and fourth cores was sent to INEEL.

Below is a description of the only boiling water reactor in the ANPP:

- The Stationary Low Power Plant (SL-1), located at INEEL, was designed by the Argonne National Laboratory to gain experience in boiling water reactor operations, develop performance characteristics, train military crews, and test components. The SL-1 reactor reached initial criticality on August 11, 1958 and had only one core. Combustion Engineering was awarded a contract by the AEC to operate the SL-1 and in turn employed the Army's military operating crew to continue running the plant. On January 3, 1961, the SL-1 was destroyed in an accident that caused the death of the three-man operating crew.

Other Nuclear Plant Designs and Concepts

The following is a list of proposed nuclear plants that were never built:

- The Mobil Low Power Plant (ML-1A) was to be a gas cooled reactor and the first planned field unit for the ML-1 series of reactors.
- The Portable Low Power Plant (PL-1) was to be a boiling water reactor to supply power for remote locations using 3 MW thermal power. The Plant was to be based on a low enriched tubular core with pelletized fuel. It would have been air transportable in 11 packages. The design for this Plant was completed on June 30, 1961.

- The Portable Low Power Plant (PL-2) was also intended to be a boiling water reactor and supply power for remote locations using 10 MW thermal power. The Plant was to use LEU pelletized fuel in a tubular core. It also would have been air transportable in 11 packages. The design for this Plant was also completed June 30, 1961.
- The Portable Low Power Plant (PL-3) was to be a pressurized water reactor and supply power for remote location using 9.3 MW thermal power. This Plant was to be based on high-enriched plate-type fuel.
- The Stationary Medium Power Plant (SM-2) was also intended to be a pressurized water reactor and the prototype for the SM-2 series of reactors to use 28 MW thermal power. This Plant was to be based on high-enriched plate-type fuel.
- The Stationary Medium Power Plant (SM-2A) was to be a pressurized water reactor and was intended to be the first planned field unit for the SM-2 series of reactors.
- The Military Compact Reactor (MCR) was to be a liquid-metal-cooled reactor. The development for this reactor ran from December 1955 to December 1965. The initial concept was for this reactor in a heavy overland cargo hauler. Later, it was transferred to the Nuclear Power Energy Depot program, which investigated ways to produce synthetic fuels in combat zones.

The Stationary Medium Power Plant (SM-1), located at Ft. Belvoir, Virginia, was the first reactor developed under the Army Nuclear Power Program.

Appendix E
Agreements for Cooperation with Foreign Countries

This appendix provides information on the quantities of HEU exported to foreign countries under international agreements for cooperation for peaceful uses of atomic energy. Under these agreements, the U.S. exported HEU to foreign countries for use in research applications, primarily as fuel for research reactors. As part of these agreements, the U.S. agreed to accept the return of this material primarily in the form of spent nuclear fuel. This appendix does not include HEU exported to foreign countries under mutual defense agreements and the acquisition of HEU from the former Soviet Republic of Kazakhstan.

For the purposes of this report, information on foreign countries is broken out into four geographical regions: (1) Middle East and South Africa, (2) Europe, (3) North and South America, and (4) Asia and Australia. Countries that are members of the International Atomic Energy Agency (IAEA) and countries that have signed the Treaty on the Non-Proliferation of Nuclear Weapons (NPT)[12] are identified.

HEU Transfers to Foreign Countries

- ✓ First destination does not mean that the receiving country was the ultimate destination for the U.S.-origin HEU but, in fact, is the first foreign country to receive the material.
- ✓ Retransfers of U.S.-origin HEU from one foreign country to another are not accounted for in this report. The U.S. relies on the IAEA to apply international safeguards on U.S.-origin HEU retransferred from one foreign country to another.

Background

The U.S. began exporting HEU in the 1950s as part of President Eisenhower's "Atoms for Peace" program. A series of agreements and treaties between the U.S. and many foreign countries allowed the export of nuclear materials and technology to assist the countries in nuclear research for power and medical purposes. These agreements established guidelines and procedures for the use of the material supplied. For example, material supplied for civil use would not be diverted for military use. The majority of the enriched uranium supplied to foreign countries was for use in experimental and research reactors.

Section 6 of this report provides the quantities of HEU exported to foreign countries of first destination. First destination does not necessarily mean that the receiving country was the ultimate destination for the U.S.-origin HEU, but in fact is the first foreign receipt of the material.

[12] The NPT was a landmark international treaty whose objectives are to prevent the spread of nuclear weapons and weapons technology, to foster the peaceful uses of atomic energy, and to further the goal of achieving general and complete disarmament. The Treaty establishes a safeguards system under the responsibility of the IAEA, which also plays a central role under the Treaty in areas of technology transfer for peaceful purposes.

For example, HEU sent to France for fabrication into reactor fuel for a Swiss reactor is counted as a delivery to France, not to Switzerland. U.S.-origin HEU has been routinely retransferred from a country of first destination to another country. While this type of transaction is not addressed in this report, this information is provided in the report entitled, *The United States Nuclear Regulatory Commission's Report to Congress on the Disposition of Highly Enriched Uranium Previously Exported from the United States (NRC 1993).*

These agreements also called for the return of the nuclear materials when it was spent or no longer required by the recipient country. Section 5 of this report provides the quantities of U.S.-origin HEU returned to the U.S. from foreign countries under agreements for cooperation.

Middle East and South Africa

The U.S. exported 63 kilograms of HEU to South Africa and three countries in the Middle East: Iran, Israel, and Turkey. All of these countries are members of the IAEA. Iran, Turkey, and South Africa are signatories of the NPT.

Iran

The U.S. shipped 6 kilograms of HEU to Iran in September 1967 as fabricated fuel for a research reactor.

This pool type reactor achieved initial criticality in October 1967 and is used for basic research, isotope production, neutron radiography, and training. In addition, small quantities of HEU as samples and standards were also shipped to Iran.

Israel

A total of 19 kilograms of HEU reactor fuel was shipped from the U.S. to Israel from 1960 to 1975. The majority of the material was fuel for the Israel Research Reactor 1 (IRR-1). This pool type reactor began operation in June 1960 and is used for on-line isotope separation, training, and activation analysis.

TURKEY

The U.S. shipped 5 kilograms of HEU to Turkey in September 1961 as the initial core load for the Turkish Research Reactor 1 (TR-1). The reactor went critical in January 1962 and operated until September 1977. Turkey has also received U.S.-origin HEU that was fabricated as reactor fuel in France for a second research reactor, TR-2. The TR-2 research reactor began operation in 1981 and was shut down in 1995. Both research reactors are pool-type reactors used for nuclear research, training, and isotope production. In 1986, a total of 5 kilograms of HEU was returned to the Idaho Chemical Processing Plant as spent reactor fuel from the TR-1 reactor.

SOUTH AFRICA

The U.S. shipped 33 kilograms of HEU to South Africa from 1965 to 1975 for use in the Safari-1 reactor. The Safari-1 reactor is a tank type research reactor that achieved an initial criticality in 1965. The reactor is used for neutron capture reactions, fission reactions, activation analysis, and training. In the 1970s, a total of 34 kilograms of HEU was returned to the Savannah River Site as spent reactor fuel from South Africa.

EUROPE

The U.S. exported over 21 metric tons of HEU to 15 countries in Europe. Most of this material was sent to Euratom countries.

All of the 15 countries identified in the map are members of the IAEA and are signatories of the NPT. All are members of Euratom with the exception of Romania, Slovenia, and Switzerland.

EURATOM

The European Atomic Energy Community (Euratom) was established in 1957. Euratom is responsible for nuclear safety, safeguards, and the peaceful use of nuclear energy within the European Community. As of September 1996, membership included Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and the United Kingdom.

Since 1957, the U.S. has shipped a total of 21,101 kilograms of HEU to Euratom countries. Specific quantities by country are shown in Section 6 of this report. The material supplied was for use in research applications, including research materials testing, experimental reactors and reactor experiments. Euratom countries have many reactors that currently use or have used HEU, these reactors include: pool-type reactors, Argonaut-type reactors, critical assembly reactors, TRIGA reactors, heavy water reactors, tank-type reactors, fast flux research reactors, liquid metal fast breeder reactors, and homogeneous reactors. The reactors are used for materials testing, analysis and irradiation, medical applications, astrophysics and propulsion, detector calibration, nuclear fuel cycle experiments, isotope production and separation, neutron radiography and spectroscopy, reactor physics, and training.

Within Euratom countries, large quantities of U.S.-origin HEU have been retransferred. For example, France and the United Kingdom have used U.S.-origin HEU to fabricate fuel for use in Euratom research reactors. In addition, Euratom countries have retransferred HEU to non-Euratom countries.

Romania

The U.S. shipped 39 kilograms of HEU to Romania during the late 1970s. The material was for use in the TRIGA II research reactor. This reactor is a TRIGA II dual core test reactor and is used for fuel testing, neutron spectroscopy, and electronic isolation material.

Slovenia

The U.S. shipped 5 kilograms of HEU to Slovenia (formerly Yugoslavia) during the 1970s. The material was for use in the TRIGA Mark II research reactor. This reactor is used for neutron dosimetry, neutron physics, neutron radiography, silicon doping, solid state physics, gamma scanning of nuclear fuel, and training.

Switzerland

The U.S. shipped 9 kilograms of HEU to Switzerland during the 1960s. The material was primarily for use in three reactors: Saphir, Diorit, and AGN 211 P. Saphir is a pool-type research reactor. Diorit is a tank-type research reactor and was shut down in 1977. AGN 211 P is a homogenous training reactor. These reactors are used for radioisotope production, activation analysis, gemstone color enhancement, and training.

North and South America

The U.S. exported over 2 metric tons of HEU to five countries in North and South America: Argentina, Brazil, Canada, Colombia, and Mexico. Most of this material was sent to Canada. All of these countries are members of the IAEA and all are signatories of the NPT .

Argentina

The U.S. shipped 58 kilograms of HEU to Argentina from 1964 through 1973. The material was for use in the RA-3 research reactor. The RA-3 is a pool-type reactor that is used for neutron radiography, isotope production, and training.

Brazil

The U.S. shipped 8 kilograms of HEU to Brazil from 1968 through 1978. The material was for use in the IEA-R1 research reactor. The IEA-R1 is a pool-type reactor that is used for neutron physics, isotope production, and training.

Canada

Since the 1950s, the U.S. has shipped a total of 2,187 kilograms of HEU to Canada. Canada has 12 research reactors that use or have used HEU. The types of reactors include heavy water, pool, and Safe Low-Power Kritical Experiment (SLOWPOKE). The reactors are used for neutron transmutation, doping of silicon, gemstone color enhancement, fusion blanket research, neutron activation analysis, training, and loss of coolant accident analysis. Beginning in the 1960s, a total of 702 kilograms of HEU was returned to either the Savannah River Site or the Idaho Chemical Processing Plant as spent reactor fuel from Canada.

Colombia

The U.S. shipped 3 kilograms of HEU to Colombia in 1964 and 1973. The material was for use in the IAN-R1 research reactor. The IAN-R1 was a pool-type reactor that was used for neutron physics, nuclear engineering, material testing, and training.

Mexico

The U.S. shipped 11 kilograms of HEU to Mexico from 1977 through 1981. The material was for use in the TRIGA Mark III research reactor. The reactor is used for dosimetry, neutron diffraction, neutrography, and training.

Asia and Australia

The U.S. exported over 2 metric tons of HEU to Australia and six countries in Asia: Japan, Pakistan, the Philippines, South Korea, Taiwan, and Thailand. Most of this material was sent to Japan. All of these countries are members of the IAEA. All are signatories of the NPT with the exception of Pakistan.

Australia

The U.S. shipped 10 kilograms of HEU to Australia from 1958 through 1964. The material was for use in the Moata and HIFAR research reactors.

The Moata is an Argonaut-type reactor and the HIFAR is a heavy water-type research reactor. The reactors are used for production of medical radioisotopes, silicon irradiation, and for neutron diffraction research.

Japan

The U.S. shipped a total of 2,054 kilograms of HEU to Japan primarily in the 1960s and 1970s. Japan has 14 reactors that use or have used HEU. The types of reactors include, heavy water test, Argonaut training, pool research, tank research, critical assembly, and fast research. The reactors

are used for reactor physics, reactor noise analysis, biological effects of low dose rate, fission tract dating, detector testing, boron neutron capture therapy, doping of silicon, tritium handling, studies on high and low temperature irradiation, thorium cycle, and training. Beginning in the 1970s, a total of 342 kilograms of HEU was returned to either the Savannah River Site or the Idaho Chemical Processing Plant as spent reactor fuel.

Pakistan

The Pakistan Research Reactor-1 (PARR-1) received its initial core load of 6 kilograms of HEU from the U.S. in March 1965. The reactor achieved initial criticality in December 1965.

Philippines

The U.S. shipped a total of 3 kilograms of HEU to the Philippines in 1967. The material was for use in the Philippines Research Reactor (PRR-1), a pool-type reactor, used for basic research.

South Korea

The U.S. shipped 28 kilograms of HEU to South Korea from 1974 through 1978. The material was for use in the TRIGA Mark-III and the TRIGA Mark-II research reactors. The reactors were used for solid state experiments, activation analysis, texture studies, and training.

Taiwan

The U.S. shipped 10 kilograms of HEU to Taiwan from 1967 through 1973. The material was for use in the Thor TRIGA research reactor. The reactor is used for neutron physics, chemistry, reactor engineering, radiation measurement, radiochemistry, and training.

Thailand

The U.S. shipped 5 kilograms of HEU to Thailand in 1962. The material was for use in the TRR-1/M1 TRIGA Mark III research reactor. The reactor is used for neutron activation analysis, and gem stone color enhancements.

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APPENDIX F
GLOSSARY OF TERMS

Accountability: That part of the safeguards and security program that encompasses the measurement and inventory verification systems, records, and reports to account for nuclear materials.

Assay: Measurement that establishes the total quantity of the isotope of an element and the total quantity of that element.

Atom: The basic component of all matter. Atoms are the smallest part of an element that have all of the chemical properties of that element. Atoms consist of a nucleus of protons and neutrons surrounded by electrons.

Atomic energy: All forms of energy released in the course of nuclear fission or nuclear transformation.

Atomic weapon: Any device utilizing atomic energy, exclusive of the means for transportation or propelling the device (where such means is a separable and divisible part of the device), the principal purpose of which is for use as, or for development of, a weapon, a weapon prototype, or a weapon test device.

Blending: The intentional mixing of two different assays of the same material in order to achieve a desired third assay.

Book inventory: The quantity of nuclear material present at a given time as reflected by accounting records.

Burnup: A measure of consumption of fissionable material in reactor fuel. Burnup can be expressed as (a) the percentage of fissionable atoms that have undergone fission or capture, or (b) the amount of energy produced per unit weight of fuel in the reactor.

Chain reaction: A self-sustaining series of nuclear fission reactions. Neutrons produced by fission cause more fission. Chain reactions are essential to the functioning of nuclear reactors and weapons.

Chemical separation: A process for extracting uranium and plutonium from dissolved spent nuclear fuel and irradiated targets. The fission products that are left behind are high-level wastes. Chemical separation is also used for reprocessing.

Conversion: A process by which the chemical or physical properties of a material are changed to facilitate further use.

Criticality: A term describing the condition necessary for sustained nuclear chain reaction.

Decay (radioactive): Spontaneous disintegration of the nucleus of an unstable atom, resulting in the emission of particles and energy.

Depleted uranium: Uranium that has a concentration of the uranium-235 isotope less than that occurring in nature (i.e., less than 0.711 percent).

Down blending: Reducing the concentration of the uranium-235 isotope in a given quantity of uranium.

Enriched material: Material in which the percentage of a given isotope has been artificially increased so that it is higher than the percentage of that isotope naturally found in the material. Enriched uranium contains more of the fissionable isotope uranium-235 than the naturally occurring percentage, which is 0.711.

Enriched uranium: Uranium that contains more of the fissionable isotope uranium-235 than the naturally occurring percentage, which is 0.711.

Enrichment: The process of increasing the relative concentration of a desired constituent (especially an isotopic constituent).

Fissile: The capability of being split by a low-energy neutron. The most common fissile isotopes are uranium-235 and plutonium-239.

Fission: The splitting or breaking apart of the nucleus of a heavy atom like uranium or plutonium, usually caused by the absorption of a neutron. Large amounts of energy and one or more neutrons are released when an atom fissions.

Fissionable: A nuclide capable of undergoing fission by any process.

Fuel: Natural or enriched uranium that sustains the fission chain reaction in a nuclear reactor.

Fuel element: Nuclear reactor fuel including both the fissile and structural materials, such as cladding, typically in the shape of a long cylinder or plate.

Gaseous diffusion: A uranium enrichment process based on the difference in rates at which uranium isotopes in the form of gaseous uranium hexafluoride diffuse through a porous barrier.

Half-life: The time it takes for one-half of any given number of unstable atoms to decay. Each isotope has its own characteristic half-life. Half-lives range from small fractions of a second to billions of years.

Highly enriched uranium: Uranium having a uranium-235 isotopic weight percent of 20 or more.

Holdup: The amount of nuclear material remaining in process equipment and facilities after the process material, stored materials, and product have been removed. Estimates or measured values of materials in holdup may be reflected in the facility's inventory records.

Inventory: (a) Book Inventory: The quantity of nuclear material present at a given time as reflected by accounting records; (b) Physical Inventory: The quantity of nuclear material that is determined to be on hand by physically ascertaining its presence using techniques that include sampling, weighing, and analysis.

Inventory difference: The algebraic difference between the nuclear material book inventory and a physical inventory.

Isotopes: Different forms of the same chemical element that differ only by the number of neutrons in their nucleus. Most elements have more than one naturally occurring isotope. Many more isotopes have been produced in reactors and scientific laboratories.

Low enriched uranium: Uranium having a uranium-235 isotopic weight percent of less than 20, but greater than natural.

Material balance: The comparison of input and output of material quantities for a process. Generally, the comparison of beginning inventory plus receipts with ending inventory plus shipments plus measured discards for a specific time interval.

Material control and accountability: The use of measurements, analyses, records, and reports to maintain knowledge of the quantities of nuclear materials present in each accountability area of a facility and the use of physical inventories and material balances to verify the presence of materials or to detect loss of materials after it occurs.

Material unaccounted for (MUF): An obsolete DOE term. See "Inventory Difference."

Measurement: The process of obtaining numerical results from experiments designed to determine a value for the physical, chemical, or isotopic property of a material or physical system. All measurements have associated random and systematic errors.

Molecules: Larger structures formed by the bonding of atoms.

Natural uranium: Uranium that has not been through the enrichment process. It is made of 99.3 percent uranium-238 and 0.7 percent uranium-235.

Neutron: A subatomic particle found in the nucleus of an atom. Together with protons, neutrons makeup 99.9 percent of an atom's mass. Uranium and plutonium atoms fission when they absorb neutrons; therefore the chain reactions that make nuclear reactors and weapons work depend on neutrons. Manmade elements can be manufactured by bombarding natural and other man-made elements with neutrons in reactors.

Normal operating loss (NOL): The measured loss of material (solids, liquids, or gases) that is separated from a process stream as waste and is not intended to be recovered. NOLs include material (1) discharged to tanks or stored in drums or other containers; (2) discharged to settling ponds, sewers, cribs, stacks, or burial grounds; (3) discarded in contaminated items such as equipment, laundry, and shoe covers; or (4) otherwise lost or discarded. NOLs must be determined by measurement or by estimate on the basis of measurement.

Nuclear components: Those nuclear explosive or device parts or subassemblies that contain fissile and/or radioactive and other materials.

Nuclear Materials Management and Safeguards System (NMMSS): The national database and information support system for nuclear materials controlled by the U.S. Government, created to support national safeguards and management objectives in the domestic and foreign utilization of nuclear resources.

Nuclear reactor: A device that sustains a controlled nuclear fission chain reaction.

Nuclear Regulatory Commission (NRC): An independent agency of the Federal Government created by the Energy Reorganization Act of 1974, which abolished the AEC and transferred its regulatory function to the NRC. The NRC is responsible for ensuring adequate protection of public health and safety, the common defense and security, and the environment in the use of nuclear materials in the United States. It is also responsible for regulation of commercial nuclear power reactors; nonpower research, test, and training reactors; fuel cycle facilities; medical, academic, and industrial uses of nuclear materials; and the transport, storage, and disposal of nuclear materials as waste.

Nuclear weapons complex: The chain of foundries, uranium enrichment plants, nuclear reactors, chemical separation plants, factories, laboratories, assembly plants, and test sites that produces nuclear weapons.

Nucleus: The protons and neutrons at the center of an atom that determine its identity and chemical and nuclear properties.

Physical inventory: The quantity of material that is determined to be on hand by physically ascertaining its presence using techniques that include sampling, weighing and analysis. The process of identifying, physically locating, and determining accountability values for nuclear material on hand.

Plutonium: A manmade fissile element. Pure plutonium is a silvery metal that is heavier than lead. Material rich in the plutonium-239 isotope is preferred for manufacturing nuclear weapons. Plutonium-239 has a half-life of 24,000 years.

Production reactor: A nuclear reactor that is designed to produce tritium or plutonium. The United States had 14 such reactors: nine at the Hanford Site and five at the Savannah River Site.

Proton: A positively charged subatomic particle. All atoms of the same chemical element have the same number of protons. The number of protons in the atom is the atomic number of the element.

Research reactor: A class of nuclear reactors used to do research into nuclear physics, reactor materials and design, and nuclear medicine. Some research reactors also produce isotopes for industrial and medical use.

Safeguards: An integrated system of physical protection, material accounting, and material control measures designed to deter, prevent, detect, and respond to unauthorized possession, use, or sabotage of nuclear materials. Safeguards include the timely indication of possible diversion, and credible assurance that no diversion has occurred.

Special nuclear material (SNM): Plutonium, uranium enriched in the isotope 233 or in the isotope 235, and any other material which, pursuant to the provisions of Section 51 of the Atomic Energy Act of 1954, as amended, has been determined to be special nuclear material.

Spent fuel: Nuclear fuel removed from a reactor following irradiation or that is no longer usable because of depletion of fissile material, poison buildup, or radiation damage.

Spent fuel reprocessing: The processing of spent nuclear fuel, after its use in a reactor, to remove fission products and to recover fissile and other valuable materials.

Tails: Uranium depleted in uranium-235 and withdrawn from the bottom stages of an isotope enrichment plant.

Transactions: Any recorded change affecting the inventory data base.

Transmutation: The conversion of one isotope into another isotope achieved through the capture or loss of subatomic particles such as neutrons, protons, alpha particles, gamma rays, etc. For uranium, two transmutation processes are important: (1) the capture of a neutron by uranium-235 leading to the production of uranium-236. This process is sometimes termed "parasitic capture" since uranium-235 fission does not occur, and (2) the capture of a neutron by uranium-238 leading to the production of uranium-239, followed by two radioactive (beta) decays that produce plutonium-239 (a manmade fissile material).

Uranium: The basic material for nuclear technology. It is a slightly radioactive naturally occurring heavy metal that is more dense than lead.

Uranium hexafluoride: A volatile compound of uranium and fluorine, symbol UF_6, used in the gaseous diffusion process.

Uranium-233: A manmade fissile isotope of uranium.

Uranium-235: The lighter of the two main isotopes of uranium. Uranium-235 makes up less than 1 percent of the uranium that is mined from the ground. It has a half-life of 714 million years. Uranium-235 is the only naturally occurring fissile element.

Uranium-238: The heavier of the two main isotopes of uranium. Uranium-238 makes up over 99 percent of uranium as it is mined from the ground. It has a half-life of 4.5 billion years and is not easily split by neutrons.

Yellowcake: A common uranium compound, U_3O_8, named for its typical color. Uranium is sent from the uranium mill to the refinery in this form.

APPENDIX G
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