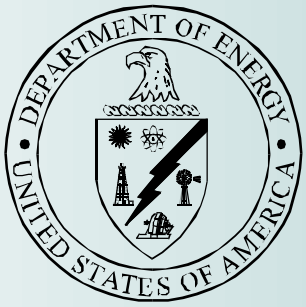
A report on the production and shipment of recycled uranium

Recycled Uranium

United States Production, Enrichment, and Utilization



May 2003

DOE/SO-0003

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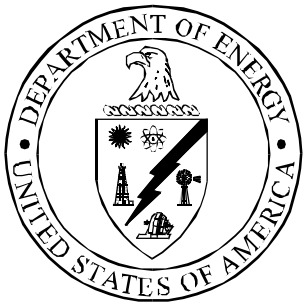
U.S. Department of Energy
Office of Security



May 2003

DOE/SO-0003

Department of Energy
Washington, DC 20585

On behalf of the Department of Energy (DOE), I am pleased to present this report entitled, "Recycled Uranium: United States Production, Enrichment, and Utilization." This report provides comprehensive information on the U.S. production of recycled uranium from spent nuclear fuel and shipment to the sites initially receiving the material.

This report on the production of recycled uranium is significant because it is an important step in the Department's commitment made in 2001 to resolve data inconsistencies among nine previously released site-specific studies. This follow-on study provides an accurate accounting of recycled uranium and its contaminants across the DOE complex. This accounting is important to understanding the full scope and impact on the health and safety associated with worker and public exposure and associated risks related to recycled uranium. This report is also an important step in fulfilling the U.S. Government's responsibilities for effectively managing its sensitive nuclear materials inventories and providing inventory-related information in support of the public interests.

We anticipate completion of additional studies on the topic of recycled uranium through the enrichment, manufacturing, and final use stages of the fuel cycle. The information contained in this first effort is a necessary threshold component for completing these additional studies. We also expect that this report will be useful to researchers, historians, and others who have an interest in the past and present U.S. nuclear programs.

Joseph S. Mahaley
Director
Office of Security

FOREWORD

In December 1999, the U.S. Department of Energy (DOE) initiated a comprehensive study of the generation, characteristics, and utilization of recycled uranium at the agency sites that were responsible for processing and using this material in support of various programs and missions of the DOE and its predecessor agencies. The study was conducted under the direction of the Office of Environment, Safety and Health (EH) primarily to address the health-related concerns raised by DOE workers at the Paducah Gaseous Diffusion Plant. The study involved collection and validation of historical data to determine the amount of recycled uranium produced, the contaminants it contained, where it was shipped, and how it was used in order to provide an estimation of the potential risk for the workers involved in recycled uranium activities.

Nine reports were prepared in 2000 that encompassed the years 1952 to 1999 for the principal DOE sites that either processed, shipped, or received recycled uranium. These sites include Hanford, Washington; Savannah River, South Carolina; Idaho National Engineering and Environmental Laboratory, Idaho; Fernald, Ohio (including West Valley, New York; Weldon Springs, Missouri; and RMI, Inc., Ohio); the Gaseous Diffusion Plants in Paducah, Kentucky; Portsmouth, Ohio; and Oak Ridge, Tennessee; the Y-12 Plant, Tennessee; and Rocky Flats, Colorado. That study concluded that the use of recycled uranium did create radiological concerns at these sites, and it has served to help DOE plan its future health programs, conduct exposure assessments, and provide health monitoring.

The reports that were published in 2000 contained some inconsistencies between quantities of recycled uranium shipped and the quantities received. These inconsistencies were caused by differing site accounting methods, as well as by the operational definitions of recycled uranium used by the sites to determine the quantities of recycled uranium shipped and received. In March of 2001, the Office of the Secretary of Energy tasked the Office of Security (SO) to review the results of the original study and resolve the data inconsistencies. The SO Office of Plutonium, Uranium, and Special Materials Inventory was assigned this task. This follow-on study, as presented in this report, has reviewed, corrected, and validated the material account records, providing a public record of U.S. production and shipment of recycled uranium and its contaminants to initial receiving sites. Recycled uranium, as defined for this report, is uranium that originated from the chemical reprocessing of spent nuclear fuels at four U.S. sites: Hanford, Washington; the Savannah River Site, South Carolina; the Idaho National Engineering and Environmental Laboratory, Idaho; and West Valley, New York.

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Acronyms and Abbreviations

AEC	Atomic Energy Commission
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	U.S. Department of Energy
EH	Office of Environment, Safety and Health
ETR	Experimental Test Reactor
FEMP	Fernald Environmental Management Project
FMPC	Feed Materials Production Center
g/l	grams per liter
gm(s)	gram(s)
H_2	hydrogen gas
HF	hydrogen fluoride
ICPP	Idaho Chemical Processing Plant
INEEL	Idaho National Environmental and Engineering Laboratory
INEL	Idaho National Engineering Laboratory
kg(s)	kilogram(s)
MgF_2	magnesium fluoride
MTR	Materials Testing Reactor
MTU	metric tons uranium
NFS	Nuclear Fuel Services
NMMSS	Nuclear Materials Management and Safeguards System
^{237}Np	neptunium-237
NPH	saturated kerosene
NRTS	National Reactor Testing Station
ORNL	Oak Ridge National Laboratory
^{238}Pu	plutonium-238

^{239}Pu	plutonium-239
ppb	parts per billion
ppm	parts per million
PUREX	Plutonium-Uranium Extraction Process
REDOX	Reduction-Oxidation process
SO	Office of Security
STR	Submarine Thermal Reactor
TBP	tributyl phosphate
^{99}Tc	technetium-99
TRU	transuranic
^{233}U	uranium-233
^{235}U	uranium-235
^{236}U	uranium-236
^{237}U	uranium-237
^{238}U	uranium-238
^{239}U	uranium-239
UF_4	uranium tetrafluoride (green salt)
UF_6	uranium hexafluoride
UO_2	uranium dioxide
UO_3	uranium trioxide (yellowcake)
U_3O_8	black oxide
USEC	United States Enrichment Corporation
WVDPA	West Valley Demonstration Project Act

Executive Summary

In August 1999, workers at the Paducah Gaseous Diffusion Plant raised concerns and initiated a lawsuit over health and safety issues related to possible exposure to contaminants, especially plutonium, in recycled uranium processed at the plant. In response to the workers' concerns, the Department of Energy (DOE) initiated an investigation of the production and use of recycled uranium. In the fall of 2000, as a result of this investigation, the principal DOE sites that produced and utilized recycled uranium published reports accounting for the production, characteristics, and use of recycled uranium at these sites. A report was also prepared and published by DOE Headquarters early in 2001 summarizing the investigation. The investigation was quite complex and considered the operations of the Department and its predecessor agencies over a 47-year period, from March 1952 to March 1999. The analysis required the review of thousands of Departmental records, dozens of processes, and the participation of many people including site and subject experts.

Accomplishments

- Balanced records of recycled uranium shipments between production and receiving sites.
- Determined that 138,604 metric tons of recycled uranium were produced by U.S. chemical processing facilities of which 118,408 metric tons were shipped to initial receiving sites.
- Determined that less than 500 grams of plutonium entered the DOE uranium processing system because of the shipment and use of recycled uranium.

Future Studies

- Conduct a material balance of recycled uranium and its contaminants for the material processed by the gaseous diffusion enrichment plants.
- Conduct a material balance of recycled uranium and its contaminants for materials processed by the manufacturing facilities.

Differences between shipper and receiver data presented were observed in the site reports published in 2000. A follow-up investigation was initiated by the Department to review the original reports and to correct and validate the recycled uranium material values. This new report, "Recycled Uranium: United States Production, Enrichment, and Utilization" presents the corrected information concerning production, characteristics, and shipment of recycled uranium from the chemical processing facilities to the sites initially receiving the material for enrichment and component manufacturing. Additional reports are planned to discuss the recycled uranium processed at the gaseous diffusion plants and at the feed material and component manufacturing plants and will document the changes to the contaminant levels caused by the enrichment and manufacturing processes.

The Department and its predecessor agencies produced recycled uranium from spent nuclear fuel in Government reprocessing plants at the Hanford, Savannah River, and Idaho sites and also at the commercial West Valley site. These plants recovered plutonium and uranium from spent nuclear fuel and target material irradiated in nuclear reactors. The recovered uranium was sent to other sites for enrichment and to make nuclear fuel for reactors and other components. Some uranium, depleted in the fissionable uranium-235 (^{235}U), was used for military tank armor, radiation shielding, and armor-piercing penetrators. Figure 1 shows the cycle of production and use of recycled uranium in the DOE complex.

Although the chemical processes used to separate the plutonium and uranium from

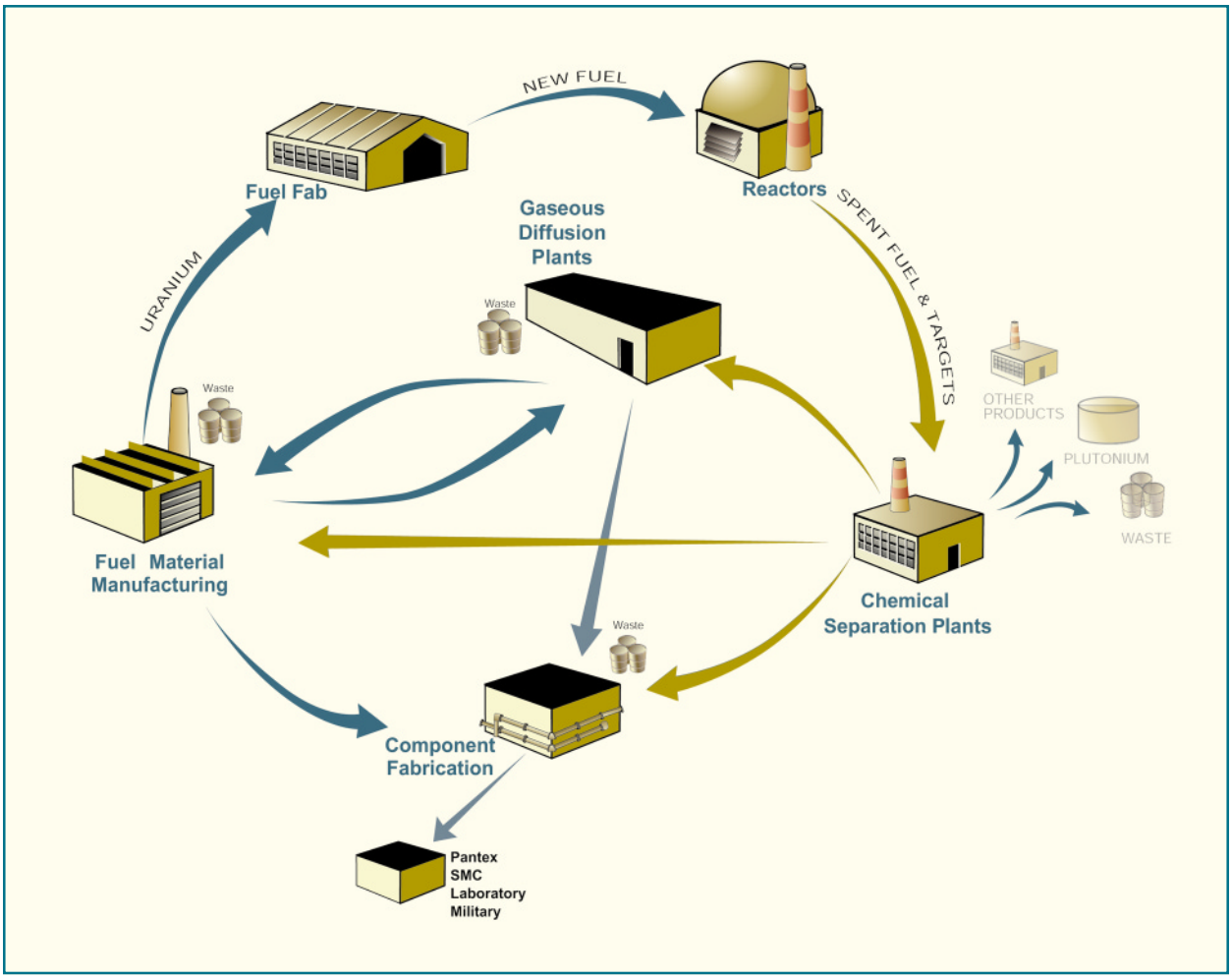


Figure 1. Flow of recycled uranium in the DOE complex. The brown arrows indicate production flow.

spent fuel and target material were very efficient and effective, the chemical properties of transuranic (TRU) elements and some fission products make the complete removal of these isotopes from uranium impossible, especially on the scale used for production. Consequently, trace concentrations of plutonium, neptunium, and technetium remain with the uranium after processing. In addition, chemical processes cannot separate uranium isotopes from each other; thus, reactor-produced uranium-236 (^{236}U) remains with the uranium recovered by chemical processes. Therefore, recycled uranium, as discussed in this report, is defined by the process that produced it (i.e., reactor irradiation followed by chemical separation), and this material can be identified by the contaminants remaining with the uranium after chemical separation. These contaminants, especially the plutonium, are the basis of the workers' concerns.

In the early days of production, Oak Ridge set an acceptance limit of 10 parts per billion (ppb) for the plutonium concentration in recycled uranium being sent to the site for subsequent processing. This limit has continued in use agency-wide for the duration of recycled uranium production. Recovered uranium having plutonium concentrations above this limit required receiving site permission prior to shipment. Because of this early plutonium limit imposed upon recycled uranium production sites, nearly all uranium coming from these sites contained less than 10 ppb of

plutonium. The measurements of plutonium in recycled uranium at the production sites were conducted principally to ensure that the shipments met acceptance requirements and not necessarily to determine the amount of plutonium present in a specific batch. This reduces the usefulness of production site data but does provide a bounding value for the possible quantity of plutonium associated with recycled uranium originating from these sites. Limits on the concentration of neptunium and technetium were discussed from time to time but never adopted.

Depending on how the recycled uranium was to be used at the receiving site, analysis of the actual concentration of contaminants may or may not have been conducted. The gaseous diffusion plants conducted some analyses of receipts, but because their processes would eliminate most of the contaminants from the product stream, the analyses for these contaminants appear to have been less than routine. The manufacturing plants, including Fernald, conducted fairly rigorous analysis of most receipts to determine the suitability of the material to specific product requirements. Although much of the recycled uranium analytical data generated by Fernald are no longer available, a body of data was retained and has been used to support this review.

The documentation of shipments and receipts of all uranium within the DOE complex is quite complete, but these records do not separate recycled uranium from uranium derived from natural sources. The three U.S. Government production facilities, Hanford, Savannah River, and Idaho, shipped both recycled uranium and uranium derived from natural sources to other sites without identification of material origin. To prepare the 2000 site reports, operational definitions for recycled uranium were developed by each site. These definitions were expected to encompass all recycled uranium but may have inadvertently included non-recycled uranium in the dataset as well. The information presented in this report resolves the data difference due to definitional and other differences that existed between shipper and receiver data in the previous recycled uranium reports. The resolution of the recycled uranium data involved the use of the Nuclear Materials Management and Safeguards System (NMMSS) database, as well as the utilization of process knowledge, in discussions and interactions with production and receiving site personnel.

The contaminant quantities presented in this report were derived from the historical contaminant data included in the nine site reports published in 2000. Commonly, the contaminant concentration data from the production site report differed from the reports provided by the receiver sites. Plutonium analyses were fairly routine because of the complex-wide specification for this contaminant, and the available site-specific data are sufficiently robust to support reasonable estimates. The estimates of neptunium and technetium were developed on the basis of much less robust data. The consistency of the data across the sites indicates that these contaminants can be estimated.

Limited data were available from Hanford, and 27 analyses were found at Fernald for Hanford recycled uranium produced in the 1980s. These data provided the basis for the Hanford recycled uranium contaminant estimates. Savannah River provided statistically analyzed data for plutonium in their recycled uranium as well as some less robust estimates of neptunium and technetium. Their contaminant concentrations showed dependency on the form of the uranium product. Receiving sites also provided information concerning Savannah River material. All available data were considered in determining the contaminant estimates for the recycled uranium

produced at Savannah River. Only one analysis could be found for the West Valley uranium. Because it was within the range of other Plutonium-Uranium Extraction (PUREX) process-produced uranium, these data were used as the basis for the contaminant estimates for the 622 metric tons of uranium (MTU) from that site. No actual analyses of recycled uranium were found for the Idaho material. The Origen-2 model was utilized to estimate the production of TRU and fission product isotopes in the principal reactor fuels processed at the site. This was combined with typical decontamination rates for the specific separation processes used, and the probable contaminant concentrations were then calculated for the Idaho product.

Figure 2 presents the total production and shipment amounts of recycled uranium from the four production sites. Based on the available material accounts, the Department and its predecessor agencies produced about 138,604 MTU of recycled uranium at the production sites, including the commercially operated West Valley site. Approximately 85 percent of the recycled

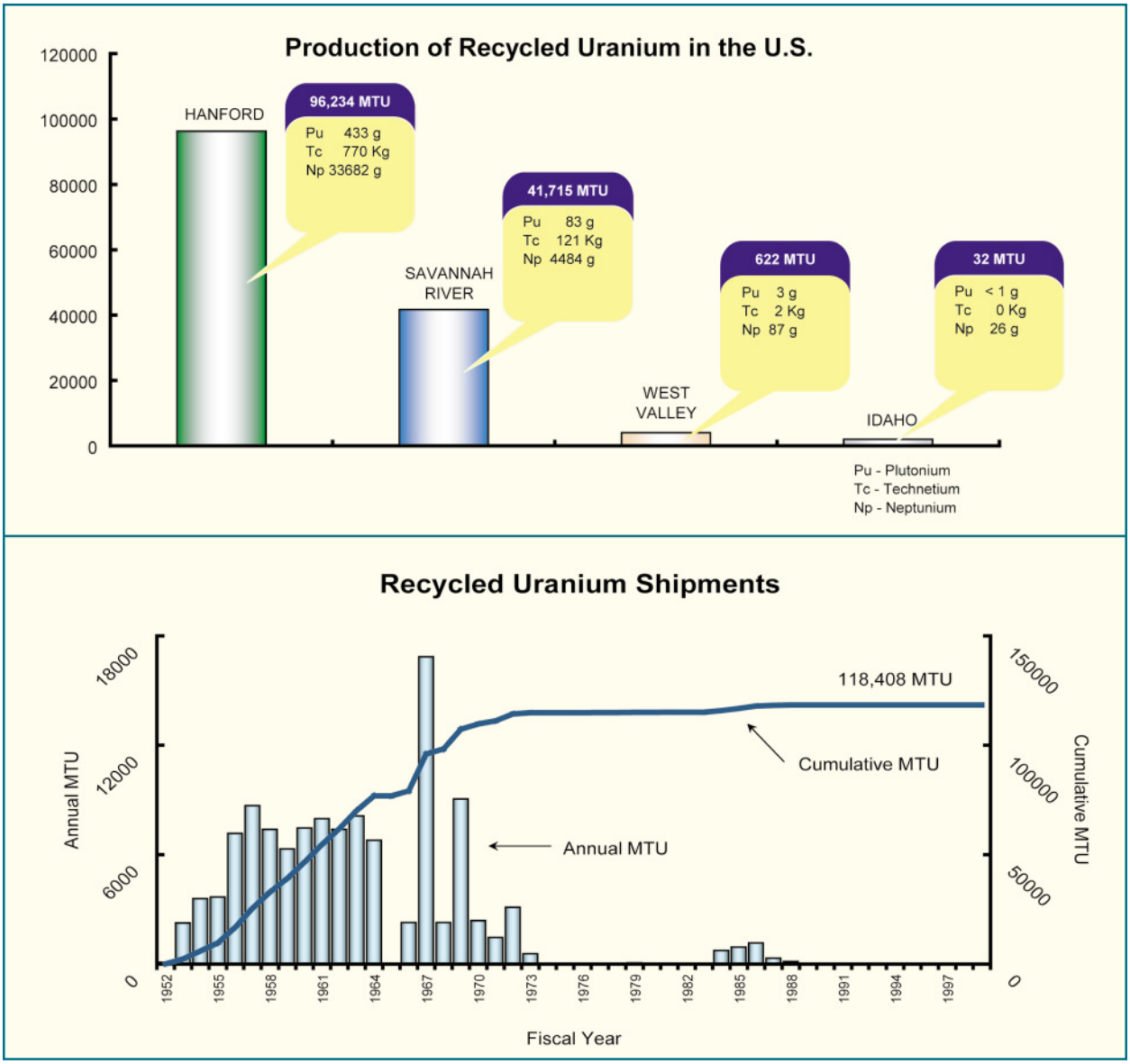


Figure 2. Production and shipments of recycled uranium.

uranium produced (about 118,408 MTU) was shipped to other sites for subsequent processing including enrichment and fuel fabrication. As of March 1999, 15 percent remained in storage at the production sites. Available data indicate that the recycled uranium produced likely contained about 519 grams of plutonium, 38 kilograms of neptunium, and nearly 900 kilograms of technetium. In addition, about 26,500 kilograms of ^{236}U, a reactor-produced uranium isotope, was present, principally in the enriched recycled uranium.

Hanford was the first production site to recover uranium from spent fuel. It produced 96,234 MTU of recycled uranium, which amounted to nearly 70 percent of the U.S.-produced recycled uranium. Hanford started shipping this material in 1952. Initially uranium was recovered from spent fuel using a solvent chemical extraction separation technique, the Reduction-Oxidation process (REDOX). Tributyl phosphate (TBP) in kerosene was used to recover uranium from waste solutions generated during plutonium recovery prior to the use of the REDOX plutonium and uranium recovery process. In 1956, Hanford started using a new process, PUREX, also based on TBP extraction, to process spent fuel. The PUREX Plant produced about 65 percent of the recycled uranium recovered at Hanford. As of March 1999, approximately 668 MTU of the produced recycled uranium remained in storage at the Hanford site.

Savannah River started plutonium and uranium recovery utilizing the PUREX process in 1955. It produced 41,715 MTU of recycled uranium and shipped 22,189 MTU to other sites for subsequent processing. The remaining 19,526 MTU is principally depleted recycled uranium that was in storage at the site as of March 1999.

Idaho was a test site for reactor design, and the Idaho Chemical Processing Plant (ICPP) was capable of custom-developing processes for plutonium and uranium recovery from the various reactor fuels used by test reactors. Its process was designed to handle the enriched uranium used by the test reactors and utilized a combination of both the REDOX and PUREX processes for most of its operations. The ICPP initiated fuel processing in 1953 and, over its processing history, recovered nearly 32 MTU of enriched recycled uranium and shipped about 30 MTU of this recycled uranium to other sites for subsequent processing.

West Valley was established as a commercial nuclear fuel reprocessing facility that used the PUREX process. It processed spent fuel from commercial electric power reactors as well as from Government reactors. It began operations in 1966 and recovered about 622 MTU in its 6 years of operation. The West Valley recycled uranium was shipped to Fernald for processing, except for a small quantity of specially produced uranium-233 (^{233}U) that was sent to the Y-12 Plant at Oak Ridge.

Three primary sites received nearly all of the recycled uranium shipped from the fuel reprocessing plants. These sites were the Paducah Gaseous Diffusion Plant, receiving 83,748 MTU; the Oak Ridge K-25 Gaseous Diffusion Plant, receiving 14,568 MTU; and the Feed Materials Production Center at Fernald, receiving 17,966 MTU. The Y-12 Plant at Oak Ridge also received 184 MTU, including most of the uranium from Idaho. The Harshaw Chemical Co. received and processed about 1,914 MTU of Hanford-origin recycled material in the early 1950s to make the material suitable for use at the Oak Ridge Gaseous Diffusion Plant. The Portsmouth Gaseous Diffusion Plant received only small quantities (4 MTU) of recycled uranium, from Idaho. Small amounts of recycled uranium were also sent

to a few other sites for specific experimental purposes, including the DOE Rocky Flats Plant and some of the national laboratories. Although the Weldon Spring site had operations similar to Fernald, records indicate it did not receive recycled uranium from production facilities.

The complex-wide mass accounting shows that the use of recycled uranium probably introduced only about one-half of a kilogram of plutonium into the DOE processing complex. The estimate for the amount of neptunium is about 38 kilograms and for technetium, it is less than 900 kilograms. Because the Paducah Gaseous Diffusion Plant received nearly 71 percent of the recycled uranium shipped from the production sites, it also received the majority of the contaminants, including about 354 grams of the plutonium, 28 kilograms of the neptunium, and 628 kilograms of the technetium. Fernald received approximately 15 percent of the material shipped from the production sites, as well as a similar fraction of the contaminants, including about 74 grams of plutonium, 5,700 grams of neptunium, and 135 kilograms of technetium. It is also estimated that Fernald received about 71 kilograms of ^{236}U with several shipments of enriched uranium. The Oak Ridge Gaseous Diffusion Plant received recycled uranium from the production sites from 1952 until 1965. During that time period, it received about 12 percent of the material shipped, which contained about 40 grams of plutonium, 3,300 grams of neptunium, and 70 kilograms of technetium. All other sites that received material from production facilities received much smaller quantities of recycled uranium and contaminants.

INTRODUCTION

In the summer of 1999, workers at the Paducah Gaseous Diffusion Plant raised concerns and initiated a lawsuit over health and safety issues related to their work including possible exposure to contaminants, especially plutonium, in recycled uranium processed at the plant. In response to the workers' concerns, in the fall of 1999, the DOE initiated an investigation of the production, characteristics, and use of recycled uranium at its sites. As a result of this investigation, the principal DOE sites that produced and utilized recycled uranium published reports in the fall of 2000, documenting the production, characteristics, and use of recycled uranium throughout the department. A summary report was also prepared and published by DOE Headquarters early in 2001.

During preparation and at publication, differences were noted between shipper and receiver data presented in these reports that were caused by accounting differences and the various operational definitions of recycled uranium used by the sites to account for the material of interest. A follow-up investigation was initiated by the Department in the spring of 2002 to review the original reports and to reconcile and validate the recycled uranium material values. This new report "Recycled Uranium: United States Production, Enrichment, and Utilization," is designed to provide a detailed, unclassified account of the production of recycled uranium for enrichment and utilization within the DOE complex. It presents a comprehensive review of all shipments of recycled uranium originating from the initial production sites over the time period from 1952 to 1999. It is the result of an exhaustive search of open literature, existent historical memoranda, shipping documentation, nuclear material accountability records, and information from studies conducted since the early 1950s. This report focuses on the initial production and shipment from the four sites having chemical separation facilities. This complex-wide analysis characterizes the recycled uranium used throughout DOE, provides quantitative information on the recycled materials, and updates the information in the August 2000 recycled uranium mass balance project reports.

This analysis is a basic mass accounting that is designed to determine:

- the amount of recycled uranium DOE and its predecessors produced and shipped; and
- the initial destinations of the recycled uranium over the nearly 50 years covered in this report.

Additional studies are planned that will present accounts of the historical enrichment and utilization of recycled uranium and the effect of these processes on the nature of recycled uranium.

Scope of This Project

The scope of this project is to present an accounting of and characteristics of recycled uranium produced by U.S. chemical separation facilities. It includes the quantities produced and shipped to other sites for use, with identification of the initial receiving sites and estimates of the contaminant characteristics of this material.

Figure 3 illustrates the production steps and initial uses of recycled uranium. This report discusses the facilities that produced the recycled uranium and those that initially received the product. Some recycled uranium was also received by DOE sites from foreign sources, including England, France, and Russia. The foreign recycled uranium is not discussed here but will be discussed in future reports.

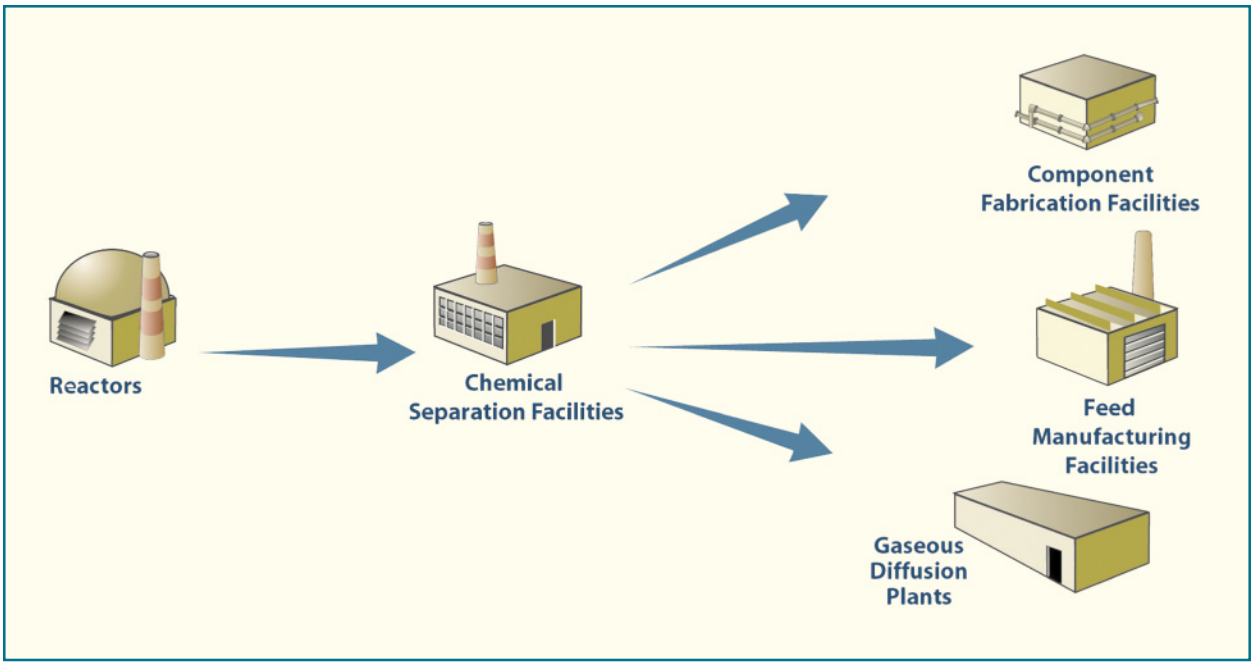


Figure 3. Production and initial uses of recycled uranium.

Historical Perspective

The Evolution of the Department of Energy

In 1939, President Franklin D. Roosevelt established the Manhattan Engineering District (popularly known as the Manhattan Project) under the auspices of the U.S. Army Corps of Engineers to conduct military-related research to develop and construct an atomic weapon. Starting principally at three remote sites around the country—Hanford near Richland, Washington; Los Alamos near Santa Fe, New Mexico; and Oak Ridge near Knoxville, Tennessee—a large research and production complex was built to support this project.

Each of the three initial sites had specific mission objectives. Hanford constructed and operated the first plutonium production reactor and its associated chemical separation plants to produce and isolate plutonium for weapons manufacture. Oak Ridge constructed and operated the first uranium enrichment facilities and conducted research into chemical separation processes. Los Alamos conducted research into nuclear fission and constructed the first atomic bomb, which was detonated on July 16, 1945, at the Trinity Site near Alamogordo, New Mexico. This project resulted in the atomic bombs used on Hiroshima and Nagasaki, Japan, in 1945.

The Atomic Energy Act of 1946 created the Atomic Energy Commission (AEC), a civilian agency that would focus on the design and production of nuclear weapons and nuclear reactors. Under the auspices of the AEC, additional sites, including the Idaho Reactor Testing Station near Idaho Falls, Idaho; the Feed Materials Production Center (FMPC) at Fernald, Ohio; the Paducah Gaseous Diffusion Plant at Paducah, Kentucky; the Portsmouth Gaseous Diffusion Plant near Piketon, Ohio; and the Savannah River Plant near Aiken, South Carolina, were established to support the agency's mission. In the early 1950s, the AEC initiated the production and utilization of recycled uranium to conserve uranium and reduce the nation's dependency on foreign supplies.

In 1974, Congress enacted the Energy Reorganization Act of 1974, which separated licensing and regulatory functions from energy development functions, abolishing the AEC, and creating the Energy Research and Development Administration, the Nuclear Regulatory Commission, and Energy Resources Council. On October 1, 1977, a new cabinet-level "Department of Energy," responsible for energy policy and implementation, as well as fissile material and nuclear weapons design, testing, and production, began operation.

Why Recycle Uranium?

The uranium-235 (^{235}U) isotope is the principal naturally occurring fissionable isotope. The ^{235}U content of natural uranium is only about 0.7 percent, but that amount provides adequate neutrons for the operation of some nuclear reactors. For efficient operations, many reactors use uranium enriched in ^{235}U. Uranium highly enriched in the ^{235}U isotope can also be used as weapons material. Therefore, the scarce ^{235}U was critical to the operation of nuclear reactors and to national security. The cost of enriching uranium, along with the desire to reduce dependency on foreign supply for natural uranium, supported the decision to recycle uranium. Hence, much of the uranium recovered from spent fuel during the chemical separation process was re-enriched and reused.

From the beginning of operations in the mid-1940s, the DOE and its predecessor agencies used uranium in fission reactors to produce plutonium for weapons production and other purposes. In the early days of plutonium production, nearly three-quarters of the uranium used came from mines in foreign countries, especially the Belgian Congo. This situation made the supply potentially susceptible to interruptions or cancellation caused by international politics and conflicts. Because of national defense requirements, uranium demand was high, and the resource was relatively scarce. In addition, a significant fraction of the uranium used was enriched in ^{235}U, increasing its value substantially and making recovery of the unconsumed uranium in spent fuel very important.

After irradiation in the reactor, the spent nuclear fuel was reprocessed in large chemical separations facilities to recover plutonium. Initially the only large-scale chemical separation system available to recover plutonium from spent reactor fuel was the bismuth-phosphate process. This process could not be used to separate and recover uranium from the fission products and transuranic (TRU) element waste. The T-Plant and B-Plant at Hanford near Richland, Washington, utilized the bismuth-phosphate process to recover plutonium from the spent reactor fuel. A photo of the T-Plant is shown in Figure 4.

Figure 4. The T-Plant chemical separation facility used the bismuth-phosphate process to recover plutonium.

In the late 1940s, solvent extraction processes were developed that would allow the simultaneous recovery of both uranium and plutonium from spent fuel and also the recovery of uranium from previously generated waste. In 1950, construction was started on the REDOX Plant at Hanford as a dual-mission facility to recover both plutonium and uranium. An additional facility, the U-Plant, was converted to use the tributyl phosphate process to recover uranium from waste generated by the bismuth-phosphate process that had previously been sent to waste tanks. Within a few years, an additional facility utilizing another extraction process based on tributyl phosphate, the Plutonium Uranium Extraction (PUREX) process, was built at Hanford. PUREX-based chemical separation facilities to process spent fuel from the new reactors at the Savannah River Site in Aiken, South Carolina, were also built. At the height of plutonium and recycled uranium production, chemical separation facilities were operating at Hanford, Savannah River, and Idaho, with additional production capacity at the commercial West Valley site that operated during the late 1960s. The locations of the four production sites are shown in Figure 5.

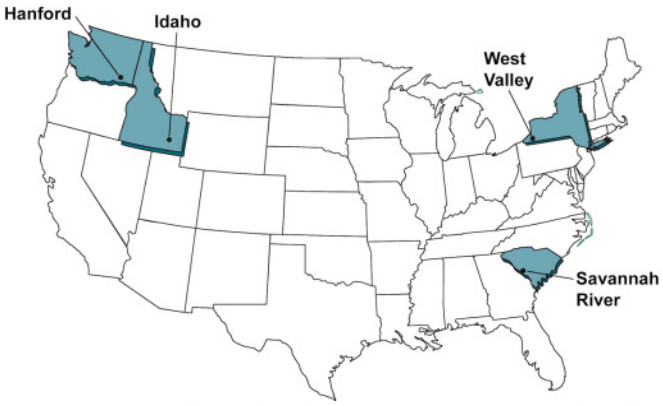


Figure 5. Locations of the four production sites.

Historical Missions of Government Sites

The three Government-owned recycled uranium production sites were established at different times. Each of these sites had reactors and chemical separation facilities to reprocess the spent fuel, recovering the plutonium produced and the unused uranium. Hanford was the first site established. It's mission was to produce plutonium to meet the increasing demand for the build up of the nation's stockpile of nuclear weapons. Idaho was the next site established for the AEC's planned series of experimental reactors. Savannah River was the third site established by the Government. The Savannah River reactors were designed and constructed to meet tritium production needs brought on by the requirements of new thermonuclear weapons. The reactor design allowed them to be capable of being operated to produce plutonium as well. This decision reflected a desire for a backup capability to the Hanford operations, as well as the ability to increase plutonium production if necessary. These sites recovered unused uranium for reuse in reactors and for other purposes.

Commercially Owned Site and Purpose

In an effort to close the uranium fuel cycle for commercial reactors and in anticipation of the development of a plutonium-fueled breeder reactor, design and construction were initiated on three commercial separation plants. The West Valley facility was the only private commercial plant in the United States completed to reprocess spent nuclear fuel. The West Valley facility is included in this analysis because it reprocessed some Government-owned spent fuel as well as spent fuel from commercial electric power reactors. The Government-owned and commercially owned uranium recovered at West Valley was shipped to DOE facilities as recycled uranium.

Isotopic Contaminants in Recycled Uranium

The irradiation of uranium in a nuclear reactor causes nuclear fission and neutron capture reactions. Fission splits the nucleus of uranium atoms producing a variety of fission product isotopes of many different elements including cesium, strontium, and technetium. Neutron-capture reactions cause the production of other uranium isotopes including uranium-236 (^{236}U) and shorter-lived isotopes (e.g., uranium-237 and uranium-239) that decay into TRU elements such as plutonium and neptunium. Although many of the reactor-produced isotopes decay quickly, several important isotopes remain, including ^{236}U, technetium-99 (^{99}Tc), and isotopes of the TRU elements, plutonium and neptunium. The chemical separation processes used to recover plutonium from spent fuel removes nearly all of the plutonium from the spent fuel by design. The subsequent separation of uranium for recovery clears it of most of the remaining TRU and fission product isotopes, allowing disposal of the fission products and TRU contamination as waste. These chemical separation processes, however, cannot remove all traces of fission products and TRU elements from the uranium product. In addition, chemical processes cannot separate isotopes of uranium from each other causing reactor-produced uranium isotopes (e.g., ^{236}U) to remain with the uranium that originated as the fuel. Therefore, recycled uranium typically contains the longer-lived, reactor-produced uranium isotope, ^{236}U, as well as trace concentrations of fission products (e.g., ^{99}Tc) and TRU elements, plutonium, and neptunium.

Uranium Basics

- When uranium is mined from the earth, it contains only about 0.7% ^{235}U.
- Industrial processes enrich uranium by concentrating the amount of ^{235}U to 3% or more for use as reactor fuel.
- Uranium with more than 20% ^{235}U is called highly enriched uranium and is used for research and defense applications.
- Fuel consists of enriched uranium surrounded by, or clad with, a metal.

A review of production site records to separate shipments of recycled uranium from those of uranium derived from natural sources is very difficult because there is no category designated for recycled uranium in material accountability records or shipping manifests. The Government-owned production sites (Hanford, Idaho, and Savannah River) also have other facilities, such as reactors, fuel fabrication facilities, and research facilities, that utilize and ship uranium. In addition, recycled uranium was not utilized or treated differently from uranium derived from natural sources. To differentiate recycled uranium, it must be traced back to its recovery at the chemical separations facilities. Of the four production sites, only West Valley was unambiguous with respect to its uranium shipments, as all uranium shipped from West Valley was recycled uranium.

Data Considerations and Analysis

The data discussed in this report were obtained or derived from several sources. The quantities of recycled uranium presented were determined from the uranium mass balance site reports published by the individual sites in 2000, with corrections based on data obtained from the NMMSS database, production history, and process knowledge. The quantities of recycled uranium shipped from a production site, as shown in the site report, were compared to the quantities received at the receiving sites. Differences were resolved by review and analysis of original shipping and receiving report information in conjunction with the available NMMSS records and interactions

with site personnel. The site reports and NMMSS data were then used to determine the values presented here as production of recycled uranium.

Knowledge of processes used at the producing and receiving sites and the material produced and used by these processes was used to help separate recycled uranium from naturally derived uranium. For example, gaseous diffusion enrichment plants were most likely to receive uranium oxide from the chemical separation process and unlikely to receive uranium metal for processing. Facilities utilizing principally uranium metal would probably not receive uranium oxide from the production sites. Shipments to Fernald were the most difficult to differentiate because the processes available at that site could utilize uranium in virtually any form. The Fernald records, however, were helpful in that most of the receipts were classified with respect to the chemical form of the received uranium. The NMMSS database was also helpful for separating recycled uranium shipments from those of non-recycled material. The material type, composition and description, and project codes in the database, when available, provided information concerning the chemical form or the use of the material. The values for recycled uranium presented in this report are the result of these considerations and represent the best estimate of the production and shipment of this material over the history of the Department and its predecessor agencies.

The quantities of the reactor-caused contaminants (plutonium, neptunium, technetium, and ^{236}U) present in the recycled uranium were determined from data obtained from radio-chemical and mass spectrographic analyses and presented in the site reports published in 2000. These reports contained estimates, or ranges of estimates, of the contaminants determined from available site data and material specifications. Commonly, the contaminant concentration data from the production site reports differed from the reports provided by the receiver sites. Much of the information provided was based on limited data. If enough data were available, the mean and standard deviation were calculated and contaminant quantities calculated on this basis. In cases of more limited data, the median of range of available data was used to estimate the contaminant quantities.

Isotopic Range

- The uranium isotopic level (%^{235}U) ranges from depleted uranium (<0.7%^{235}U) to high enriched uranium (>20%^{235}U).

Impurities

- Fission product, typically ^{99}Tc.
- Uranium isotope ^{236}U.
- Transuranic isotopes, typically ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am.

Plutonium – From the early utilization of recycled uranium, there was an acceptance limit established for the allowable plutonium concentration in material. The Oak Ridge facilities sent a memorandum to Hanford indicating that recycled uranium containing greater than 10 ppb of plutonium had an increased radiation hazard of more than 10 percent compared to the hazard of working with natural uranium for the production and machining of recycled uranium metal. This memo suggested that Hanford make processing modifications, if feasible, to reduce the plutonium content of recovered uranium to less than 10 ppb and indicated that material above this limit should not be sent without prior authorization from the receiving site. This specification was adopted agency-wide for recycled uranium production. In response, the production sites analyzed the recycled uranium in a manner sufficient to demonstrate that their product met the acceptance criteria. The production site data generated to ensure that its material met the specification would not necessarily provide an actual concentration but did

demonstrate that the product material had a plutonium concentration not exceeding 10 ppb. The production sites did document the few small shipments that were made of material that exceeded the specification and required special authorization. The plutonium specification, therefore, provides a bounding value for the possible plutonium content of recycled uranium.

The plutonium concentration data presented in all of the site reports indicate that the chemical separation facilities at the production sites were able to remove all but the smallest traces of plutonium from the recovered uranium. The available data show that most of the recycled uranium represented in the data had plutonium concentrations of less than 5 ppb, with some material having less than 1 ppb. The data available from both the production sites and the receiving sites were compared. There were insufficient data to provide individual annual values. Estimates in this report of the more hazardous isotopes were designed to be conservative. Where possible, an average value and standard deviation were calculated. In an attempt to ensure that the contam-ination not be under-estimated, the value used to calculate the quantity of plutonium contained in the recycled uranium from a production site was the average concentration plus one-half the standard deviation. The actual concentration range and appropriate value for the calculation of plutonium quantity appear to be production site dependent, and the values that were used for this report reflect the site dependence.

Neptunium – Although there were discussions among production sites and receiver sites concerning a specification for the maximum allowable neptunium content in recycled uranium, no specification for neptunium was ever adopted. Because there was no specification for neptunium requiring its analysis, the production sites did not routinely analyze their uranium product for this actinide element. There is nothing to establish a bounding value for neptunium. In the late 1950s, the use of neptunium-237 (^{237}Np) to make plutonium-238 (^{238}Pu) for heat sources for remote power generation was initiated. This resulted in activities to recover neptunium from spent reactor fuel and the analyses of some recycled uranium in the effort to improve the neptunium recoveries. Including the data generated to determine neptunium recoveries, there are only limited and scattered data concerning the neptunium content of recycled uranium.

The data that are available suggest that the concentration range is production site specific. To determine the value to be used to calculate the quantity of neptunium associated with the recycled uranium from a production site, the data available from both the production site and the receiving sites were compared. Because of the data limitations, the method used for plutonium could not be used in all cases. Instead, a value was selected from the apparent range for a production site that was midway between the median and the maximum concentration of the data. This provided some assurance that neptunium was not likely to be underestimated.

Technetium – The production sites only measured technetium under special circumstances, therefore, only a few data points exist. For example, Hanford had only a few data points indicating part per million (ppm) levels in its uranium oxide, and Savannah River based its values on a single study that showed a much higher concentration of technetium associated with uranyl nitrate solution than with uranium oxide. Some receiver sites had more, but still quite limited, data. There was no specification for the technetium content in recycled uranium and, therefore, no method to establish a bounding value.

The available data suggested a concentration range up to a maximum of about 10–15 ppm for uranium trioxide (UO_3 or "yellowcake") and higher concentrations for uranyl nitrate solutions. This behavior is expected because the calcination (denitration) process is likely to volatilize and release much of the technetium contained in the uranyl nitrate solutions. The value selected was the median value for the data range of the production facility.

Uranium-236 – The production sites using highly enriched uranium routinely measured ^{236}U in their enriched recycled uranium. There are essentially no measurements of this isotope in low enriched, normal, and depleted uranium. The values used to calculate the ^{236}U content of recycled uranium were taken directly from the site reports and were specific to the production site and year of production.

Production Sites

Introduction

All uranium designated as recycled uranium for this report was initially generated by the chemical recovery from irradiated or spent reactor fuel. For the time period from 1944 until 1952, all uranium used by the Department was derived from natural sources because processes that recover uranium from spent fuel were not available. The value and scarcity of uranium, especially uranium enriched in the ^{235}U isotope, prompted the development of processes to recover uranium from spent reactor fuel, and such processes were being researched shortly after the establishment of the Manhattan Engineering District. Starting in 1952, large scale uranium recovery processes became available. Initially two processes, the Reduction Oxidation Extraction (REDOX) process and the tributyl phosphate in saturated kerosene (TBP-NPH) process were utilized at the Hanford site. The REDOX process utilized the hexone solvent extraction separation technique and was used to recover both plutonium and uranium from the spent reactor fuel. Another extraction process, the bismuth-phosphate process, was utilized to recover uranium from the high-level wastes produced by the original plutonium recovery process. In the mid-1950s, the Plutonium Uranium Extraction Process (PUREX) was developed. This process utilized TBP in kerosene to recover both plutonium and uranium from the spent reactor fuel. Virtually all subsequent spent reactor fuel reprocessing has been based on PUREX. This process has been responsible for more than 75 percent of the uranium recovered from spent fuel in the United States. Department plants at Hanford, Savannah River, and the commercially operated West Valley site utilized this process. The Idaho Chemical Processing Plant utilized a process based on a combination of PUREX and REDOX.

Hanford

Site History and Description

The Hanford Site (formerly known as the Hanford Engineering Works) is located in the desert of southeastern Washington, near the city of Richland (Figure 6). The site was selected because of its remoteness, the region's abundant supply of water for reactor cooling, and the plentiful supply of inexpensive electricity from hydroelectric dams. The isolation of the site was required for secrecy and safety.

The Hanford Site was established during World War II as part of the Manhattan Engineering District. Its primary mission was to manufacture plutonium for national defense. Construction was started in 1942, and in 1944 the Hanford B-Reactor, the nation's first plutonium production reactor, was started. Just 27 months after construction began, Hanford-produced plutonium provided the charge for the

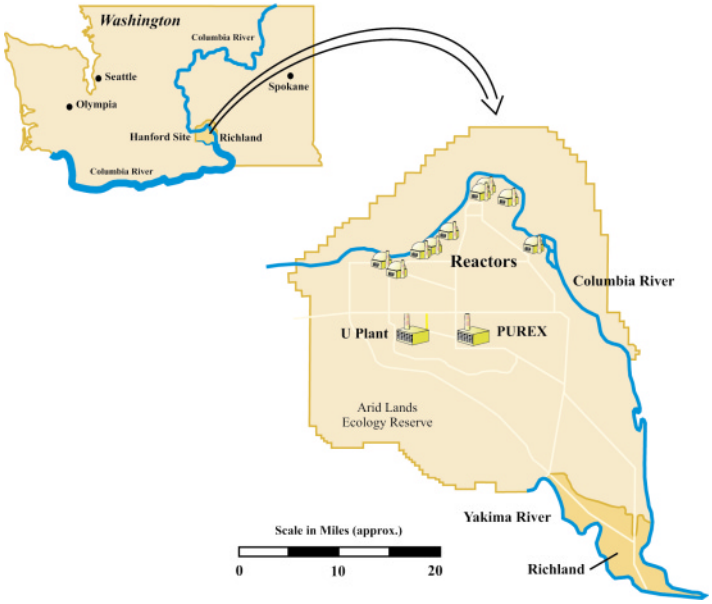


Figure 6. The Hanford Site, located in southeastern Washington State.

world's first nuclear detonation in Alamogordo, New Mexico, and later the material for the bomb that was used against Nagasaki, Japan, to help end World War II.

Hanford began to recover uranium from spent reactor fuel in early 1952 as soon as production-scale chemical separation processes were available. The site's uranium recovery included "mining" of the waste from plutonium production high-level waste tanks, as well as direct simultaneous recovery with plutonium from spent fuel. During Hanford's production period, 1943 through 1990, the U.S. Government built and operated nine production reactors, five chemical separation plants (three capable of uranium recovery), several reactor fuel manufacturing facilities, and a UO_3 production facility.

Chemical Processing Plants

The Hanford reactors irradiated uranium fuel having normal to low ^{235}U enrichment. The irradiated fuel from the reactor was sent to chemical separations plants to fulfill the site's primary mission, the recovery of plutonium. Other materials, including tritium, uranium-233 (^{233}U), and ^{237}Np, were also produced to support various missions.

During the early years of operation (1944–1956), Hanford processed irradiated uranium fuel using a bismuth phosphate process in two shielded and remotely operated canyon-type facilities, B-Plant and T-Plant. The process involved dissolving the aluminum fuel cladding and sending the cladding solution to underground waste tanks. The bare fuel was then dissolved, and the plutonium was precipitated. The

Hanford Historical Timeline

1942–44	The Hanford Engineering Works is constructed under contract with the Manhattan Engineering District of the U.S. Army Corps of Engineers.
1944	Hanford B-Reactor starts operating.
1944–45	Plutonium recovered for initial weapons test.
1952	REDOX chemical separations plant is built and begins recovery of uranium from spent reactor fuel. UO_3 Plant is built to convert uranyl nitrate solutions produced by REDOX and U-Plant to a dry UO_3 powder for shipment. *First shipment of recycled uranium* (Hanford to the Oak Ridge K-25 Gaseous Diffusion Plant).
1956	PUREX plant begins processing of spent reactor fuel, including recovery of uranium.
1958	U-Plant placed in standby and subsequently retired.
1963	N-Reactor, which uses a multi-pass process, is the ninth reactor to begin operations. It produces both plutonium and steam for electricity generation.
1964–71	The single-pass reactors are shut down.
1967	REDOX plant is shut down.
1972–83	PUREX and UO_3 plants are placed on standby.
1984	PUREX operation is resumed to process irradiated N-Reactor fuels.
1987	N-Reactor is shut down.
1990	PUREX plant is closed; uranium recovery at Hanford is ceased; deactivation activities are in process.
1993	*Last shipment of UO_3.*
1994	UO_3 plant terminates operations.

remaining solution (bearing the uranium, fission products, and other metal wastes) was sent to large underground waste storage tanks.

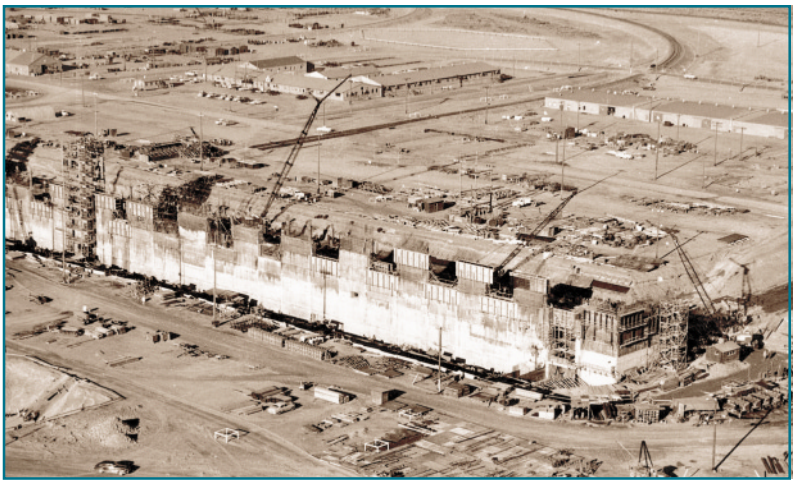


Figure 8. PUREX Plant, shown under construction in 1954, produced about 50% of the U.S.-produced recycled uranium.

Uranium recovery operations started at Hanford in 1952. Hanford developed a process utilizing a hexone solvent extraction separation technique called the REDOX process, which recovered both plutonium and uranium from the spent reactor fuel. Figure 7 shows a photograph of the REDOX Plant at Hanford. The REDOX Plant operated from early 1952 until 1967. Also, in 1952, the U-Plant, which had been used as a training facility for B-Plant and T-Plant operators, was converted to use a unique extraction process utilizing TBP-NPH, to extract uranium from the high-level wastes produced by the bismuth-phosphate process (T- and B-Plants). The U-Plant operated until 1958. Uranium was recovered by both the REDOX and TBP processes in the form of a concentrated solution of uranyl nitrate, which was then converted into the oxide at the UO_3 Plant for sampling and shipment off the site.

In 1956, the PUREX Plant (Figure 8), also based on TBP solvent extraction, began processing irradiated fuel to recover both plutonium and uranium. The uranium recovered by PUREX was also in the form of concentrated uranyl nitrate solution, which was sent to the UO_3 Plant (Figure 9). PUREX became the sole irradiated-fuel processing plant at Hanford after 1967 when the REDOX facility was retired. PUREX ceased operations in early 1990. In total, the Hanford PUREX production accounted for about two-thirds of all uranium recovered for recycle at Hanford and nearly half of all of the recycled uranium produced by U.S. reprocessing plants. Although uranium recovery was secondary to plutonium production at Hanford, the site produced nearly 70 percent of all U.S. recycled uranium.

Figure 7. The Hanford REDOX Plant recovered uranium from spent fuel from 1952–1967.

The UO_3 Plant was built in 1952 to convert uranyl nitrate solution produced by REDOX, U-Plant, and later PUREX, to a dry UO_3 powder, that was more suitable for shipment off the site. In this plant, the

Figure 9. Aerial view of the UO_3 Plant at Hanford Site, which processed about 80% of the recycled uranium shipped.

uranyl nitrate solution was concentrated and then heated in a calciner to decompose the uranyl nitrate to UO_3 powder. Nitric acid was recovered for reuse. Initially, the UO_3 Plant used pot calciners for thermal decomposition of the uranyl nitrate. The pot calciners were replaced with continuous rotary calciners in 1956. After sampling and packaging, the UO_3 product was shipped offsite by rail. Figure 10 shows a photo of T-hoppers, the principal container used to ship Hanford UO_3.

Material Account

Hanford Uranium Shipments

Figure 11 displays Hanford's shipments of recycled uranium on an annual and cumulative basis. Hanford produced about 96,234 metric tons of recycled uranium (MTU). This quantity represents nearly 70 percent of total U.S. production. Hanford shipped 95,566 MTU to other sites for subsequent processing, including 74,491 MTU sent to Paducah and 4,276 MTU sent to the Oak Ridge gaseous diffusion plants for enrichment. The FMPC at Fernald received nearly 14,859 MTU for processing to uranium metal and other products. The Harshaw Chemical Company received about 1,914 MTU; the Oak Ridge Y-12 Plant received a little more than 4 MTU; and a few other sites, including Oak Ridge National Laboratory (ORNL) and the Savannah River site, received a combined total of about 22 MTU.

Contaminant Data

Figure 12 shows the total contaminants contained in the recycled uranium produced and shipped by Hanford and displays quantities of recycled uranium sent to the major receiving sites. The requirement that recycled uranium contain less than the 10 ppb plutonium was imposed on Hanford (10 ppb value established early by the Oak Ridge site) for acceptance of its UO_3 at receiving sites. Limited analytical data showed values from 1 to 5 ppb and a few

Figure 10. T-hoppers used for shipment of Hanford UO_3.

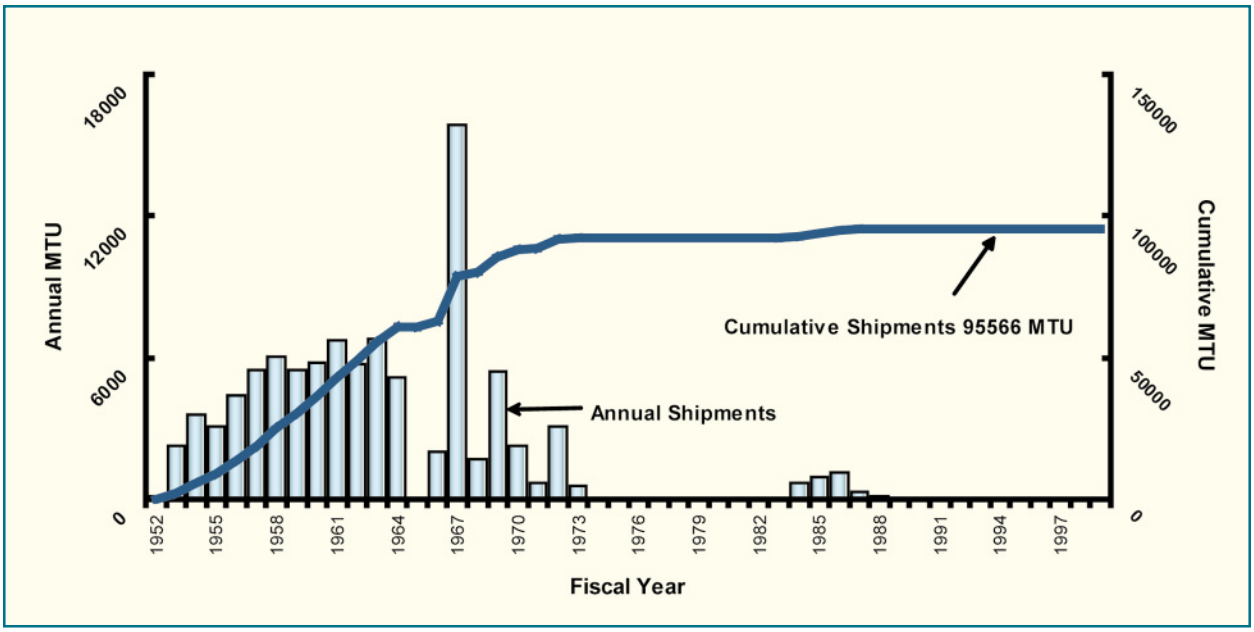


Figure 11. Hanford's annual and cumulative shipments of recycled uranium produced.

higher values, with an average value of about 3 ppb. Data from Fernald for 27 batches of material received in the 1980s shows a range from about 1 ppb to about 12 ppb; mean value is about 3 ppb with a standard deviation of approximately 3 ppb. A value of 4.5 ppb plutonium (average value plus one-half the standard deviation) was used to calculate plutonium quantities. For neptunium, Hanford had very limited data. Data from Fernald for 27 batches of material received in the 1980s shows a range from

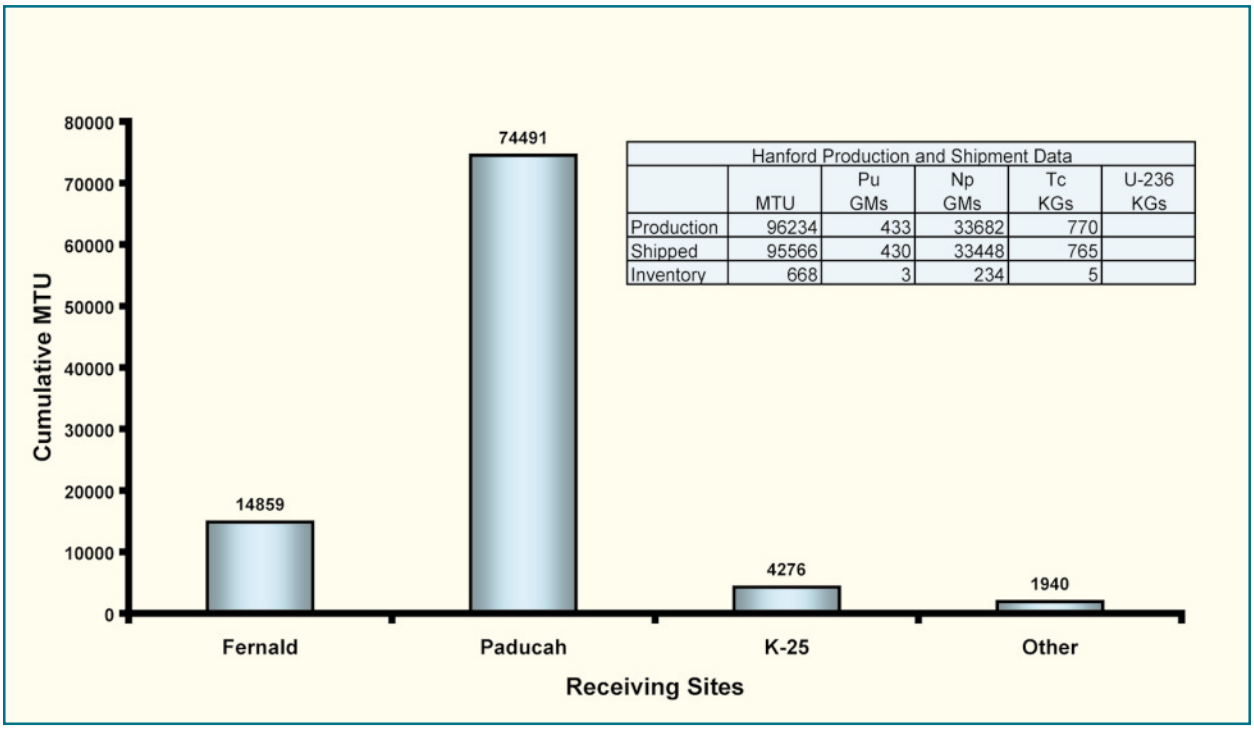


Figure 12. Hanford's total production, shipments, and remaining inventory of recycled uranium produced and associated contaminants with receiving sites identified.

about 30 ppb to nearly 600 ppb, mean value of about 275 ppb and a standard deviation of about 150 ppb. A value of 350 ppb neptunium (average value plus one half the standard deviation) was used for Hanford UO_3 to conservatively account for the neptunium shipped from Hanford. There are no data available for ^{236}U in Hanford UO_3. Hanford did not conduct measurements of technetium. Data from Fernald for 27 batches of material received in the 1980s shows ranges from about 5 ppm to more than 14 ppm, mean value of about 7 ppm, and a standard deviation of about 2 ppm. A value of 8 ppm technetium was used for Hanford UO_3 to account for the technetium received at the initial receiving sites. On this basis, it is estimated that the Hanford shipments of recycled uranium contained about 430 grams of plutonium, 33,448 grams of neptunium, and nearly 765 kilograms of technetium.

Savannah River Site

Site History and Description

The Savannah River Site is located near Aiken, South Carolina, on the Savannah River. The location of the Savannah River Site and a site map are presented in Figure 13. Previously known as the Savannah River Plant, the site was established in 1950 and started operations in 1952. It continues limited operations today. Over its history it has operated a fuel and target manufacturing facility, five production reactors, two chemical separation areas, and various waste management facilities. The principal products of Savannah River were tritium and plutonium for national defense. Reactor operations were terminated in 1989.

For its reactor operations, the Savannah River Site received uranium metal for target fabrication from the FMPC at Fernald and enriched uranium metal for driver fuel from

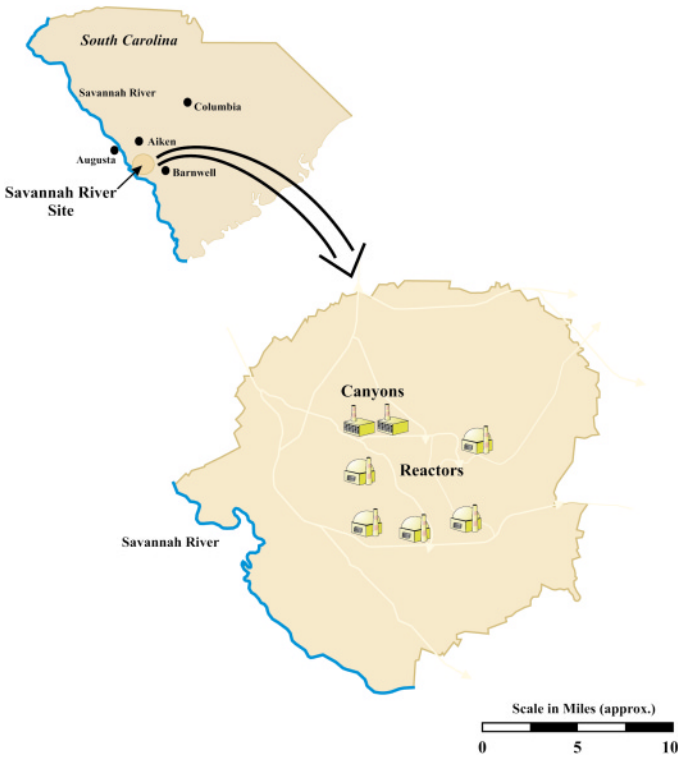


Figure 13. The Savannah River Site, located in southwestern South Carolina.

Y-12 in Oak Ridge. The site shipped uranium, mainly as UO_3, to the gaseous diffusion enrichment plants at Oak Ridge and Paducah. Most enriched recycled uranium was returned to Y-12 as uranyl nitrate solution, but small quantities of enriched uranyl nitrate were also shipped to Fernald. Currently, the Savannah River Site continues to operate one of its two chemical separation areas to stabilize nuclear materials for long-term storage and disposition.

From the beginning of its chemical separation operations, Savannah River recovered unused uranium from spent fuel and targets. The site began shipments of recycled uranium in 1955 and continued producing and shipping the material nearly continuously for 41 years. For most of their operational life, the Savannah River reactors utilized mixed cores of depleted or natural uranium targets and enriched uranium drivers. There were two chemical separation canyons at Savannah River; one,

SRS Historical Timeline

1950 The Atomic Energy Commission contracts for the design, construction, and management of the Savannah River Plant.

1952 Site begins fuel fabrication operations for reactors.

1953 R-Reactor starts operating.

1954 F-Canyon begins operation utilizing PUREX process to recover plutonium and uranium from reactor targets. P-Reactor, L-Reactor, and K-Reactor start operating.

1955 H-Canyon begins operation utilizing PUREX process to recover uranium, neptunium, and plutonium from reactor-driver fuel. C-Reactor starts operating. *First shipment of recycled uranium.*

1992 DOE announces the phaseout of all uranium processing; however, the Canyons remain active to stabilize nuclear materials.

1994 *Final shipment of recycled uranium.*

F-Area (Figure 14), designed to process the target material and recover plutonium, neptunium, and depleted uranium, and the other, H-Area (Figure 15), designed to recover uranium, neptunium, and ^{238}Pu. Both canyons utilized the PUREX process for their operations. The uranium recovered by PUREX is in the form of uranyl nitrate solution. At Savannah River, the depleted uranyl nitrate solution was further processed by denitration to UO_3 for shipment, storage, or disposal. Most enriched uranyl nitrate was shipped as a solution, but records indicate some enriched material was denitrated and shipped as UO_3.

Figure 14. F–Area Canyon Facility recovered uranium from targets.

Figure 15. H–Area Canyon Facility (221-H Building) recovered uranium from enriched driver fuel.

Material Account

Savannah River Uranium Shipments

Figure 16 displays Savannah River's shipments of recycled uranium on an annual and cumulative basis. Over the operational history of the chemical separation canyons, 41,715 MTU of recycled uranium was recovered. Of this, about 22,189 MTU was sent to other sites for enrichment or other processes. As of March 1999, about 19,526 MTU, principally depleted UO_3, was stored at the site pending dispositioning. Of the recycled uranium shipped from Savannah River, about 88 percent was sent for enrichment to the Oak Ridge gaseous diffusion plant (10,292 MTU) and the Paducah Gaseous Diffusion Plant (9,257 MTU). Fernald received nearly 2,486 MTU for conversion to uranium metal and other products. The Oak Ridge Y-12 Plant received nearly 153 MTU of recycled uranium, mostly enriched uranyl nitrate solution. Savannah River also sent about 2 MTU of recycled uranium to other sites.

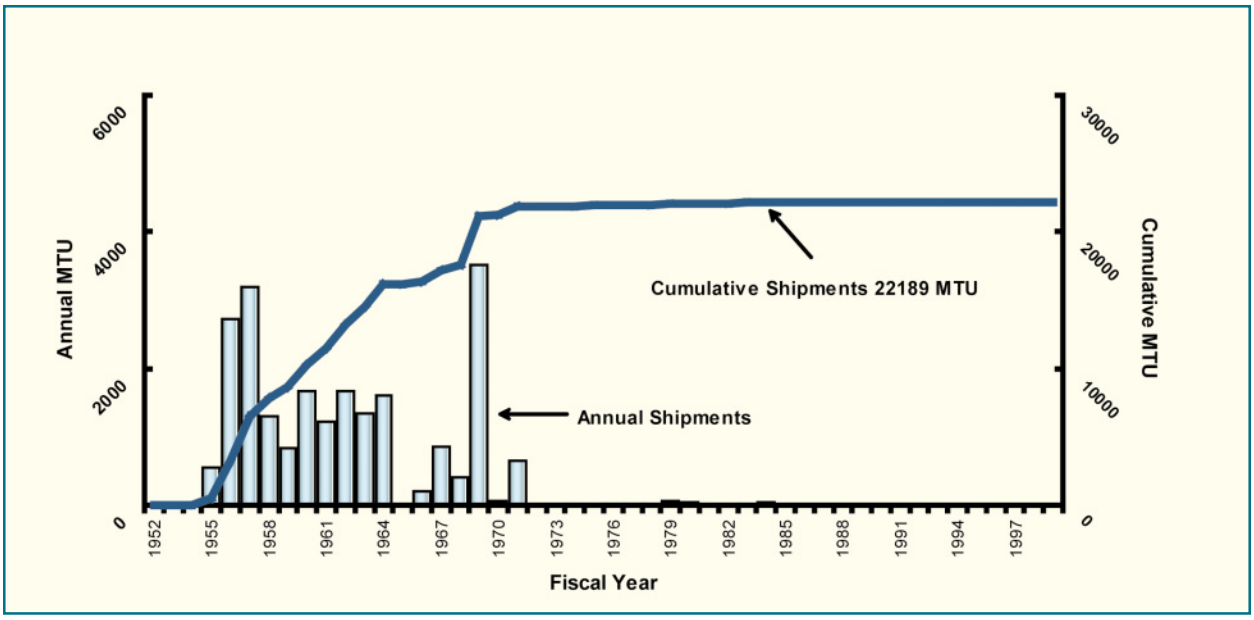
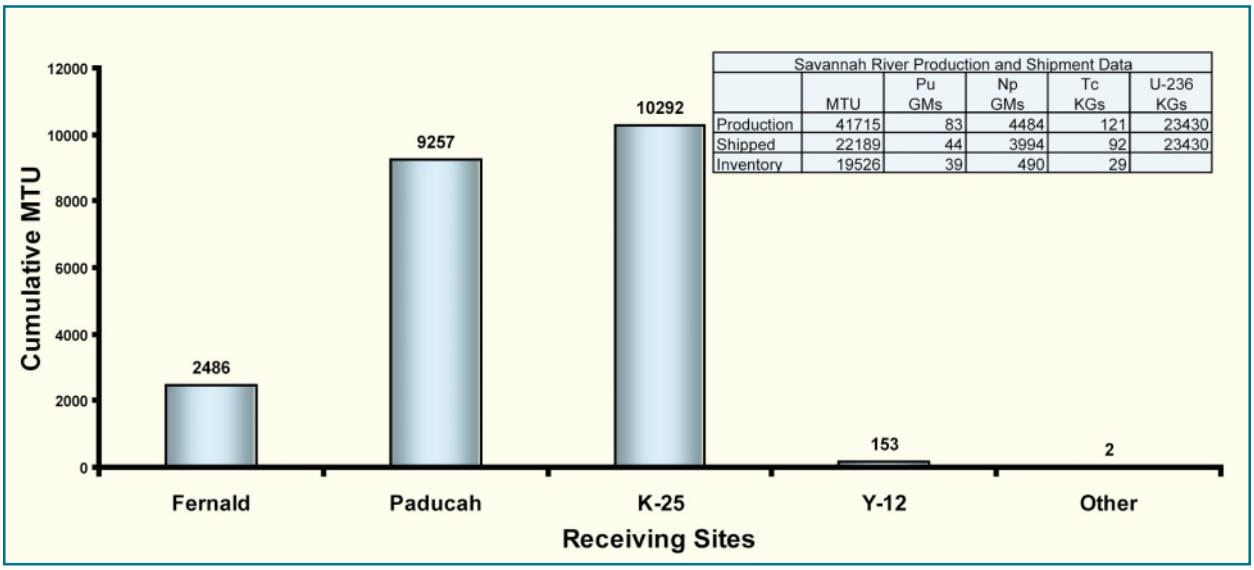


Figure 16. Savannah River's annual and cumulative shipments of recycled uranium produced.

Contaminant Data

Figure 17 shows the total contaminants contained in the recycled uranium produced and shipped by Savannah River and displays quantities of recycled uranium sent to the major receiving sites. The plutonium data for the Savannah River-produced UO_3 indicated a range from less than 1 ppb to a few samples at about 3 ppb, with an average of about 1.5 ppb. The standard deviation is about 1 ppb. A value of 2 ppb plutonium (mean value plus one-half the standard deviation) was used to conservatively account for the plutonium received at the initial receiving sites. For neptunium, the data indicated a range from less than 100 ppb to nearly 300 ppb. The mean value was about 130 ppb, and the standard deviation was about 100 ppb. For



Savannah River Production and Shipment Data

	MTU	Pu GMs	Np GMs	Tc KGs	U-236 KGs
Production	41715	83	4484	121	23430
Shipped	22189	44	3994	92	23430
Inventory	19526	39	490	29	

Figure 17. Savannah River's total production, shipments, and remaining inventory of recycled uranium produced and associated contaminants with receiving sites identified.

technetium, only limited data were available from the site; however, more data were available from receiving sites. The data indicated a range from less than 1 ppm to nearly 9 ppm for UO_3. A value of 3.5 ppm technetium, (the approximate median value) was used. For enriched uranyl nitrate solution, the technetium concentration of 82 ppm recommended in the Savannah River site report was used to calculate the quantities of technetium presented in this report. To calculate ^{236}U quantities in this report, the individual values determined from operational data presented in the Savannah River Site report were used.

Savannah River shipped about 22,189 MTU of recycled uranium. Based on the contaminant concentration, this recycled uranium contained about 44 grams of plutonium, 4,000 grams (gms) of neptunium and about 92 kilograms (kgs) of technetium. Most of the recycled uranium was depleted uranium. There are no data for ^{236}U for depleted or normal material. About 2,066 MTU of enriched uranium is included in the shipped material, and it contained more than 23,000 kgs of ^{236}U plus about 17 percent (16 kgs) of the technetium.

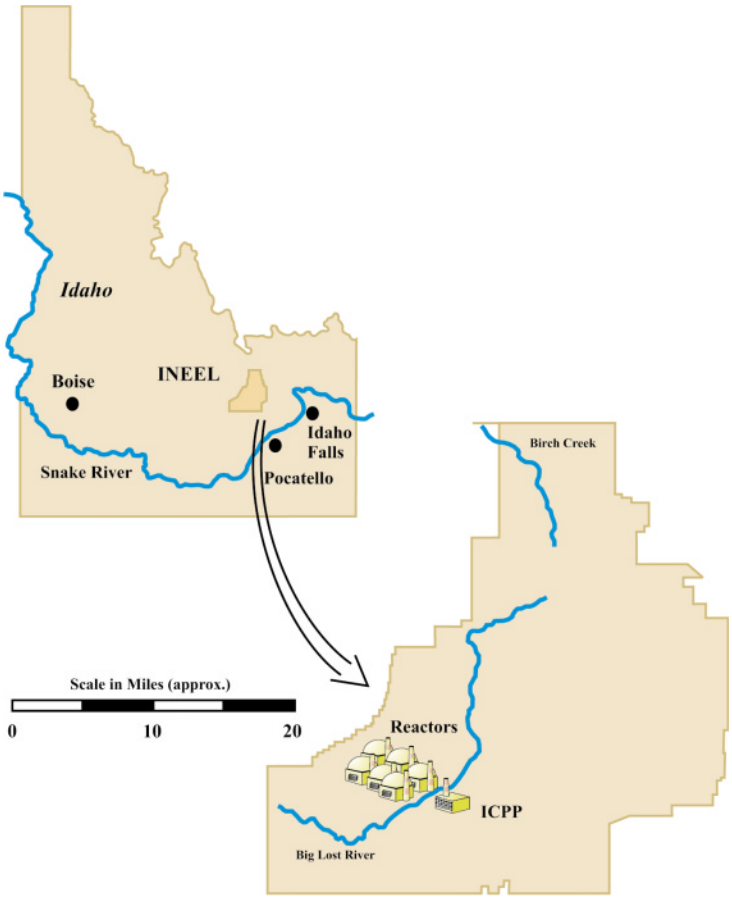


Figure 18. Idaho National Engineering and Environmental Laboratory.

Idaho National Engineering and Environmental Laboratory

Site History and Description

After World War II, the newly created AEC needed a remote site where prototype nuclear reactors could be designed, built, and tested. The old Naval Proving Ground near Pocatello, Idaho, proved to be an ideal location. As a result, the Idaho National Engineering and Environmental Laboratory (INEEL) began operation in 1949 as the National Reactor Testing Station (NRTS). The 890-square-mile reservation was chosen for its isolation in the southeastern Idaho desert. It is located approximately 50 miles west of Idaho Falls and 20 miles east of Arco. Figure 18 shows the location of the INEEL site in the state of Idaho and a map of the site. Figure 19 is an aerial photograph of the site.

Fifty-two nuclear reactors, most of them first-of-a-kind, were built at the site, including the U.S. Navy's first prototype nuclear propulsion plant. The reactor testing programs were designed to demonstrate nuclear reactor concepts, test materials in nuclear radiation environments, and demonstrate reactor safety. The Idaho Chemical Processing Plant (ICPP) was a specialized plant designed to reprocess the unique fuels required by the

INEEL Historical Timeline

1949 The AEC establishes the NRTS in the southeastern Idaho desert on the site of the World War II Naval Proving Ground.

1950 Designed ICPP processing of reactor fuel to be used at Idaho to allow recovery of uranium in fuel.

1951 First shipment of reactor fuel is received for processing at the ICPP.

1953 Spent fuel is reprocessed using the REDOX method, allowing recovery of uranium. *First shipment of recycled uranium.*

1957 ICPP converts to combined PUREX/REDOX method, improving recovery of uranium.

1971 Denitration method was used at the end of processing to convert material to dry oxide form.

1974 The NRTS becomes Idaho National Engineering Laboratory (INEL) to become one of the elite "National" laboratories.

1986 *Last shipment of recycled uranium.*

1988 The ICPP ceases operations for facility upgrades.

1991 DOE announces the phaseout of reprocessing operations because of reduced need for highly enriched uranium and current world political climate.

1998 Reprocessing facility is deactivated.

Figure 19. INEEL, established in 1949 in southeastern Idaho.

various test reactors. Most of the fuel reprocessed at ICPP came from three reactors; the Experimental Test Re-actor (ETR), the Materials Testing Reactor (MTR), and the Submarine Thermal Reactor (STR).

The ICPP

The INEEL site has a long history of radioactive waste storage, processing, and research. In 1950, chemists and engineers at the AEC's Oak Ridge reservation developed the chemical process for the MTR fuel. The process dissolved MTR fuel and extracted the enriched uranium that had not fissioned during reactor operation. The ICPP was built to utilize this process and to allow modifications to recover enriched uranium from the fuel used at the other INEEL reactors.

A year's accumulation of irradiated fuel was needed for the first production run, so the basin was finished first while the rest of the plant was still under construction. The first shipment arrived at the plant in November 1951. In February 1953, the operators had test-run the plant using nonirradiated uranium and calibrated the plant instrumentation. Over time, the plant recovered enriched uranium from the many fuel types required by the test reactors, challenging the chemists and engineers to develop specialized processes utilizing the flexibility designed into the small-scale ICPP. Figure 20 shows a photograph of the ICPP and surrounding buildings.

Figure 20. ICPP received spent fuel for processing.

Material Account

Idaho Uranium Shipments

Figure 21 displays Idaho's shipments of recycled uranium on an annual and cumulative basis. Idaho processed small quantities (a total of about 32 MTU) of a large variety of enriched uranium experimental fuel types during its years of operation. Most of the Idaho recycled uranium (26 MTU) was sent to the Oak Ridge Y-12 Plant. About 4 MTU was sent to Portsmouth, and smaller quantities were sent to Rocky Flats and Pacific Northwest National Laboratory.

Contaminant Data

Figure 22 shows the total contaminants contained in the recycled uranium produced and shipped by Idaho and displays quantities of recycled uranium sent to the major receiving sites. The contaminant concentrations used to calculate the quantities of contaminants delivered to receiving sites were based on values presented in the Idaho site report. These values were derived from modeling the quantities of contaminants produced by reactor irradiation and then calculating the concentration of the contaminants remaining after chemical processing. Three reactor types were used in the modeling of constituent production. Typical decontamination rates for the triple extraction process were used to determine the effectiveness of the chemical processing.

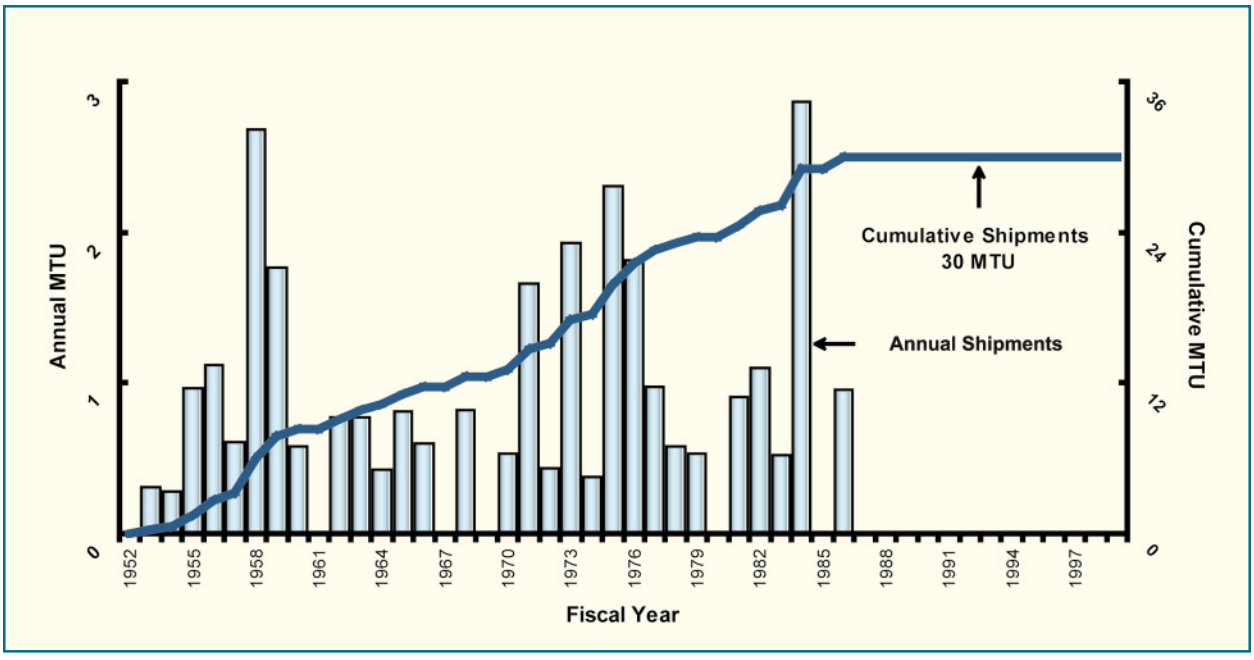
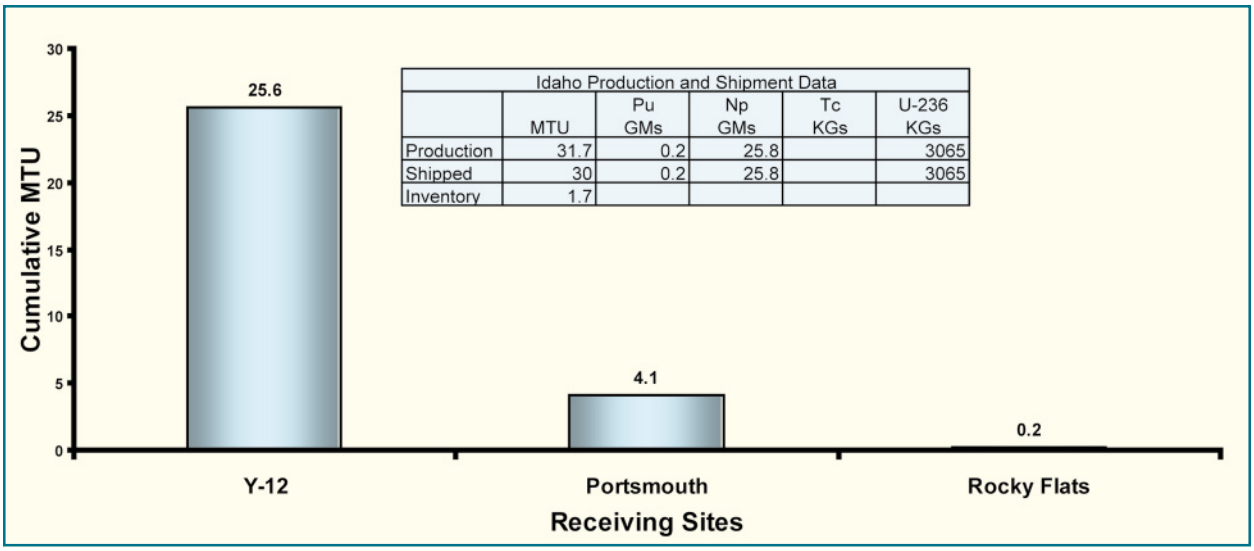


Figure 21. Idaho's annual and cumulative shipments of recycled uranium produced.



Idaho Production and Shipment Data

	MTU	Pu GMs	Np GMs	Tc KGs	U-236 KGs
Production	31.7	0.2	25.8		3065
Shipped	30	0.2	25.8		3065
Inventory	1.7				

Figure 22. Idaho's total production, shipments, and remaining inventory of recycled uranium produced and associated contaminants with receiving sites identified.

The data indicated that about 70 percent of the material conformed to a general constituent description in that it contained approximately 0.12 ppb plutonium, 1.2 ppm neptunium, and only 1.1 ppb technetium. The remaining material could not be generalized with respect to constituent concentrations but had to be treated on an individual shipment basis because of variations in fuel type, irradiation, and subsequent processing. There was little or no chemical analysis data to verify the constituent concentrations presented in the site report. However, the contaminant data presented were consistent with typical process flowsheet data. The calculated concentrations for each shipment are presented in the site report. Based on information contained in the Idaho site report, their recycled uranium contained about 3,100 kilograms of ^{236}U, 26 grams of neptunium, and less than 1 gram of plutonium.

West Valley

Site History and Description

The Western New York Service Center at West Valley, New York, is located in Cattaraugus County approximately 35 miles southeast of Buffalo, New York. Figure 23 shows the location of the West Valley site in New York State.

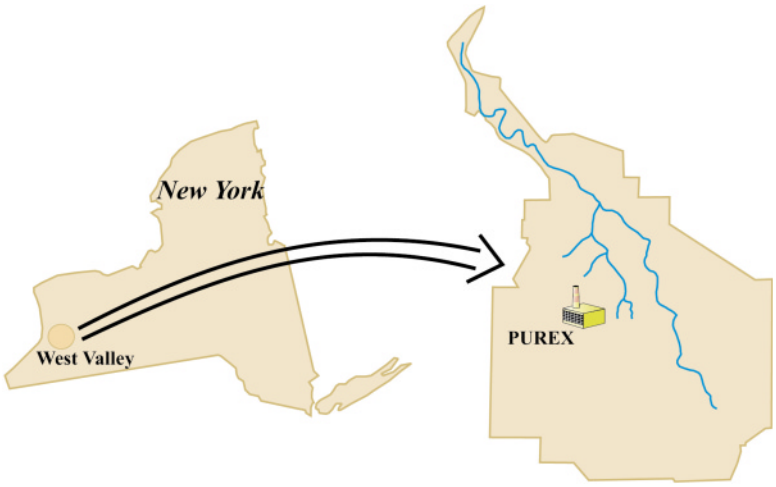


Figure 23. West Valley Demonstration Project – a privately owned spent fuel reprocessing facility located in New York.

West Valley Historical Timeline

1954 The Atomic Energy Act encourages private industrys' participation in nuclear fuel processing.

1961 The State of New York acquires land for an atomic industrial area.

1962 Nuclear Fuel Services, Inc. (NFS) is established as a reprocessing company.

1965 NFS is granted a license to receive and store nuclear fuel at West Valley. Operations begin using PUREX process for plutonium and uranium recovery from reactor spent fuel.

1966 *First shipment of recycled uranium.*

1972 Reprocessing operations are suspended.

1973 *Final shipment of recycled uranium.*

1976 NFS ceases its reprocessing operations permanently.

1980 DOE begins decontaminating and decommissioning the facility.

Until 1965, all nuclear fuel reprocessing was accomplished at U.S. Government-owned facilities. Recovery and reuse of plutonium from spent nuclear fuel was anticipated to be a profitable business, especially when the breeder reactor, under development, would be built. Under direction of the State of New York Office of Atomic Development, West Valley became the only private facility in the United States to reprocess spent nuclear fuel. The State leased the facility to Davison Chemical Company, which established NFS, Inc. as a reprocessing company.

The facility operated from 1965 through 1972. It had remote handling capabilities and used the PUREX process to recover plutonium and uranium. West Valley had a design capacity of 300 tons per year but processed only a total of about 625 tons during its 6 years of operation. The maximum quantity of fuel processed in any year was less than 200 tons. Throughout its operational history, West Valley received both commercial and Government spent fuels. In 1972, fuel reprocessing was halted in order to upgrade the facility to increase its reprocessing capacity and to meet new regulatory requirements. In 1980, NFS determined that the costs for the upgrade were too great to restart, and it discontinued its lease of the site. No additional fuel was reprocessed after 1972. As the owner and remaining licensee for the site, the State of New York remained responsible for its environmental remediation. Under the West Valley Demonstration Project Act (WVDPA) of 1980, the DOE and its site contractors have been working with the State in the solidification of high-level radioactive wastes and the decontamination and decommissioning of the facility. Figure 24 shows a photograph of the West Valley site.

Figure 24. West Valley Demonstration Project was anticipated to profit from processing reactor spent fuel.

Material Account

Recycled Uranium Shipments

Figure 25 displays West Valley's shipments of recycled uranium on an annual and cumulative basis. The West Valley Facility

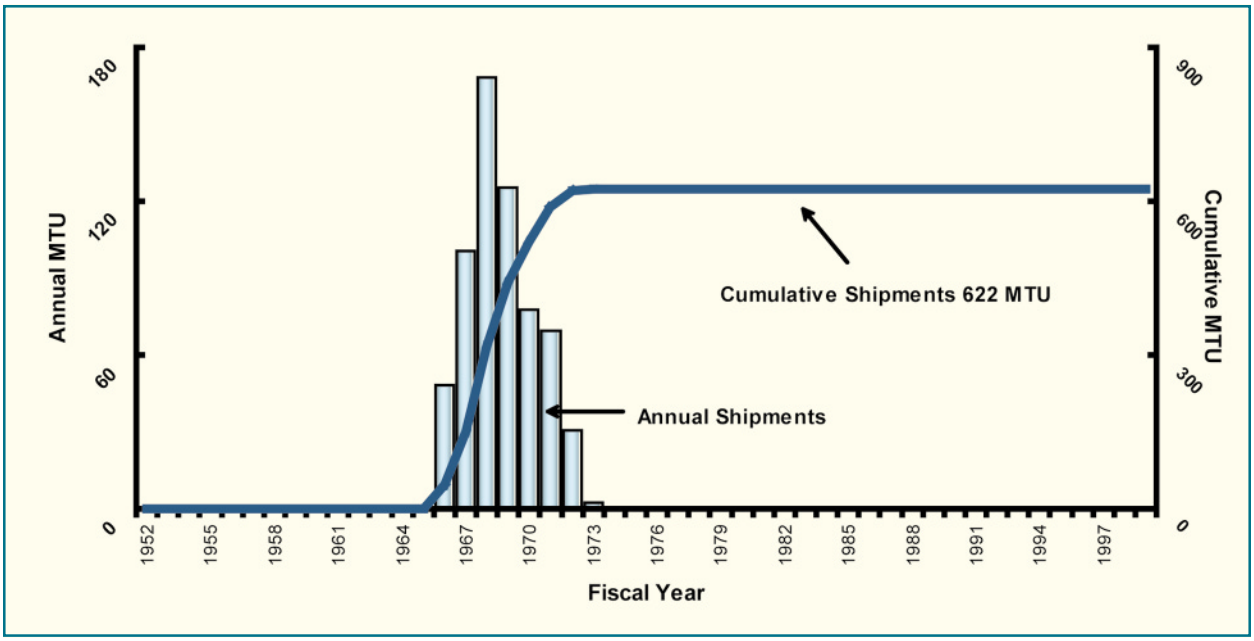


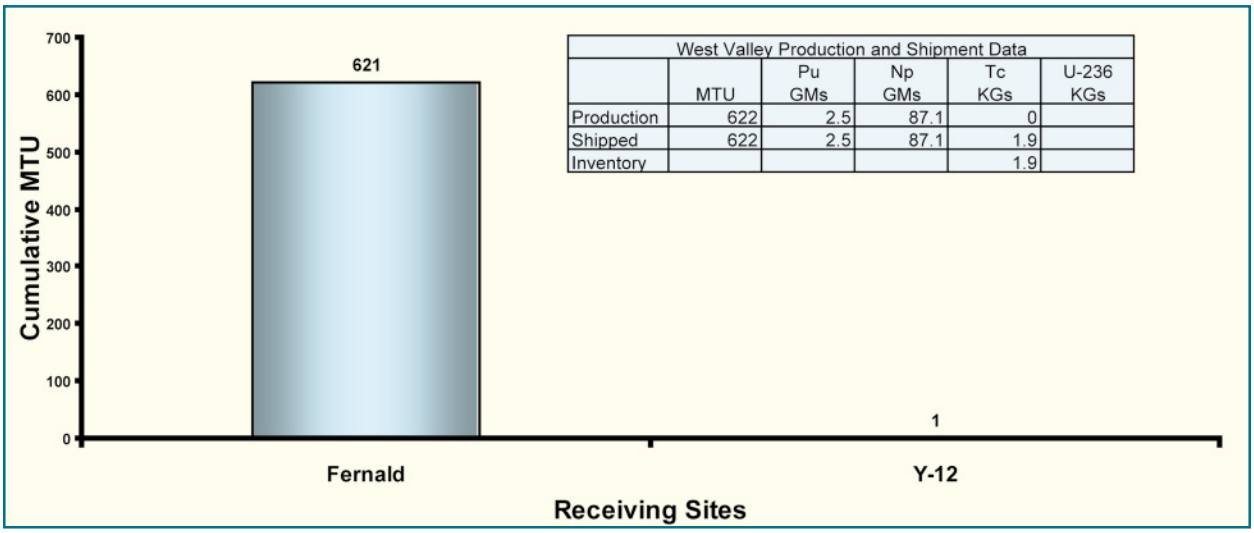
Figure 25. West Valley's annual and cumulative shipments of recycled uranium produced.

processed 27 batches of nuclear fuel during its 6 years of operation. This fuel reprocessing involved about 625 MTU of fuel and resulted in the recovery of approximately 622 MTU. Of the 622 MTU recovered, approximately 359 MTU was recovered from fuel that originated from U.S. Government reactors, and the remaining material was from commercial electrical power reactors. About 30 MTU was recovered from Government reactor fuel that contained no recoverable plutonium. Approximately 0.9 MTU was recovered from a spent fuel shipment containing a mixture of highly enriched uranium with thorium that had been irradiated to produce fissionable ^{233}U.

From the uranium recovered, about 466 MTU was uranium enriched in ^{235}U, 13 MTU was normal uranium, and 142 MTU was depleted in ^{235}U. All of the uranium recovered at the West Valley facility, except that recovered from the thorium mixture, was shipped to Fernald in the form of uranyl nitrate solutions. This material was used for conversion to metal or other uranium compounds for use within the DOE complex. The uranium recovered from the thorium mixture was shipped as uranyl nitrate solution to Y-12 where it was processed into a stable, dry oxide material. It is currently in storage at Oak Ridge.

Contaminant Data

Figure 26 shows the total contaminants contained in the recycled uranium produced and shipped by West Valley and displays quantities of recycled uranium sent to the major receiving sites. There is very limited available data concerning the reactor-produced constituent content in the recycled uranium from West Valley. Fernald was able to locate data from the analysis of a sample from one of the shipments from West Valley. The values in this data set were within the range of data from other PUREX-produced uranium (e.g., Savannah River and Hanford recycled uranium). Therefore, the Fernald data were used to estimate the contaminant quantities presented for the 622 MTU of recycled uranium produced at the West Valley site. The values of 4 ppb plutonium, 140 ppb neptunium, and 3.1 ppm technetium were used for West Valley uranyl nitrate shipped to Fernald.



West Valley Production and Shipment Data

	MTU	Pu GMs	Np GMs	Tc KGs	U-236 KGs
Production	622	2.5	87.1	0	
Shipped	622	2.5	87.1	1.9	
Inventory				1.9	

Figure 26. West Valley's total production, shipments, and remaining inventory of recycled uranium produced and associated contaminants with receiving sites identified.

There are no data available for ^{236}U in West Valley uranyl nitrate. On this basis, it is estimated that the recycled uranium from West Valley contained about 2.5 grams of plutonium, 87 grams of neptunium, and less than 2 kilograms of technetium. The 0.9 MTU of West Valley recycled uranium that was sent to Y-12 was ^{233}U produced from thorium. This material is not believed to contain the usual contaminants. No data are available for contaminants, and thus, constituent quantities were not calculated for this material.

Receiving Sites

Introduction

After production at the chemical processing facilities, recycled uranium must go through a number of chemical and physical processes before it can be returned to the reactor as fuel or be utilized for other purposes. Included in these processes are enrichment at the gaseous diffusion plants and conversion to metal for reactor fuel or other components. These processes were carried out at other sites, which have been referred to in this report as the receiving sites. Nearly all of the recycled uranium produced by the U.S. production sites was shipped to three principal DOE sites, including the Oak Ridge and Paducah Gaseous Diffusion Plants and the FMPC at Fernald. The Oak Ridge Y-12 Plant also received some recycled uranium, principally enriched material. Harshaw Chemical Company received recycled uranium in the early 1950s to prepare the material for use at the Oak Ridge gaseous diffusion plant. Small quantities were also sent to the Portsmouth Gaseous Diffusion Plant, Oak Ridge National Laboratory, Brookhaven National Laboratory, and General Atomics in San Diego. The Savannah River Site also received a small amount of depleted recycled uranium from Hanford.

Gaseous Diffusion Plants

DOE established three gaseous diffusion uranium enrichment plants in the United States: the first one, the K-25 Complex at Oak Ridge, Tennessee, was built as part of the Manhattan Engineering District for atomic weapons development during World War II. The Paducah Gaseous Diffusion Plant in Paducah, Kentucky, was the second gaseous diffusion plant to be built, and it started operations in 1950. Finally, the

Portsmouth Gaseous Diffusion Plant was built in Piketon, Ohio, during the early 1950s and started operation in 1955. Figure 27 shows the locations of the three gaseous diffusion enrichment plants on a map of the United States.

After the Paducah Gaseous Diffusion Plant began operation, K-25 began working with that plant in an integrated enrichment operation, where Paducah enriched normal or slightly depleted uranium to about 2 percent, and this material was used as feed at K-25 for further enrichment. The Portsmouth plant also operated in an integrated enrichment operation with the other gaseous diffusion plants using their low enriched product as feed for further enrichment.

At each of these three sites, uranium was "enriched" in the ^{235}U isotope by the diffusion of gaseous uranium hexafluoride (UF_6) across barriers (porous membranes shaped into the form of a tube), causing a separation of the uranium isotopes according to the isotope atomic weight. The ^{235}U enriched uranium is used to fuel nuclear reactors and for nuclear weapons production.

Figure 27. Location of enrichment plants.

Paducah Gaseous Diffusion Plant

Site History and Description

The Paducah Gaseous Diffusion Plant has operated since 1952 on a Federal reservation 10 miles west of the city of Paducah, Kentucky, and 3 miles south of the Ohio River. A map of the plant location is shown in Figure 28.

Historically, the plant enriched uranium for government programs and commercial nuclear power plants from its natural ^{235}U content of about 0.7 percent to about 2.0 percent. The Energy Policy Act of 1992 transferred responsibility for Paducah from DOE to a newly created entity, the United States Enrichment Corporation (USEC). The USEC leases the enrichment facility from DOE.

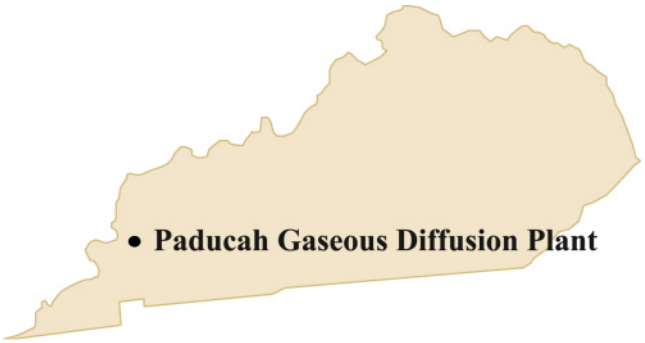


Figure 28. Location of the Paducah Gaseous Diffusion Plant in Kentucky.

The Paducah site occupies a 748-acre security zone within a 3,425-acre Federal reservation. A photograph of the site is presented in Figure 29. Most of the enrichment process and support activities involving recycled uranium took place in six facilities—the Feed Plant (C-410/420), Isotope Recovery and Decontamination (C-400), Gaseous Diffusion Process Buildings (C-331, C-333, C-335, and C-337), Purge and Product Withdrawal Building (C-310), Surge and Tails Building (C-315), and

Paducah Gaseous Diffusion Plant Historical Timeline

1950	Site selected at the location of the former Kentucky Ordnance Works.
1952	First production cells in operation.
1954	*First receipts of recycled uranium for enrichment.*
1960	Plant shifts from military mission to commercial focus, supplying enriched uranium to electric utilities.
1973	*Last receipts of recycled uranium from production facilities.*
1993	USEC assumes responsibility for plant.

Uranium Metal Production Facility (C-340). The Feed Plant, Isotope Recovery, and Uranium Metal Production Facility are no longer active.

Feed Plant – Buildings C-410 and C-420

To enrich uranium in a cascade, the feed product must be in the form of UF_6. Prior to 1976, most of the uranium Paducah received for enrichment was UO_3 from ore processing refineries and uranium recovery facilities at Hanford and the Savannah River Site. Uranium trioxide was converted to UF_6 in the Paducah Feed Plant. Between 1953 and 1964, and intermittently from 1968 through 1977, the Feed Plant produced UF_6 from UO_3 produced at Hanford and the Savannah River Site. The feed plant reduced UO_3 to uranium dioxide (UO_2) by reacting it with hydrogen (H_2). The UO_2 was then converted to uranium tetrafluoride (UF_4 or "green salt"), using hydrogen fluoride gas (HF), and finally to UF_6, using fluorine gas in the facility commonly called the fluorination tower. The Feed Plant was shut down in 1977. Recycled uranium as a percentage of all uranium processed ranged from 3 percent in 1955 to 65 percent in 1973 and averaged 17 percent over the time periods that this material was used.

The existence of TRU isotopes and fission products was first documented at Paducah in 1957 with the identification of neptunium and technetium. The ash from the fluorination of UF_4 contained most of the radioactive impurities from recycled uranium, especially the plutonium. The concentration of transuranic isotopes and fission products in the recycled uranium originally entering the feed plant was very small, estimated by the Paducah laboratory to be 3 ppb plutonium, 225 ppb neptunium, and 6.7 ppm technetium. The transuranics, including the neptunium and plutonium, were dramatically reduced in concentration in the UF_6 from feed plant processing and cascade feeding. Plutonium does not form volatile fluoride compounds and is generally left in the fluorination tower ash.

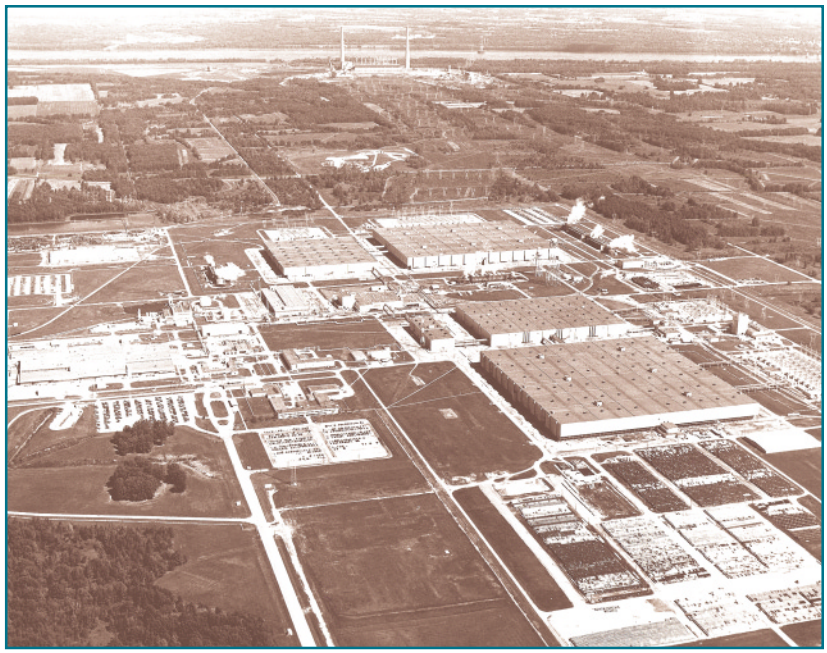


Figure 29. Aerial view of the Paducah Gaseous Diffusion Plant.

Isotope Recovery – Building C-400

Uranium recovery facilities in C-400 were used to chemically separate and recover uranium, neptunium, and technetium from a variety of waste materials. Uranium recovery processed fluorination tower ash, sintered metal filters, decontamination and scrubber solutions, filter and vacuum cleaner particulate, laboratory waste, and spilled materials to extract uranium and convert it to an oxide for the Feed Plant. The aqueous raffinate from the solvent extraction columns contained varying amounts of ^{237}Np, plutonium-239, thorium-234, protactinium-234, and ^{99}Tc, which were discharged to the environment.

A neptunium recovery operation began at Paducah in November 1958 in response to a request from the AEC. The solvent extraction and evaporation method recovered neptunium from receiver ash and cylinder wash solution. Evaporation concentrated the recovered neptunium to 20–25 grams per liter (g/l) before moving the solution to Building C-710 for additional processing, concentration, and storage.

The site estimates that this process recovered nearly 4.3 kilograms of neptunium between November 1958 and October 1961. A new process using magnesium fluoride (MgF_2) traps was started in 1961 and continued until the late 1970s. The site estimates that a small quantity of neptunium was discharged to the environment through building drains as a result of isotope recovery operations.

Technetium-99 is a fission product received by Paducah in recycled uranium. The material passed through the cascade with the enriched product stream causing operational and contamination problems. However, it also became a valuable isotope to recover. Recovery efforts began in 1960 at the request of the AEC, and approximately 25 kilograms were scavenged from various effluent streams. Technetium traps were installed in the feed plant and cascade process streams in 1961 and 1963 to reduce technetium concentration in the enriched product. The traps were processed through the uranium recovery facilities in building C-400, and the concentrated technetium solution was shipped to ORNL for further processing.

Gaseous Diffusion Process – Buildings C-331, C-333, C-335, and C-337

The main process buildings at Paducah (C-331, C-333, C-335, and C-337) contain cascades, which consist of multiple enrichment cells. Each enrichment cell contains eight stages; each stage consists of a compressor, chiller, diffusion barrier, and supporting valves and piping. The stages are arranged in series to progressively enrich UF_6.

Enrichment occurs as the UF_6 is pumped into the diffusion barrier in the converter cell. The lighter ^{235}U isotope passes through the barrier tubing slightly more often than the heavier uranium-238 (^{238}U). The gaseous UF_6 from both sides of the barrier is pumped through another converter cell, with the enriched UF_6 and depleted UF_6 flowing in countercurrent directions. Enriched UF_6 product travels to the top of the cascade, while the depleted UF_6 goes towards the bottom. Both enriched product and depleted tails are drained into cylinders and allowed to cool until solid. The Paducah cascade consists of more than 1,800 stages in the four process buildings and is capable of uranium enrichment from normal levels (0.711 percent ^{235}U) to almost 3 percent ^{235}U. Product was normally shipped to the Oak Ridge gaseous diffusion plant or to the Portsmouth Gaseous Diffusion Plant for further enrichment, while tails were either stored onsite or re-fed into the cascade.

The neptunium and any remaining plutonium do not volatize as readily as the

UF_6 in the feed cylinders when being fed into the cascade; therefore, the TRU materials tended to remain in the cylinder residue, called a "heel." Technetium is volatile and tended to migrate to the top of the cascade with the enriched product. It was drained off into the product or vented into the atmosphere.

Purge/Product Withdrawal – Building C-310 and Surge/Tails – Building C-315

Enriched and depleted UF_6 gases were withdrawn in Buildings C-310 and C-315. Both materials were withdrawn from the cascade by pumps that discharged through a condenser, piping, and cylinder pigtail to the intended UF_6 receiver cylinder. The cylinders were filled with liquid UF_6 and allowed to cool until solid before handling.

Uranium Metal Production – Building C-340

Along with the enriched uranium produced at Paducah, the plant also produced uranium metal. Metals production involved several steps. Depleted UF_6 process gas was reacted with H_2 in a heated tower to produce UF_4 powder and HF. The HF was collected and returned to the Feed Plant on a periodic basis. Metallic uranium was produced by reacting the UF_4 with magnesium in a retort vessel. Magnesium metal and green salt were mixed in a steel vessel lined with MgF_2 and heated in an induction furnace. After cooling, the contents were dumped onto a grate to separate the metallic uranium (derby) from the slag. The C-340 operation was also capable of re-melting the uranium derbies and casting specific shapes. Melting operations were conducted in a furnace with a controlled atmosphere.

Material Account

Recycled Uranium Receipts from Production

Figure 30 displays Paducah's receipts of recycled uranium from production facilities on an annual and cumulative basis. The Paducah Gaseous Diffusion Plant received recycled uranium from production at both Hanford and Savannah River. The first recycled uranium received at Paducah was about 2,233 MTU shipped from Hanford in 1954. Paducah received a total of 74,491 MTU of recycled UO_3 from Hanford, which was nearly two-thirds of the recycled uranium shipped by the production sites. In the years 1965, 1966, 1968, and 1970, no recycled uranium was shipped from Hanford to Paducah. The Hanford UO_3 represented nearly 90 percent of the recycled uranium received by Paducah from production facilities.

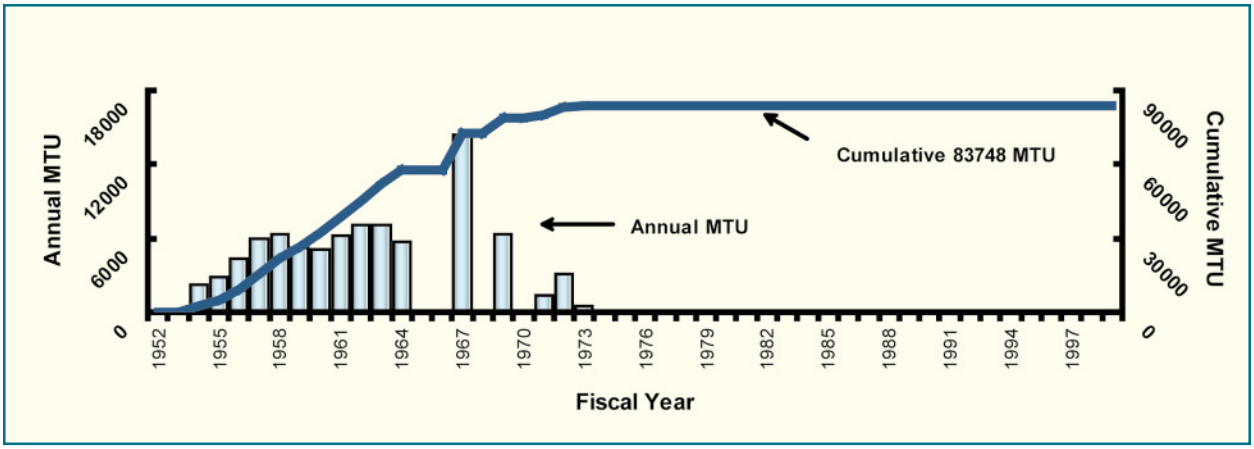


Figure 30. Paducah's annual and cumulative receipts of recycled uranium from production facilities.

Starting in 1955, Paducah received recycled uranium from Savannah River production. The Savannah River shipments continued until 1971, but there were no shipments in 1959, 1960, 1965, 1966, 1967, and 1970. In total about 9,257 MTU of UO_3 were received from Savannah River, which was slightly more than 10 percent of all of the recycled uranium received from production facilities.

Contaminants in Recycled Uranium

Figure 31 shows the total contaminants contained in the recycled uranium received by Paducah and displays quantities of recycled uranium received from the producing sites. The recycled uranium received at Paducah contained about 354 grams of plutonium, nearly 28,000 grams of neptunium, and about 628 kilograms of technetium. These quantities were determined from the data calculated for each contaminant in the shipping sites recycled uranium as presented in this report. Paducah received about 74 percent of the TRU and fission product contaminants that were part of recycled uranium products from the production sites.

Oak Ridge Gaseous Diffusion Plant (K-25)

The Oak Ridge Reservation

Oak Ridge, Tennessee was one of three sites established in 1942 by the Manhattan Engineering District for the development of the atomic bomb. Originally called the Clinton Engineering Works, the site supported three major operation centers: the Y-12 Plant, the X-10 Plant, and the K-25 Plant, which were identified by these code names to disguise their operations. Y-12 was the first to be constructed, and it used an electromagnetic system for uranium isotope separation and enrichment. The X-10 Plant (also called the Clinton Pile) housed the first large-scale graphite reactor and support buildings to demonstrate the production and chemical separation of plutonium. X-10 later became the ORNL. The K-25 Plant used the gaseous diffusion process to produce uranium enriched in the ^{235}U isotope. The three plants were located in different valleys within a tightly controlled security area. In 1943, the employees chose "Oak Ridge" as the name for the Government town that supports the plants.

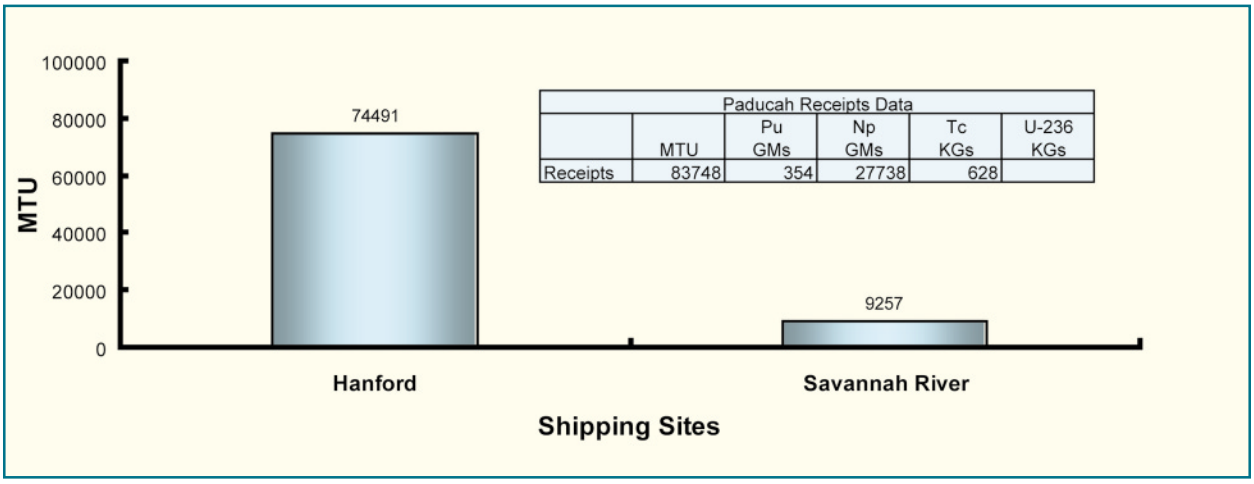


Figure 31. Paducah's total receipts of recycled uranium and associated contaminants with production sites identified.

Site History and Description

Located on a 1,500-acre tract approximately 11 miles west of the city of Oak Ridge, Tennessee, the K-25 Plant was built during World War II to produce enriched uranium to support the Manhattan Project. A map of the plant location is shown in Figure 32. A photograph of K-25 is shown in Figure 33. The plant was named K-25 after the designation of the first gaseous diffusion building constructed on the site. Eventually the site encompassed more than 100 different facilities and became capable of enriching uranium up to 93 percent ^{235}U. When the Government began providing low enriched uranium for commercial nuclear power reactors, K-25 became an integral part of that effort.

In 1985, K-25 was placed on standby status because of an overcapacity of enrichment capabilities. In 1987, the plant's enrichment production was officially shut down. The site then served as the base of operations for environmental activities at five major facilities. Recently, DOE has also initiated a program of re-industrialization at the site, which in 1997 became known as the East Tennessee Technology Park.

Facility Description

Oak Ridge began enriching uranium in 1945 with a large gaseous diffusion enrichment cascade located in Building K-25. Over time, the plant added four more gaseous diffusion buildings: K-27, K-29, K-31, and K-33. As each new building was readied for production, all of the cascades were linked to function as an integrated unit. Over the productive life of the plant, a broad range of configurations was used. Factors influencing changes in cascade configuration included maintenance and upgrade programs; variations in feed enrichment assay levels; and the need for various product assays. The plant used two different feed production facilities (in K-1131 and, later, in K-1420) over the operation period. As the Paducah and Portsmouth Gaseous Diffusion Plants began production, K-25 worked with those plants in an integrated enrichment operation. The Oak Ridge gaseous diffusion plant received the first recycled uranium produced by a U.S. production facility in 1952.

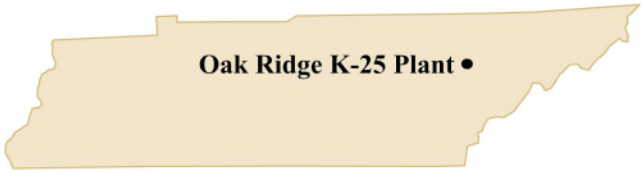


Figure 32. Location of the Oak Ridge K-25 Plant in Tennessee.

From 1952 to 1960, Oak Ridge operated K-1131 as the onsite fluorination plant for both natural and recycled uranium feed. At the K-1131 feed plant, natural or recycled uranium received as UO_3 was reduced by H_2 to UO_2. The UO_2 was hydrofluorinated to produce UF_4. The UF_4 was then fluorinated in a fluorination (commonly called flame) tower reactor to produce UF_6 as feed for the gaseous diffusion process. With recycled uranium, separation of the transuranics and fission products did not

Oak Ridge Gaseous Diffusion Plant Historical Timeline

1942	Site selected in East Tennessee near the city of Knoxville for the Oak Ridge Reservation, initially called the Clinton Engineering Works.
1945	First production of enriched uranium by the gaseous diffusion process.
1952	*First receipts of recycled uranium for enrichment from U.S. production facility.*
1965	*Last receipts of recycled uranium from production facility.*
1985	Gaseous diffusion plant placed in standby.
1987	Gaseous diffusion plant shut down.

Figure 33. Aerial view of the Oak Ridge K-25 facility.

occur during the reduction and hydrofluorination steps. Transuranics, and to a lesser extent, fission products, were concentrated during the conversion of UF_4 to UF_6. The transuranics formed nonvolatile compounds and were largely deposited with the ash.

Metal canisters for ash collection and particulate filters to filter the UF_6 gas were attached to the fluorination reactors. Filters were cleaned and reused or treated as radioactive waste. Residual ash was removed from the tower and sent to Building K-1231 where recovery processes attempted to extract any residual uranium. K-1231 included an ash pulverizer at the west end of the building. Following successive re-feedings into the K-1131 towers, the spent ash was discarded. The spent ash was also packed and shipped to Paducah or, possibly, to the Oak Ridge Y-12 Plant.

Beginning in 1950, UF_6 feed was delivered in various years to one of three buildings (K-31, K-33 feed room, and K-1131). The feed buildings, in turn, fed various units in the cascade, which also varied over time, depending on the enrichment of the UF_6 feed and how the cascade was configured. The cascade had side and top purge cascades. The purpose of the side purge was the removal of intermediate molecular weight gasses, such as coolant vapor and chlorine fluorides. The top purge was for the lighter gasses. Tails were withdrawn from one of two locations in the cascade, Building K-601 and Building K-1131. The UF_6 tails were placed in large steel cylinders, cooled, and stored.

Building K-1410 was built in 1944 and operated through 1979. For many years, this facility was used for receiving, emptying, and refilling spent cascade traps from the K-25 building. Records show that from 1946 to 1962, it was used for decontamination of uranium-contaminated equipment and for recovery of uranium from feed plant ash.

Beginning about 1960, as a part of the decontamination and uranium operations, Building K-1420 accepted oxides for processing from offsite sources, including Hanford and Savannah River. The K-1420 processing included fluorination to UF_6 and associated ash recovery and disposal operations. Equipment from every process building, including the feed plant, was decontaminated and serviced in this facility. During the 1970s, Building K-1420 was used for major gaseous diffusion equipment upgrades as part of a cascade improvement and upgrade program. K-1420 operations also involved removing heels from 2.5-ton cylinders (and possibly larger cylinders), cleaning the cylinders, and processing the heels material.

Material Account

Recycled Uranium Receipts from Production

Figure 34 displays K-25's receipts of recycled uranium from production facilities on an annual and cumulative basis. The first recycled uranium produced by the Hanford

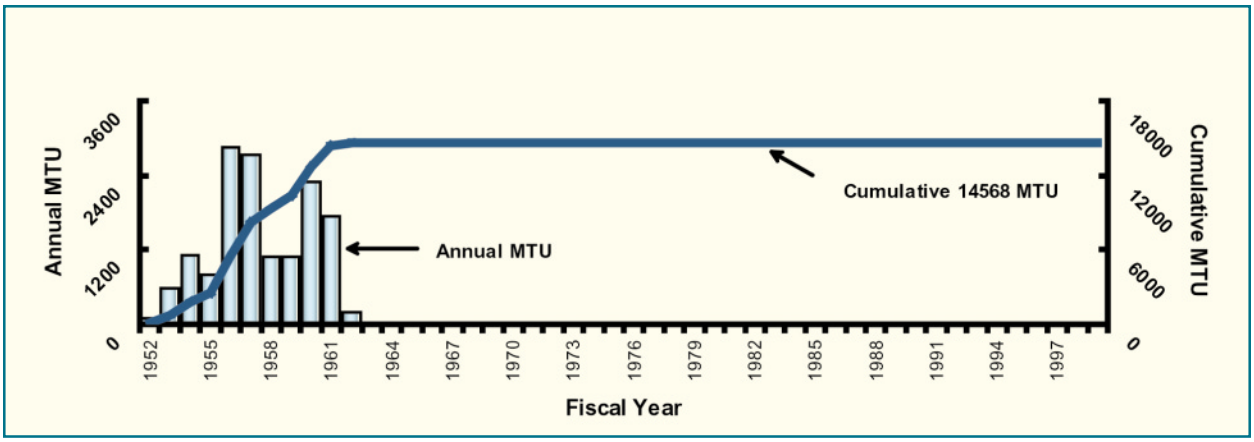


Figure 34. K-25's annual and cumulative receipts of recycled uranium from production facilities.

chemical separation facility was sent to the K-25 Plant for enrichment in 1952. That year, Hanford sent about 100 MTU of recycled uranium to K-25. Over the 12-year period from 1952 to 1963, Hanford shipped about 4,276 MTU of recycled uranium to the K-25 Plant.

The K-25 Plant also received recycled uranium from the Savannah River production plant starting in 1955. A total of 10,292 MTU was received from the Savannah River Site between 1955 and 1965.

Contaminant Data

Figure 35 shows the total contaminants contained in the recycled uranium received by K-25 and displays quantities of recycled uranium sent from the producing sites. The recycled uranium delivered to K-25 contained about 40 grams of plutonium, 3,300 grams of neptunium, and 70 kilograms of technetium.

Portsmouth Gaseous Diffusion Plant

Site History and Description

The Portsmouth Gaseous Diffusion Plant has operated since 1955 on a Federal reservation 70 miles south of Columbus, Ohio. A map of the site location is presented in Figure 36. Historically, the plant

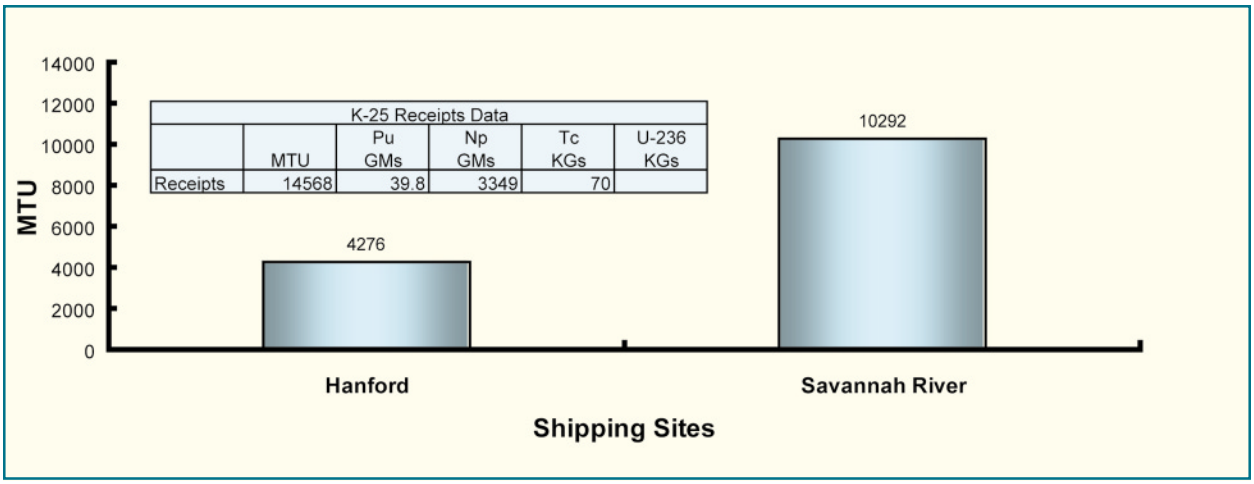


Figure 35. K-25's total receipts of recycled uranium and associated contaminants with production sites identified.

Figure 36. Location of the Portsmouth Gaseous Diffusion Plant in Ohio.

Portsmouth Gaseous Diffusion Plant Historical Timeline

1952	Site selected in Ohio Valley in Pike County.
1954	First production cells in operation.
1960	Plant shifts from military to commercial focus of supplying enriched uranium to electric utilities.
1973	*First receipts of recycled uranium for enrichment.*
1976	*Last receipts of recycled uranium from production facilities.*
1993	USEC assumes responsibility for plant.

enriched uranium for government programs and commercial nuclear power plants at levels ranging from a few percent to over 95 percent ^{235}U. In 1991, the production of highly enriched uranium (over 20 percent ^{235}U) was terminated and the high enrichment cascade shut down. As with Paducah, the Energy Policy Act of 1992 established USEC to manage and operate DOE's enrichment plant at Portsmouth.

Plant Description

Portsmouth consists of 109 buildings and individual plants occupying 500 acres (Figure 37). Four main facilities that were potentially involved with recycled uranium include the Feed Manufacturing Plant, Oxide Conversion Facility, Enrichment Facilities (Cascades), and Decontamination and Uranium Recovery Facility. The following describes the specific functions of each of these facilities and their involvement in the processing of recycled uranium.

Feed Manufacturing Plant – Building X-344

The X-344 Feed Manufacturing Plant converted UF_4 to UF_6. The UF_4 was of normal enrichment and was received from two sources, Weldon Spring and Fernald. The plant used direct fluorination tower reactors to convert UF_4 to UF_6 prior to feeding it into the cascades. The Feed Manufacturing Plant operated from May 1958 until February 1962, producing a total of 11,890 MTU of UF_6 feed for the cascades. The facility could have been a concentrator of recycled uranium constituents if any of the UF_4 that was processed had been from recycled uranium. However, no records could be found to indicate that the feed plant used any

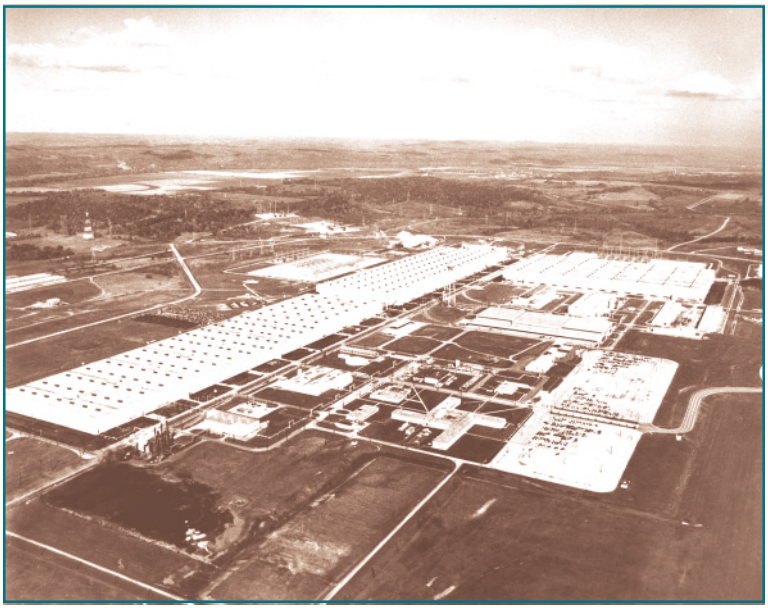


Figure 37. Aerial view of the Portsmouth Gaseous Diffusion Plant.

recycled uranium, and the site was able to account for all feeds used.

Oxide Conversion Facility – Building X-705

The Oxide Conversion Facility is located in Building X-705 (Areas E, F, and H) and provided the capability to generate UF_6 directly from black oxide (U_3O_8). Oxide processing at this facility involved recycled uranium and was responsible for some of the highest concentrations of TRU isotopes at Portsmouth. The Oxide Conversion Facility operated from 1957 to 1978 and produced about 233 MTU of UF_6.

Although several configurations were used to convert U_3O_8 to UF_6, all follow the same basic process. Uranium oxide is reacted with HF and fluorine to produce UF_6. The UF_6 is drawn off as a gas then liquefied and stored in cylinders. The process produces a very pure UF_6 and traps most of the other contaminants in the tower or filter ash and filters, or in various chemical trapping media.

Uranium oxide from both offsite and onsite sources fed the Oxide Conversion Facility. An onsite uranium recovery program scavenged uranium from plant scrap and by-product materials and produced uranium oxide, which was converted to UF_6 by the conversion facility or stored. Most of the UF_6 produced by the Oxide Conversion Facility was fed to the enrichment cascade, where it was mixed with a much larger quantity of UF_6 from non-recycled (natural) uranium and was enriched to meet customer requirements.

Cascades – Buildings X-333, X-330, and X-326

The main process buildings at Portsmouth (X-330, X-333, and X-326) contain cascades that consist of multiple enrichment cells. Each enrichment cell has 8, 10, or 12 stages; each stage consists of a compressor, chiller, diffusion barrier, motor, and supporting valves and piping. The stages are arranged in series to progressively enrich UF_6.

Enrichment occurred as the UF_6, in a gaseous form, was pumped through the diffusion barrier in the cell. The lighter ^{235}U isotope passed through the pores in the barrier tubes slightly more often than the heavier ^{238}U isotope. The gaseous UF_6 from both sides of the barrier was pumped through another converter; enriched UF_6 and depleted UF_6 flowed in countercurrent directions. Enriched UF_6 product, which contains more ^{235}U, traveled to the top of the cascade while the depleted UF_6 (containing less ^{235}U) went toward the bottom. Both enriched product and depleted tails were fed into cylinders and allowed to cool until solid. The Portsmouth cascade originally consisted of 4,080 stages in the three process buildings and was able to enrich uranium to 97 percent ^{235}U. Typical feedstock was either normal or slightly enriched UF_6 from commercial suppliers or the Oak Ridge and Paducah enrichment plants.

Decontamination and Uranium Recovery – Building X-705

The Uranium Recovery Facility has produced approximately 38.2 MTU of U_3O_8 since it began operation in 1956. Uranium-bearing solutions, scrap, and waste materials were chemically treated to extract the uranium. The concentrated uranium solution was kiln-dried to form U_3O_8, which was sent to the Oxide Conversion Facility where it was turned into UF_6 for cascade feed or put in storage. Transuranic isotopes tend to travel with the U_3O_8 and concentrate in the ash generated from the UF_6 conversion step.

Material Account

Recycled Uranium Receipts from Production

Figure 38 displays Portsmouth's receipts of recycled uranium from production facilities on an annual and cumulative basis. Because the Portsmouth Gaseous Diffusion Plant utilized partially enriched uranium as starting material, this plant received only small quantities of recycled uranium from the production plants. The only documented recycled uranium sent to Portsmouth was 4.1 MTU from Idaho between 1973 and 1976.

Contaminants

Figure 39 shows the total contaminants contained in the recycled uranium received by Portsmouth and displays quantities of recycled uranium sent from the producing sites. Based on information provided by Idaho, it is estimated that the recycled uranium received by Portsmouth contained less than a milligram of plutonium and technetium, and less than a gram of neptunium. The principal reactor-produced contaminant was about 14 kilograms of ^{236}U.

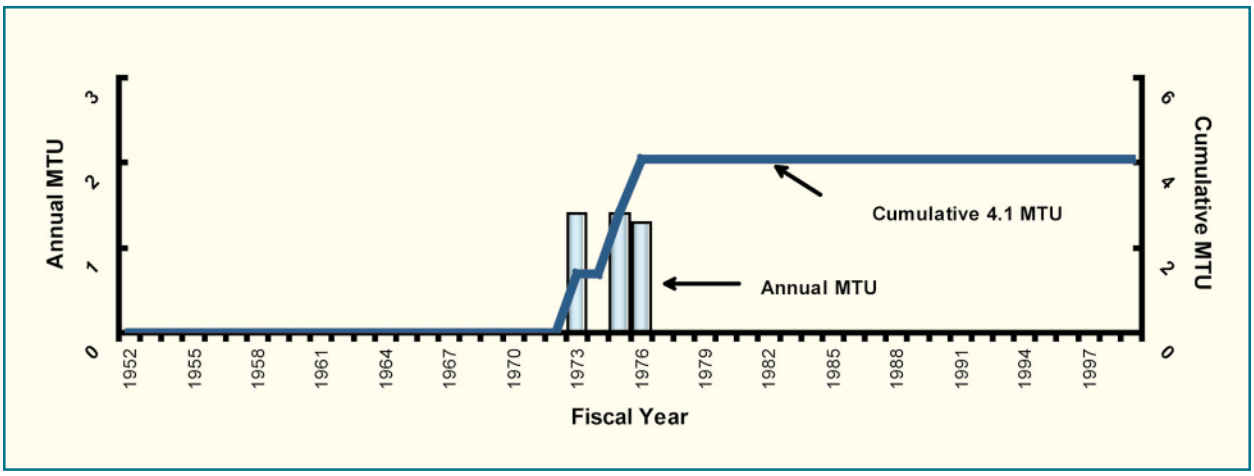


Figure 38. Portsmouth's annual and cumulative receipts of recycled uranium from production facilities.

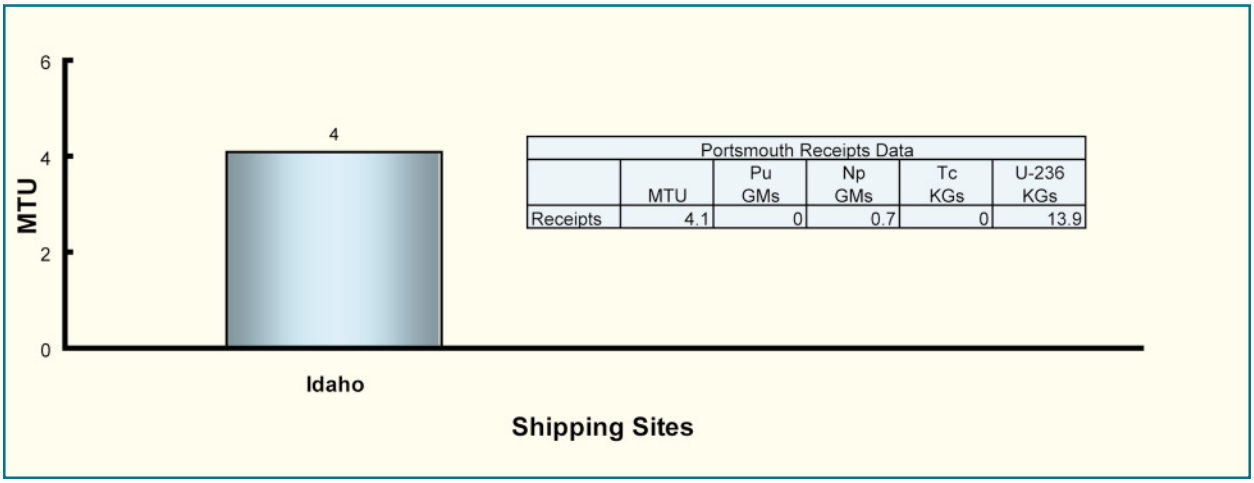


Figure 39. Portsmouth's total receipts of recycled uranium and associated contaminants with production sites identified.

Other Receiving Sites

Fernald

Site History and Description

The Fernald Environmental Management Project (Fernald) is located in southwestern Ohio, approximately 20 miles northwest of downtown Cincinnati, near the communities of Fernald, Miamitown, and Ross. The DOE-owned property was formerly known as the Feed Materials Production Center. A map showing the site location is presented in Figure 40. Production operations were active from 1952 through 1989. Fernald supported defense program missions by producing various uranium products at several enrichment assays. The current focus of activities at the site are investigation and cleanup under the Comprehensive Environmental Response, Compensation, and Liability Act. A photograph of the site is presented in Figure 41.

Plant Description

Fernald consisted of eight major production plants—each having a mission in processing uranium. The uranium processing followed a specific flow pattern that depended on the final form of uranium required by the customer. Within the flow pattern, each succeeding plant provided the next stage's intermediate product until the final desired uranium form was produced. The principal product of Fernald was uranium cores for nuclear reactor fuel. The processing plants are primarily identified by their plant number, which loosely corresponds to the number of the process steps in the conversion of uranium ores and compounds into metal. Because of the variety of processes used at Fernald, this plant could utilize uranium in nearly any chemical form. All Fernald processing plants, except Plant 7, processed recycled uranium during their operational history.

Figure 40. Location of the Fernald Site in Ohio.

Fernald Historical Timeline

Late 1940s	AEC authorized construction of single consolidated uranium processing facility.
1951	AEC announces that site near Fernald, Ohio, chosen for consolidated uranium processing facility. Pilot Plant constructed and starts operations by October 1951.
1953	*Initial small quantities of recycled uranium received from Hanford.*
1954	All FMPC plants operational.
1957	Nearly continuous receipts of recycled uranium started.
1989	*Final receipts of recycled uranium and FMPC begins shut down of operations.*
1991	Final plant closure approved by Congress and name changed to Fernald Environmental Management Project to reflect new mission of site cleanup.

Sampling Operations (Plant 1)

Plant 1 originally received and stored uranium ore. It was designated as the official AEC sampling station for determining uranium and isotopic assays of uranium ores and concentrates. In later years, Plant 1 became the receiving and sampling facility for all offsite shipments of

Figure 41. Aerial view of the Fernald FMPC.

nuclear materials. This facility also housed milling processes for size reduction of feed materials. Plant 1 became operational in December 1953 and discontinued operations in July 1989.

Refinery Operations (Chemical Plants 2, 3)

The conversion of uranium feed materials to UO_3 was accomplished using a three-step operation, designated as digestion, extraction, and denitration. Digestion began with acid leaching of uranium from dry solid feed materials. Next came solvent extraction to produce a solution of uranyl nitrate. The final step, denitration, was the conversion of uranyl nitrate solution to UO_3 by thermal decomposition.

Refinery operations began in December 1953 and Plants 2/3 operations were temporarily curtailed in 1962. Limited operations were resumed within 1 year and continued intermittently until 1972, when the concentrate conversion campaign at Paducah was started. During this campaign, the UO_3 produced was shipped to the Paducah Gaseous Diffusion Plant instead of Plant 4. Plant 2/3 ceased all operations in July 1989.

Chemical Operations (Green Salt Plant 4)

UO_3 produced in Plant 2/3 or received from offsite was converted to UF_4 in Plant 4. Green salt (Figure 42) was the source material for making uranium metal derbies (Figure 43). Derbies were made in a two-step operation beginning with the reduction of UO_3 with H_2 to UO_2. The second step, hydrofluorination, involved converting the UO_2 powder to green salt using anhydrous hydrofluoric acid. Plant 4 operations began in October 1953 and were dis-continued in July 1989.

Metal Production Operations (Plant 5)

Plant 5 converted UF_4 into uranium metal derbies via a thermite reduction process using magnesium metal granules. By-product MgF_2 slag was generated in substantial quantities by the reduction process. About half of the slag generated was milled for reuse as refractory liner in the metal reduction process vessels. The remaining slag was processed to recover the uranium or discarded as waste depending on the uranium enrichment contained in the

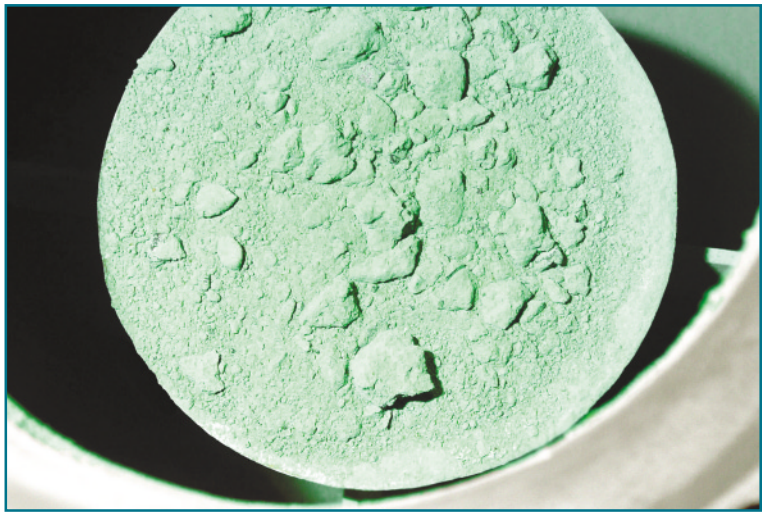


Figure 42. UF_4 (green salt).

Figure 43. Uranium metal derbies.

slag. Surplus slag from enriched uranium reduction underwent chemical treatment for uranium recovery, while depleted slag was discarded. Derbies and metal scraps were vacuum-cast into ingots in Plant 5 and Plant 9. Derbies were also shipped to other DOE sites. Vacuum cast ingots were cropped by sawing approximately 2 inches from the top section and sent to Plant 9 for center drilling and surface machining or to the Rolling Mill in Plant 6. Plant 5 became operational in 1953. Operations were discontinued in July 1989.

Rolling Mill Operations (Plant 6)

Plant 6 fabricated cropped ingots into finished uranium cores. Cylindrical cropped ingots having a diameter of 6 to 8 inches were heat-treated prior to Plant 6 operation. The rolling mill became operational in mid-1952. In 1971, the rolling mill was shut down, and all machined ingots were heat-treated in Plant 6 before being shipped to Reactive Metals Inc. (RMI) for extrusion into tubes (Figure 44).

Chemical Operations (Plant 7)

Plant 7 supplemented the supply of green salt produced by Plant 4 to meet the peak demands for uranium metal in the mid-1950s. Uranium hexafluoride cylinders shipped from the gaseous diffusion plants were placed into autoclaves and heated to generate UF_6 gas. Gaseous UF_6 and H_2 generated by ammonia dissociation were mixed in a reaction tube to produce UF_4.

Plant 7 operated for 2 years beginning in June 1954 and was shut down in May 1956 with the completion of the Paducah Feed Plant. No operations involving recycled uranium took place in Plant 7.

Figure 44. Cut tubes from Plant 6.

Scrap Recovery Operations (Plant 8)

The Scrap Recovery Plant began operations in November 1953. Process residues and low-assay uranium materials generated by site production operations were recovered in this plant. Low-grade metal scrap that was unacceptable for recycling via remelting was furnaced to U_3O_8 and subsequently used as feed material. Limited operations associated with site closure are ongoing at this plant.

Special Products Operations (Plant 9)

The cropped ingots were sent to the Special Products Plant 9 for center drilling and surface machining. The plant also vacuum cast uranium ingots and machined special orders. Plant 9 began operations in 1953 and discontinued operations in July 1989.

Pilot Plant

The Pilot Plant contained a variety of chemical and metallurgical processes that were operated to support the site's mission. Beginning in 1958, the Pilot Plant used a small-scale UF_6-to-UF_4 reduction process to produce low enriched UF_4. With the introduction of low enriched uranium processing in Plant 2/3 in 1965, the Pilot Plant UF_6-to-UF_4 facility was operated to produce "sweetener" for adjusting the assay of recycled uranium.

Material Account

Recycled Uranium Receipts from Production

Figure 45 displays Fernald's receipts of recycled uranium from production facilities on an annual and cumulative basis. Throughout its operational lifetime, Fernald received 17,966 MTU of recycled uranium oxide and uranyl nitrate from DOE production sites. Most of the recycled uranium (14,859 MTU, 83 percent) came from Hanford as uranium oxide. Savannah River shipped 2,486 MTU to Fernald, and West Valley shipped 621 MTU.

Contaminants

Figure 46 shows the total contaminants contained in the recycled uranium received by Fernald and displays quantities of recycled uranium sent from the producing sites. Based on available data, it is estimated that the recycled uranium from the production sites contained about

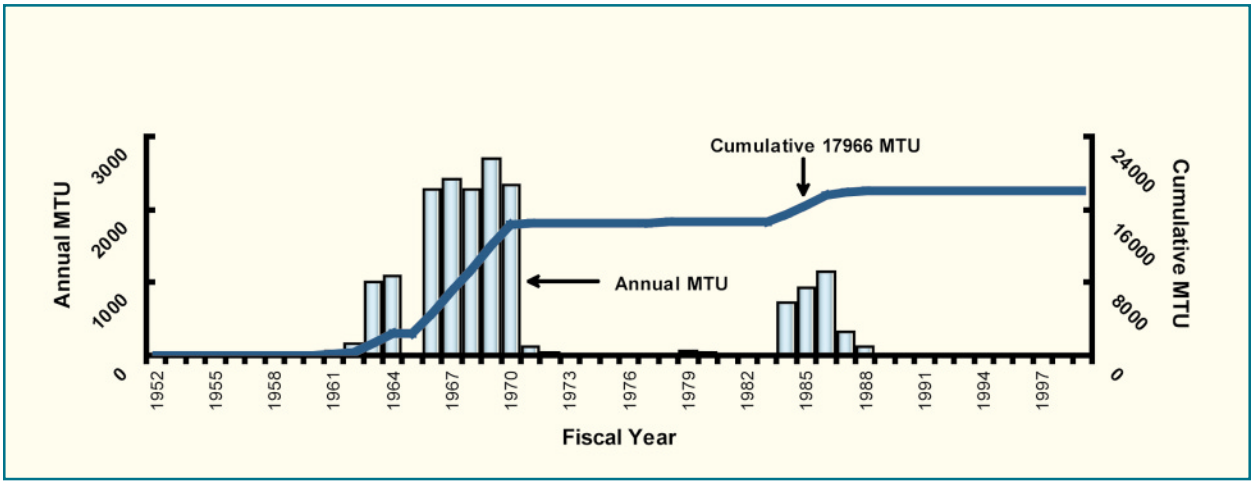


Figure 45. Fernald's annual and cumulative receipts of recycled uranium from production facilities.

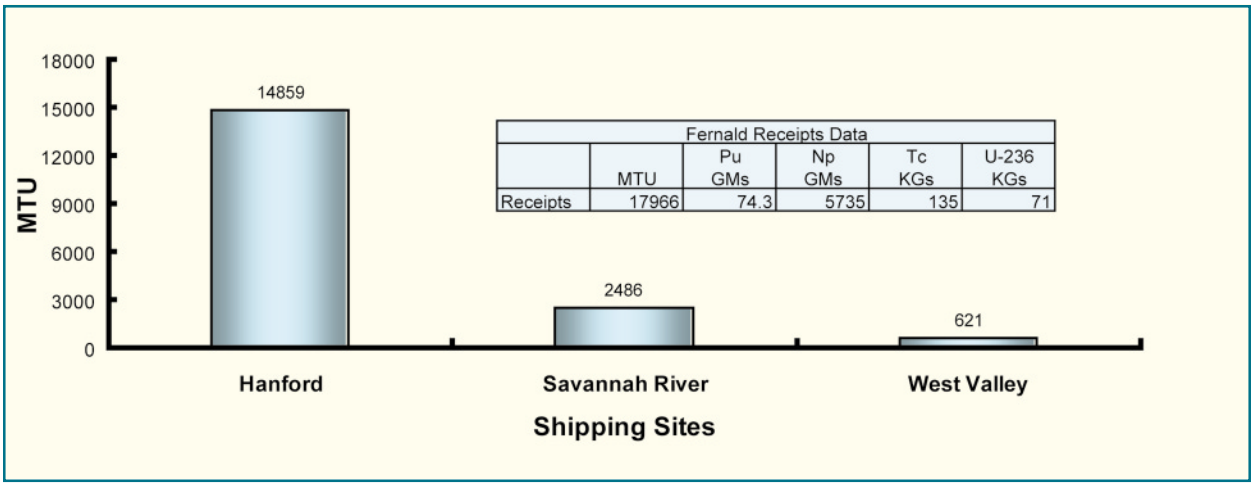


Figure 46. Fernald's total receipts of recycled uranium and associated contaminants with production sites identified.

74 grams of plutonium. In addition, about 5,700 grams of neptunium, and about 135 kilograms of technetium were contained in the recycled uranium received at Fernald. The enriched recycled uranium received by Fernald from Savannah River contained about 71 kilograms of ^{236}U.

Y-12

Site History and Description

The Y-12 Plant industrial complex occupies approximately 3,400 acres, with a surrounding buffer zone of an additional 2,800 acres approximately 7 miles east of the Oak Ridge K-25 Plant. The location in Tennessee is depicted in Figure 47. The plant is situated in Bear Creek Valley, at the eastern boundary of the reservation, approximately 3 miles from the population center of the city of Oak Ridge. The plant site is bounded on the south by Chestnut Ridge and on the north by Pine Ridge. This site was originally chosen for the Electromagnetic Plant, which initially occupied 825 acres. The Electromagnetic Plant used staged calutrons (production mass spectrographs) to produce enriched uranium for the Manhattan Project. A photograph of the site is presented in Figure 48.

After the electromagnetic enrichment process was rendered obsolete by the gaseous diffusion process in the mid-1940s, Y-12 became an enriched uranium weapons component facility. Since then, the Y-12 Plant has become a center for handling, processing, manufacturing, assembling, storing, and disassembling uranium material and nuclear weapons components. Material processing has included the recovery of highly enriched uranium from recycled uranium generated from reactor returns.

Plant Operations

The processing of the material, including uranium recovery, purification, and conversion, was performed in two large facilities, Building 9212 (1953–1989) and Building 9206 (early 1970s–1989).

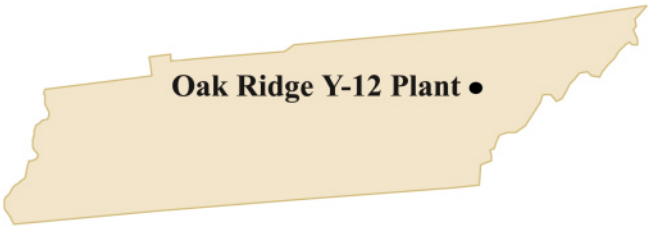


Figure 47. Location of the Oak Ridge Y-12 Plant in Tennessee.

Y-12 Plant Historical Timeline

1942	Site selected in East Tennessee near the city of Knoxville for the Oak Ridge Reservation, initially called the Clinton Engineering Works.
1943	Plant constructed for electromagnetic enrichment of uranium.
1953	Building 9212 starts operation for recovery, purification, and conversion of uranium including recycled uranium. *First receipts of recycled uranium from ICPP.*
1970	Building 9206 starts operation for recovery, purification, and conversion of uranium, including recycled uranium.
1990	*Last receipts of enriched recycled uranium.*
1993	*Last receipts of recycled uranium.*

Materials processed at the plant include highly enriched, low enriched, and depleted uranium that was shipped to the plant from various DOE production and processing sites. During certain historical time periods, a small portion of highly enriched uranium receipts contained recycled uranium from reactor returns.

Facilities Involved with Recycled Uranium

The recycled uranium streams that the site received from the production sites included uranyl nitrate solution and UO_3. These streams impacted a number of plant facilities. Facilities with significant involvement with recycled uranium handling and processing included the Building 9212 complex, Building 9206, Building 9720-5, Y-12 Plant uranium warehouse, S-3 Ponds, and West End Treatment Facility. With the exception of the S-3 Ponds, which have been dredged and capped, many of these facilities continue in use today. Building 9206 is now primarily used for storage of in-process materials.

From 1953 until the early 1970s, all processing of Savannah River and Idaho recycled uranium material to metal product was performed in the Building 9212 complex. From the early 1970s until 1989, Building 9206 was responsibile for most of the activities associated with processing recycled uranium material into metal product. Building 9212, however, did continue to evaporate and concentrate the uranyl nitrate solutions before sending them to Building 9206.

Savannah River typically shipped uranyl nitrate solution to the Y-12 Plant in tanker trucks. After primary evaporation, the material went through purification by solvent extraction; denitration to produce UO_3; conversion to UF_4; and reduction to metal, using calcium metal as the reducing agent. After the metal was cleaned, it was either prepared in Building 9212 for shipment back to Savannah River or was stored.

Figure 48. Aerial view of the Y-12 Plant.

From 1953 until the mid-1980s, the ICPP processed spent Navy, research, and experimental reactor fuel to recover and recycle enriched uranium. The resultant product was shipped to the Y-12 Plant for processing into metal and subsequent shipment to Savannah River. Initially, Idaho provided uranyl nitrate solution; however, after a denitrator was installed at Idaho in 1970, it provided material to the Y-12 Plant as UO_3. After undergoing initial dissolution, the UO_3 was processed at Y-12 using the same steps as the uranyl nitrate solution.

Solvent extraction raffinate from Savannah River and Idaho materials was isolated at Building 9206 and transported to the Building 9212 complex. This raffinate was mixed with other Building 9212 complex raffinate and processed through a biodenitrification reactor prior to being discharged to the West End Treatment Facility. Prior to the mid-1980s, waste from the biodenitrification reactor effluent was discharged directly to the S-3 Ponds.

The primary and secondary extraction process steps consisted of contacting the aqueous uranyl nitrate feed-stream with organic solvents in a countercurrent pulse column. As the two liquids were contacted, the uranium was extracted out of aqueous uranyl nitrate solution by preferential dissolution into the organic phase, leaving impurities behind in the raffinate stream. The uranium was then stripped from the loaded solvent by "washing" it with acidified water.

Based on process knowledge, it is believed that approximately 50 to 75 percent of the transuranics and fission product constituents were removed through the solvent extraction purification step. This portion of the recycled uranium constituents traveled with the raffinate through the nitric acid recovery step and, ultimately, to discharge and/or disposal. Until the mid-1980s, waste acid from the nitric acid recovery step was directly discharged to the S-3 Ponds. Contaminated pond sludge was allowed to accumulate in S-3 Ponds for more than 30 years. This practice was discontinued after the West End Treatment Facility became operational and the S-3 Ponds were closed. Following closure of the S-3 Ponds, the contaminated water was decanted, processed for permitted discharge to the East Fork Poplar Creek, and the residual sludges in the ponds were capped.

The entering ^{236}U remained with the enriched uranium throughout the Y-12 Plant chemical complex (along with residual amounts of plutonium, neptunium, and technetium) and ultimately collected in the product stream. Calcium fluoride slag, which is a byproduct of the metal reduction process, was removed from the metal reactor and size-reduced for acid leaching and recycling into the uranium recovery process. Process knowledge indicates that this approach effectively accomplished a further removal of the plutonium, neptunium, and technetium from the product because of the migration of these constituents into the slag.

Material Account

Recycled Uranium Receipts from Production

Figure 49 displays Y-12's receipts of recycled uranium from production facilities on an annual and cumulative basis. The Oak Ridge Y-12 Plant received recycled uranium from all of the production sites for a total of about 184 MTU. Most of this recycled uranium was enriched material from Savannah River (153 MTU) and Idaho (26 MTU). Hanford shipped a little more than 4 MTU and West Valley shipped about 0.9 MTU of specially produced ^{233}U generated by reactor irradiation of thorium.

Contaminants

Figure 50 shows the total contaminants contained in the recycled uranium received by Y-12 and displays quantities of recycled uranium sent from the producing sites. It is estimated that less than 1 gram of plutonium, about 54 grams of neptunium, and about 9 kilograms of technetium were contained in the recycled uranium received by Y-12. The principal contaminant in the recycled uranium received by Y-12 was approximately 26,375 kilograms of ^{236}U.

Other Sites

Harshaw Chemical Co.

Site History and Description

Starting in the early 1940s, the Harshaw Chemical Company located 5 miles southwest of downtown Cleveland, Ohio, conducted a number of chemical operations to produce UF_4 and UF_6 for uranium enrichment. This work started under contract with the Manhattan Engineering

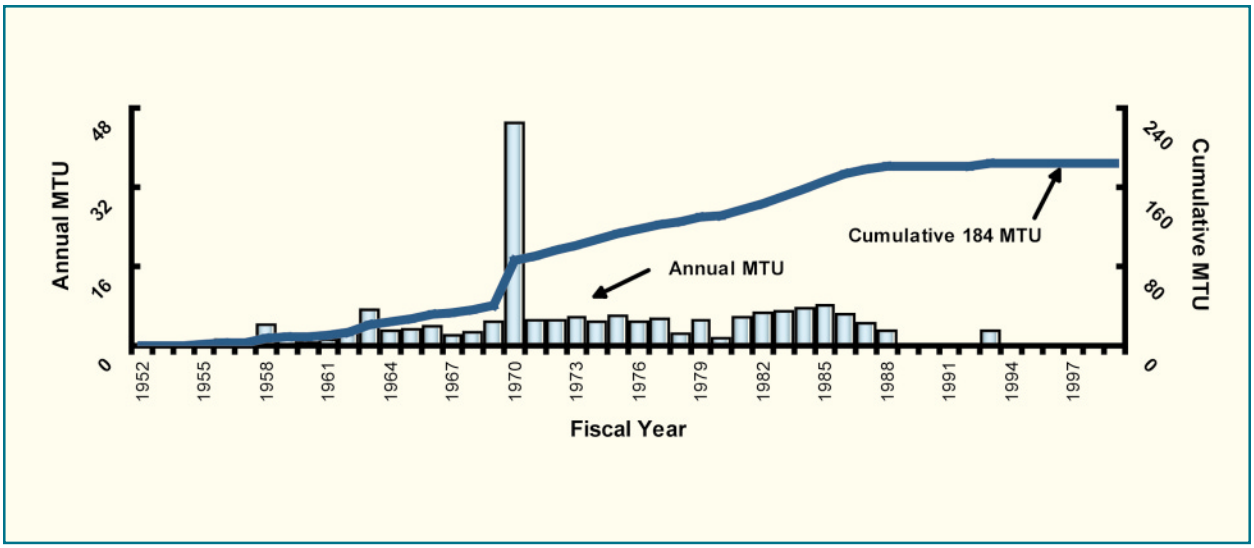


Figure 49. Y-12's annual and cumulative receipts of recycled uranium from production facilities.

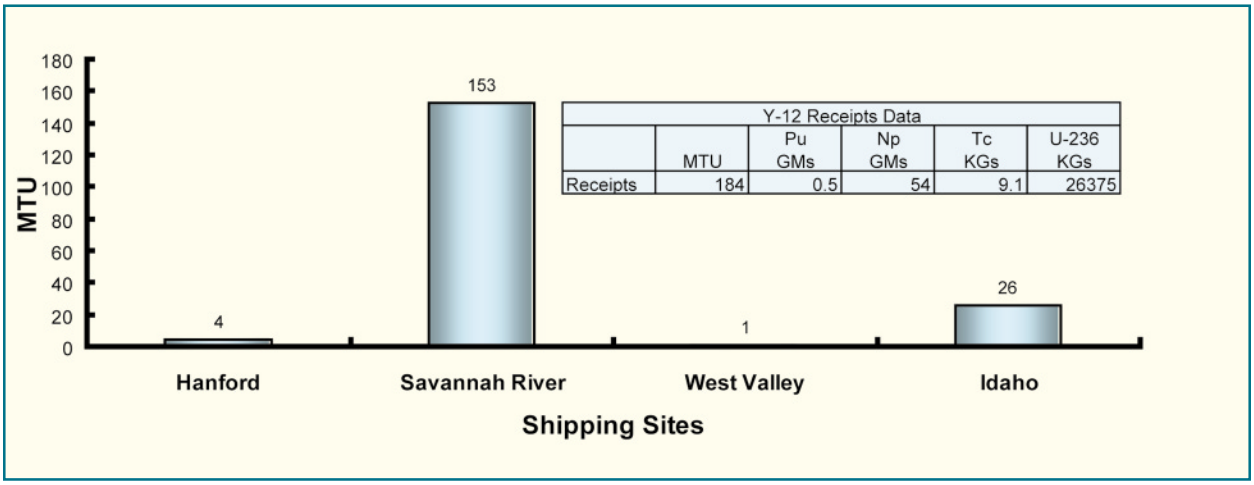


Figure 50. Y-12's total receipts of recycled uranium and associated contaminants with production sites identified.

Harshaw Chemical Company Historical Timeline

1944	Harshaw Chemical Company contracted by Manhattan Engineering District to refine yellow cake to pure uranium orange oxide, to make UF_4 and UF_6 for uranium enrichment operations in Oak Ridge, Tennessee.
1953	*Initial recycled uranium received from Hanford to prepare for use at Oak Ridge gaseous diffusion plant.*
1954	*Final receipts of recycled uranium.*
1959	Uranium processing for U.S. Government terminated.

District operations during World War II and continued later with the AEC. Harshaw was a principal supplier of UF_6 for the K-25 Gaseous Diffusion Plant in Oak Ridge from 1944 until the mid- to late-1950s when the feed plants became operational and capable of supplying the required UF_6.

Material Account

Recycled Uranium Receipts

In 1953 and 1954, records indicate that Hanford shipped 1,675 and 239 MTU respectively of recycled uranium to Harshaw to prepare it for enrichment at K-25. Based on the Hanford UO_3 constituent concentrations, it is likely that the material shipped to Harshaw contained about 9 grams of plutonium, 670 grams of neptunium, and 15 kilograms of technetium.

Other Minor Sites

- Over the time period from 1953 until 1964, Hanford shipped about 17.4 MTU of recycled uranium to **ORNL**. This material is estimated to contain less than 0.1 gram of plutonium, 6 grams of neptunium, and about 0.1 kilogram of technetium.

- Idaho shipped about 0.2 MTU of enriched recycled uranium to the **Rocky Flats** Plant in 1955. There were about 26 kilograms of ^{236}U in this material, which was the only constituent having a significant content.

- In 1982, Savannah River shipped about 0.8 MTU of depleted recycled uranium to **General Atomics** in San Diego. This uranium is estimated to have contained less than 0.1 kilogram of technetium, much less than 1 gram of neptunium, and only a few milligrams of plutonium.

- In 1988, Hanford shipped about 4.8 MTU of depleted recycled uranium to the **Savannah River Site**. This uranium likely contained much less than 0.1 gram of plutonium, nearly 2 grams of neptunium, and much less than 0.1 kilogram of technetium. These values were determined using the concentration data for Hanford recycled uranium as presented in previous sections. The ^{236}U content of Hanford recycled uranium was not determined.

- Savannah River shipped about 1.4 metric tons of depleted recycled uranium to **Brookhaven National Laboratory** in 1996. It is estimated that this material contained much less than 0.1 kilogram of technetium, less than 1 gram of neptunium, and only a few milligrams of plutonium.

Conclusions

From 1952 until 1999, the chemical separation facilities at the production sites in the United States recovered approximately 138,604 MTU of uranium from spent reactor fuel and target material. Spent reactor fuel reprocessing continues only at the Savannah River Site to stabilize this material for storage or disposal. Figure 51 shows the percent of total

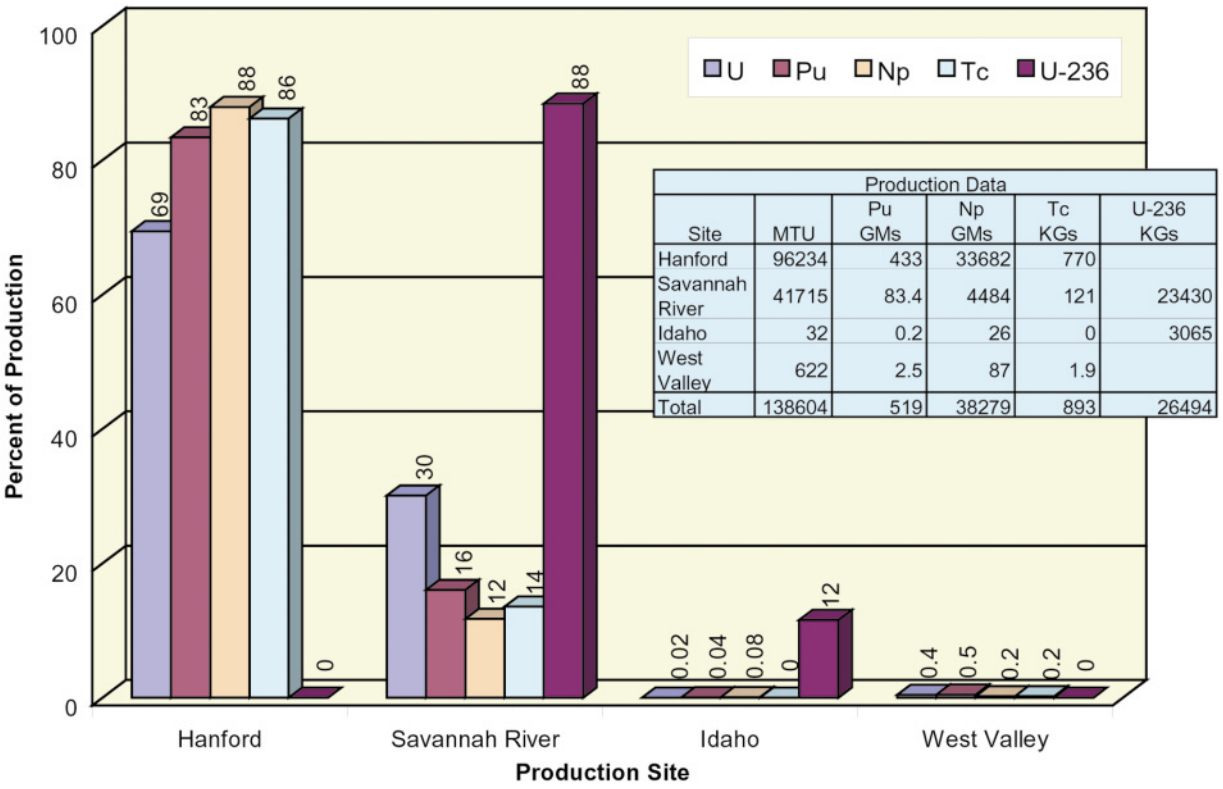


Figure 51. Production and shipments of recycled uranium.

production of recycled uranium produced by each of the production sites and percent of each of the contaminants in the recycled uranium from these sites. The table included in the figure shows the quantities of recycled uranium produced and the quantities of the contaminants in the uranium by production site. More than 85 percent (118,408 MTU) of the recycled uranium produced was shipped to other DOE sites for further processing, including enrichment, and conversion to reactor fuel and weapon components.

The processes used to recover uranium from the spent reactor fuel and target material were very efficient and effective, but they were not capable of removing the last traces of reactor-produced TRU elements (e.g., plutonium and neptunium) and fission products (e.g., technetium) from the recovered uranium. Therefore, the recycled uranium contained low concentrations of these contaminants. The recycled uranium also contained reactor-produced uranium isotopes, principally ^{236}U. Based on data from the production sites and additional data from some receiving sites, the quantities of these contaminants can be estimated. On this basis, it is estimated that the 118,408 MTU of recycled uranium shipped from production sites and placed back into use contained less than 500 grams of plutonium, about 38 kilograms of neptunium, and 858 kilograms of technetium. For most of the recycled uranium, there are no available data concerning ^{236}U; however, this isotope was generally monitored for enriched uranium. It is estimated that the enriched recycled uranium shipped from production sites contained about 26,500 kilograms of ^{236}U.

Beginning in 1952, Hanford produced nearly 70 percent (96,234 MTU) of the U.S. recycled uranium. Production at Hanford ceased in

1990. The site shipped 95,566 MTU to other facilities for additional processing. About 97 percent of the Hanford recycled uranium was shipped to three processing sites: Paducah, Fernald, and K-25. During 2 years in the early 1950s, Harshaw Chemical Company also received recycled uranium from Hanford to prepare it for use at K-25. Hanford also sent small quantities of recycled uranium to several other sites. Nearly 81 percent of the recycled uranium placed back into use in DOE operations was produced at Hanford. The contaminant data indicate that the Hanford recycled uranium placed back into use contained about 90 percent of the TRU and fission product contamination that reentered DOE operations.

Nearly all of the remaining U.S. recycled uranium production was carried out at the Savannah River Site, which recovered 41,715 MTU over the time period from 1955 to 1999. Savannah River shipped a total of 22,035 MTU to K-25, Paducah, and Fernald. The site also shipped about 153 MTU of enriched recycled uranium to Y-12. The Savannah River recycled uranium shipped to other sites for reuse contained about 10 percent of the TRU and fission product contamination that re-entered DOE operations. Approximately 88 percent of ^{236}U contamination was contained in the enriched recycled uranium shipped from Savannah River to Y-12 for reuse. As of March 1999, the Savannah River site had about 19,526 MTU of mostly depleted recycled uranium in storage.

The ICPP in Idaho recovered about 32 MTU of enriched uranium from a variety of experimental and test reactors. This material contained the remaining 12 percent of the ^{236}U, which was its principal contaminant. About 86 percent of the Idaho recycled uranium was shipped to Y-12 with most of the remaining material being sent to Portsmouth.

New York's West Valley facility processed 27 batches of nuclear fuel producing about 622 MTU (less than one-half of one percent of total U.S. production) of recycled uranium. Of this, about 58 percent originated from U.S. Government reactors and the remaining material was from commercial electrical power reactors. Approximately 0.9 MTU was composed of ^{233}U produced from thorium. All of the West Valley uranium except the ^{233}U was shipped to Fernald. The ^{233}U was sent to Y-12 and is currently stored at ORNL.

As of March 1999, approximately 20,196 MTU of recycled uranium remains in storage at production sites. Most of this (19,526 MTU) is principally depleted recycled uranium currently stored at the Savannah River Site. About 668 MTU was in storage at the Hanford site and nearly 2 MTU remains at the ICPP. The recycled uranium held in storage is estimated to contain about 42 grams of plutonium, 724 grams of neptunium, and nearly 35 kilograms of technetium.

Appendix

Shipment and Receipts Data Sheets

Table A-1

HANFORD SHIPMENT DATA
Key Receiving Sites (MTU)

Year	Fernald	Paducah	K-25	Other*	Total	Contaminants		
						Pu (gms)	Np (gms)	Tc (kgs)
1952			100		**100**	0	35	0.8
1953	0		578	1679	**2257**	10	790	18.1
1954		2233	1115	241	**3589**	16	1256	28.7
1955		2587	526	1.2	**3114**	14	1090	24.9
1956		4105	324	1.5	**4430**	20	1551	35.4
1957	0	5386	98	0.7	**5485**	25	1920	43.9
1958	5	6056	7	1.6	**6071**	27	2125	48.6
1959	19	5202	261	1.0	**5484**	25	1919	43.9
1960	21	5148	610	6.1	**5785**	26	2025	46.3
1961	50	6094	611	0.4	**6755**	30	2364	54.0
1962	170	5492	45	0.1	**5707**	26	1997	45.7
1963	1002	5772	0	0.0	**6774**	30	2371	54.2
1964	1097	4087		0.2	**5184**	23	1814	41.5
1965								
1966	2025				**2025**	9	709	16.2
1967	1458	14433			**15891**	72	5562	127.1
1968	1692				**1692**	8	592	13.5
1969	1870	3537			**5407**	24	1893	43.3
1970	2237				**2237**	10	783	17.9
1971	0	722			**722**	3	253	5.8
1972		3078		0.1	**3079**	14	1078	24.6
1973		558			**558**	3	195	4.5
1974								
1975								
1976								
1977	0				**0**	0	0	0.0
1978				0.0	**0**	0	0	0.0
1979								
1980				0.0	**0**	0	0	0.0
1981								
1982				0.0	**0**	0	0	0.0
1983								
1984	706				**706**	3	247	5.6
1985	918				**918**	4	321	7.3
1986	1151			0.0	**1151**	5	403	9.2
1987	314				**314**	1	110	2.5
1988	123			4.8	**128**	1	45	1.0
1989	0				**0**	0	0	0.0
1990								
1991								
1992								
1993				2.9	**3**	0	1	0.0
Shipped	**14859**	**74491**	**4276**	**1940**	**95566**	**430**	**33448**	**765**
Inventory					**668**	**3**	**234**	**5.3**
Total	**14859**	**74491**	**4276**	**1940**	**96234**	**433**	**33682**	**770**

*1953-1954 shipments (1914 MTU) to Others are depleted uranium to Harshaw. All remaining shipments to Others were to SRS, Y-12, and ORNL.

NOTES:
U-236 concentrations are not specified for this recycled uranium.
Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

Table A-2

SAVANNAH RIVER SHIPMENT DATA
Key Receiving Sites (MTU)

Year	Fernald	Paducah	K-25	Y-12	Other	Total	Contaminants (gms) Pu (gms)	Np (gms)	U-236 (kgs)	Tc (kgs)
1955		283	272			**555**	1.1	100		1.9
1956		195	2539			**2734**	5.5	492		9.6
1957		565	2635			**3200**	6.4	576		11.2
1958		230	1077			**1307**	2.6	235		4.6
1959			828			**828**	1.7	149		2.9
1960			1677			**1677**	3.4	302		5.9
1961	1	91	1122	1.1		**1215**	2.4	219		4.3
1962		1533	139	1.9		**1674**	3.3	301		6.0
1963		1343		6.4		**1349**	2.7	243		5.2
1964	1	1603		2.6		**1606**	3.2	289		5.8
1965			2	2.6		**5**	0.0	1	156	0.2
1966	202			3.3		**205**	0.4	37	567	1.0
1967	859			2.2		**862**	1.7	155	503	3.2
1968	412	2		2.0	0.0	**416**	0.8	75	545	1.6
1969	706	2815		4.0	0.1	**3525**	7.0	634	986	12.6
1970	22			44.6	0.0	**66**	0.1	12	606	0.4
1971	60	597		3.4		**660**	1.3	119	984	2.6
1972	0			4.7	0.0	**5**	0.0	1	1309	0.4
1973				5.0		**5**	0.0	1	1462	0.4
1974	15			4.4		**19**	0.0	3	1351	1.6
1975				5.0		**5**	0.0	1	1454	0.4
1976	12			4.3		**16**	0.0	3	1383	1.3
1977	14			4.4		**19**	0.0	3	1612	0.7
1978	28			2.0		**30**	0.1	5	724	1.2
1979	66			4.5		**71**	0.1	13	1391	0.6
1980	36			1.4	0.0	**38**	0.1	7	390	2.6
1981	0			4.8	0.0	**5**	0.0	1	1419	0.4
1982				5.6	0.8	**6**	0.0	1	1752	0.4
1983	23			6.5		**30**	0.1	5	1844	0.5
1984	27			4.6	0.0	**32**	0.1	6	899	0.5
1985				8.2	0.0	**8**	0.0	1	390	0.7
1986				5.4	0.0	**5**	0.0	1	498	0.4
1987				4.6		**5**	0.0	1	705	0.4
1988				3.1		**3**	0.0	1	478	0.3
1989				0.1		**0**	0.0	0	12	0.0
1990				0.1		**0**	0.0	0	10	0.0
1991										
1992										
1993										
1994										
1995					0.0	**0**	0.0	0		0.0
1996					1.4	**1**	0.0	0		0.0
Shipped	**2486**	**9257**	**10292**	**153**	**2.3**	**22189**	**44.4**	**3994**	**23430**	**91.9**
Inventory						**19526**	**39.1**	**490**		**29.3**
Total	**2486**	**9257**	**10292**	**153**	**2.3**	**41715**	**83.4**	**4484**	**23430**	**121**

NOTE: Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

Table A-3

IDAHO SHIPMENT DATA
Key Receiving Sites (MTU)

Year	Y-12	Portsmouth	Flats	Other	Total	Contaminants			
						Pu (gms)	Np (gms)	U-236 (kgs)	Tc (kgs)
1953	0.3				**0.3**	0.0	0.4	40	0.0
1954	0.3				**0.3**	0.0	0.3	36	0.0
1955	0.7		0.2		**1.0**	0.0	1.2	125	0.0
1956	1.1				**1.1**	0.0	1.3	146	0.0
1957	0.6				**0.6**	0.0	0.7	80	0.0
1958	2.7				**2.7**	0.0	3.2	349	0.0
1959	1.8				**1.8**	0.0	2.1	229	0.0
1960	0.6				**0.6**	0.0	0.7	75	0.0
1961									
1962	0.8				**0.8**	0.0	0.9	101	0.0
1963	0.8				**0.8**	0.0	0.9	100	0.0
1964	0.4				**0.4**	0.0	0.5	55	0.0
1965	0.8				**0.8**	0.0	1.3	163	0.0
1966	0.6				**0.6**	0.0	0.7	77	0.0
1967									
1968	0.8				**0.8**	0.0	1.0	107	0.0
1969									
1970	0.5				**0.5**	0.0		105	0.0
1971	1.7				**1.7**	0.0	2.0	215	0.0
1972	0.4				**0.4**	0.0		87	0.0
1973	0.6	1.4			**1.9**	0.0	0.7	77	0.0
1974	0.4				**0.4**	0.0	0.5	50	0.0
1975	0.9	1.4			**2.3**	0.0	1.1	122	0.0
1976	0.5	1.3			**1.8**	0.0	0.8	108	0.0
1977	1.0				**1.0**	0.0	1.2	127	0.0
1978	0.5			0.0	**0.6**	0.0	0.1	8	0.0
1979	0.5				**0.5**	0.0	0.9	107	0.0
1980									
1981	0.9				**0.9**	0.0	1.4	181	0.0
1982	1.1				**1.1**	0.0	0.0	4	0.0
1983	0.5				**0.5**	0.0	0.6	67	0.0
1984	2.9				**2.9**				0.0
1985									
1986	1.0				**1.0**	0.0	1.1	124	0.0
Shipped	**25.7**	**4.1**	**0.2**	**0.0**	**30.0**	**0.2**	**25.8**	**3065**	**0.0**
Inventory					**1.7**				
Total	**25.7**	**4.1**	**0.2**	**0.0**	**31.7**	**0.2**	**25.8**	**3065**	**0.0**

NOTES:

Pu values were determined primarily from the shipments made in 1973, 1975, 1976, 1978 and 1982 and are derived from the data in the site report.

Contaminants calculated on basis of kilograms of recycled uranium in shipment using concentration data provided in site report. Two shipments, to LANL in 1984 and to Y-12 in 1994, reported in the site report were of processed unirradiated fuel. These shipments are not included because they do not meet the definition of recycled uranium used for this report.

Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

Table A-4

WEST VALLEY SHIPMENT DATA
Key Receiving Sites (MTU)

Year	Fernald	Y-12	Total	Contaminants		
				Pu (gms)	Np (gms)	Tc (kgs)
1966	48		**48**	0.2	7	0.1
1967	101		**101**	0.4	14	0.3
1968	168		**168**	0.7	24	0.5
1969	124	0.9	**125**	0.5	18	0.4
1970	78		**78**	0.3	11	0.2
1971	69		**69**	0.3	10	0.2
1972	31		**31**	0.1	4	0.1
1973	3		**3**	0.0	0	0.0
Shipped	**621**	**0.9**	**622**	**2.5**	**87.1**	**1.9**
Total	**621**	**0.9**	**622**	**2.5**	**87.1**	**1.9**

NOTES:

U-236 concentrations are not specified for this recycled uranium.

Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

Table A-5

TOTAL RECYCLED URANIUM SHIPMENT DATA
Shipping Sites (MTU)

Year	Hanford	Savannah River	Idaho	West Valley	Total	Contaminants			
						Pu (gms)	Np (gms)	U-236 (kgs)	Tc (kgs)
1952	100				**100**	0.4	35		0.8
1953	2257		0.3		**2258**	10.2	790	40	18.1
1954	3589		0.3		**3589**	16.2	1257	36	28.7
1955	3114	555	1.0		**3670**	15.1	1191	125	26.9
1956	4430	2734	1.1		**7165**	25.4	2044	146	45.0
1957	5485	3200	0.6		**8686**	31.1	2497	80	55.1
1958	6071	1307	2.7		**7380**	29.9	2363	349	53.1
1959	5484	828	1.8		**6314**	26.3	2071	229	46.8
1960	5785	1677	0.6		**7463**	29.4	2327	75	52.1
1961	6755	1215			**7970**	32.8	2583		58.4
1962	5707	1674	0.8		**7382**	29.0	2300	101	51.7
1963	6774	1349	0.8		**8124**	33.2	2615	100	59.4
1964	5184	1606	0.4		**6791**	26.5	2104	55	47.3
1965		5	0.8		**5**	0.0	2	319	0.2
1966	2025	205	0.6	48	**2278**	9.7	753	644	17.3
1967	15891	862		101	**16853**	73.6	5731	503	130.6
1968	1692	416	0.8	168	**2277**	9.1	692	652	15.7
1969	5407	3525		125	**9057**	31.9	2545	986	56.3
1970	2237	66	0.5	78	**2381**	10.5	806	711	18.5
1971	722	660	1.7	69	**1453**	4.8	383	1199	8.6
1972	3079	5	0.4	31	**3115**	14.0	1083	1396	25.1
1973	558	5	1.9	3	**568**	2.6	197	1539	4.9
1974		19	0.4		**20**	0.0	4	1401	1.6
1975		5	2.3		**7**	0.1	2	1576	0.4
1976		16	1.8		**18**	0.1	4	1491	1.3
1977	0	19	1.0		**20**	0.0	5	1739	0.7
1978	0	30	0.6		**31**	0.1	6	732	1.2
1979		71	0.5		**71**	0.1	14	1498	0.6
1980	0	38			**38**	0.1	7	390	2.6
1981		5	0.9		**6**	0.0	2	1600	0.4
1982	0	6	1.1		**8**	0.1	1	1756	0.4
1983		30	0.5		**30**	0.1	6	1911	0.5
1984	706	32	2.9		**741**	3.2	253	899	6.1
1985	918	8			**926**	4.1	323	390	8.0
1986	1151	5	1.0		**1157**	5.2	405	622	9.7
1987	314	5			**318**	1.4	111	705	2.9
1988	128	3			**131**	0.6	45	478	1.3
1989	0	0			**0**	0.0	0	12	0.0
1990		0			**0**	0.0	0	10	0.0
1991									
1992									
1993	3				**3**	0.0	1		0.0
1994									
1995		0			**0**	0.0	0		0.0
1996		1			**1**	0.0	0		0.0
Shipped	**95566**	**22189**	**30.0**	**622**	**118408**	**477**	**37555**	**26494**	**858**
Inventory	**668**	**19526**	**1.7**		**20196**	**42.1**	**724**		**34.6**
Total	**96234**	**41715**	**31.7**	**622**	**138604**	**519**	**38279**	**26494**	**893**

NOTE: Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

Table A-6

PADUCAH RECEIPTS DATA
Key Shipping Sites (MTU)

Year	Hanford	Savannah River	Total	Contaminants		
				Pu (gms)	Np (gms)	Tc (kgs)
1954	2233		**2233**	10.0	782	17.9
1955	2587	283	**2870**	12.2	956	21.7
1956	4105	195	**4300**	18.9	1472	33.5
1957	5386	565	**5951**	25.4	1987	45.1
1958	6056	230	**6286**	27.7	2161	49.3
1959	5202		**5202**	23.4	1821	41.6
1960	5148		**5148**	23.2	1802	41.2
1961	6094	91	**6185**	27.6	2149	49.1
1962	5492	1533	**7025**	27.8	2198	49.3
1963	5772	1343	**7115**	28.7	2262	50.9
1964	4087	1603	**5690**	21.6	1719	38.3
1965						
1966						
1967	14433		**14433**	64.9	5052	115.5
1968		2	**2**	0.0	0	0.0
1969	3537	2815	**6352**	21.5	1745	38.1
1970						
1971	722	597	**1319**	4.4	360	7.9
1972	3078		**3078**	13.9	1077	24.6
1973	558		**558**	2.5	195	4.5
Total	**74491**	**9257**	**83748**	**354**	**27738**	**628**

NOTE: Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

Table A-7

K-25 RECEIPTS DATA
Key Shipping Sites (MTU)

Year	Hanford	Savannah River	Total	Contaminants		
				Pu (gms)	Np (gms)	Tc (kgs)
1952	100		**100**	0.4	35	0.8
1953	578		**578**	2.6	202	4.6
1954	1115		**1115**	5.0	390	8.9
1955	526	272	**798**	2.9	233	5.2
1956	324	2539	**2863**	6.5	570	11.5
1957	98	2635	**2733**	5.7	509	10.0
1958	7	1077	**1084**	2.2	196	3.8
1959	261	828	**1090**	2.8	241	5.0
1960	610	1677	**2287**	6.1	515	10.7
1961	611	1122	**1733**	5.0	416	8.8
1962	45	139	**184**	0.5	41	0.8
1963	0		**0**	0.0	0	0.0
1964						
1965		2	**2**	0.0	0	0.0
Total	**4276**	**10292**	**14568**	**39.8**	**3349**	**70**

NOTE: Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

Table A-8

PORTSMOUTH RECEIPTS DATA
Key Shipping Sites (MTU)

Year	Idaho	Total	Contaminants			
			Pu (gms)	Np (gms)	U-236 (kgs)	Tc (kgs)
1973	1.4	**1.4**	0.0	0.7	5	0.0
1974						
1975	1.4	**1.4**	0.0	0.0	5	0.0
1976	1.3	**1.3**	0.0	0.0	4	0.0
Total	**4.1**	**4.1**	**0.0**	**0.7**	**13.9**	**0.0**

NOTE: Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

Table A-9

FERNALD RECEIPTS DATA
Key Shipping Sites (MTU)

Year	Hanford	Savannah River	West Valley	Total	Contaminants			
					Pu (gms)	Np (gms)	U-236 (kgs)	Tc (kgs)
1953	0			**0**	0.0	0		0.0
1954								
1955								
1956								
1957	0			**0**	0.0	0		0.0
1958	5			**5**	0.0	2		0.0
1959	19			**19**	0.1	7		0.2
1960	21			**21**	0.1	7		0.2
1961	50	1		**51**	0.2	18		0.4
1962	170			**170**	0.8	60		1.4
1963	1002			**1002**	4.5	351		8.0
1964	1097	1		**1097**	4.9	384		8.8
1965								
1966	2025	202	48	**2274**	9.7	752		17.1
1967	1458	859	101	**2418**	8.7	679		15.0
1968	1692	412	168	**2273**	9.1	690		15.5
1969	1870	706	124	**2700**	10.3	799		17.8
1970	2237	22	78	**2336**	10.4	798		18.2
1971	0	60	69	**129**	0.4	21		0.4
1972		0	31	**31**	0.1	4		0.1
1973			3	**3**	0.0	0		0.0
1974		15		**15**	0.0	3	17	1.2
1975								
1976		12		**12**	0.0	2	14	1.0
1977	0	14		**15**	0.0	3		0.4
1978		28		**28**	0.1	5	23	1.0
1979		66		**66**	0.1	12		0.2
1980		36		**36**	0.1	7	17	2.5
1981		0		**0**	0.0	0		0.0
1982								
1983		23		**23**	0.0	4		0.1
1984	706	27		**733**	3.2	252		5.7
1985	918			**918**	4.1	321		7.3
1986	1151			**1151**	5.2	403		9.2
1987	314			**314**	1.4	110		2.5
1988	123			**123**	0.6	43		1.0
1989	0			**0**	0.0	0		0.0
Total	**14859**	**2486**	**621**	**17966**	**74.3**	**5735**	**71**	**135**

NOTE: Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

Table A-10

Y-12 RECEIPTS DATA
Key Shipping Sites (MTU)

Year	Hanford	Savannah River	West Valley	Idaho	Total	Contaminants			
						Pu (gms)	Np (gms)	U-236 (kgs)	Tc (kgs)
1953				0.3	**0.3**	0.0	0	40	0.0
1954				0.3	**0.3**	0.0	0	36	0.0
1955				0.7	**0.7**	0.0	1	97	0.0
1956				1.1	**1.1**	0.0	1	146	0.0
1957	0.0			0.6	**0.6**	0.0	1	80	0.0
1958	1.4			2.7	**4.1**	0.0	4	349	0.0
1959	0.1			1.8	**1.9**	0.0	2	229	0.0
1960	0.0			0.6	**0.6**	0.0	1	75	0.0
1961		1.1			**1.1**	0.0	0		0.1
1962		1.9		0.8	**2.7**	0.0	1	101	0.2
1963		6.4		0.8	**7.2**	0.0	2	100	0.5
1964		2.6		0.4	**3.0**	0.0	1	55	0.2
1965		2.6		0.8	**3.4**	0.0	2	319	0.2
1966		3.3		0.6	**3.9**	0.0	1	644	0.3
1967		2.2			**2.2**	0.0	0	503	0.2
1968		2.0		0.8	**2.8**	0.0	1	652	0.2
1969		4.0	0.9		**4.9**	0.0	1	986	0.3
1970		44.6		0.5	**45.1**	0.1	8	711	0.3
1971		3.4		1.7	**5.1**	0.0	3	1199	0.3
1972		4.7		0.4	**5.1**	0.0	1	1396	0.4
1973		5.0		0.6	**5.6**	0.0	1	1534	0.4
1974		4.4		0.4	**4.8**	0.0	1	1384	0.4
1975		5.0		0.9	**5.9**	0.1	2	1571	0.4
1976		4.3		0.5	**4.8**	0.1	2	1473	0.4
1977		4.4		1.0	**5.4**	0.0	2	1739	0.4
1978		2.0		0.5	**2.5**	0.0	0.4	703	0.2
1979		4.5		0.5	**5.0**	0.0	2	1498	0.4
1980		1.4			**1.4**	0.0	0	373	0.1
1981		4.8		0.9	**5.7**	0.0	2	1600	0.4
1982		5.6		1.1	**6.7**	0.1	1	1756	0.4
1983		6.5		0.5	**7.0**	0.0	2	1911	0.5
1984		4.6		2.9	**7.5**	0.0	1	899	0.4
1985		8.2			**8.2**	0.0	1	390	0.7
1986		5.4		1.0	**6.4**	0.0	2	622	0.4
1987		4.6			**4.6**	0.0	1	705	0.4
1988		3.1			**3.1**	0.0	1	478	0.3
1989		0.1			**0.1**	0.0	0	12	0.0
1990		0.1			**0.1**	0.0	0	10	0.0
1991									
1992									
1993	2.9				**2.9**	0.0	1		0.0
Total	**4.4**	**153**	**0.9**	**25.7**	**184**	**0.5**	**54**	**26375**	**9.1**

NOTE: Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

Table A-11

RECEIPTS DATA - OTHER MINOR SITES
Key Shipping Sites (MTU)

Year	Hanford	Savannah River	Idaho	Total	Contaminants			
					Pu (gms)	Np (gms)	U-236 (kgs)	Tc (kgs)
1953	1679			**1679**	7.6	588		13.4
1954	241			**241**	1.1	84		1.9
1955	1.2		0.2	**1.4**	0.0	1	29	0.0
1956	1.5			**1.5**	0.0	1		0.0
1957	0.7			**0.7**	0.0	0		0.0
1958	0.2			**0.2**	0.0	0		0.0
1959	0.9			**0.9**	0.0	0		0.0
1960	6.1			**6.1**	0.0	2		0.0
1961	0.4			**0.4**	0.0	0		0.0
1962	0.1			**0.1**	0.0	0		0.0
1963	0.0			**0.0**	0.0	0		0.0
1964	0.2			**0.2**	0.0	0		0.0
1965								
1966								
1967								
1968		0.0		**0.0**	0.0	0		0.0
1969		0.1		**0.1**	0.0	0		0.0
1970		0.0		**0.0**	0.0	0		0.0
1971								
1972	0.1	0.0		**0.1**	0.0	0		0.0
1973								
1974								
1975								
1976								
1977								
1978	0.0			**0.1**	0.0	0	6	0.0
1979								
1980	0.0	0.0		**0.0**	0.0	0		0.0
1981		0.0		**0.0**	0.0	0		0.0
1982	0.0	0.8		**0.9**	0.0	0		0.0
1983								
1984		0.0		**0.0**	0.0	0		0.0
1985		0.0		**0.0**	0.0	0		0.0
1986	0.0	0.0		**0.0**	0.0	0		0.0
1987								
1988	4.8			**4.8**	0.0	2		0.0
1989								
1990								
1991								
1992								
1993								
1994								
1995		0.0		**0.0**	0.0	0		0.0
1996		1.4		**1.4**	0.0	0		0.0
Total	**1936**	**2.3**	**0.3**	**1939**	**8.7**	**678**	**34.6**	**15.5**

NOTE: Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

Table A-12

TOTAL RECEIPTS DATA
Key Receiving Sites

Year	Fernald	Paducah	K-25	Portsmouth	Y-12	Others	Total	Contaminants			
								Pu (gms)	Np (gms)	U-236 (kgs)	Tc (kgs)
1952			100				**100**	0.4	35		0.8
1953	0		578		0.3	1679	**2258**	10.2	790	40	18.1
1954		2233	1115		0.3	241	**3589**	16.2	1257	36	28.7
1955		2870	798		0.7	1.4	**3670**	15.1	1191	125	26.9
1956		4300	2863		1.1	1.5	**7165**	25.4	2044	146	45.0
1957	0	5951	2733		0.6	0.7	**8686**	31.1	2497	80	55.1
1958	5	6286	1084		4.1	0.2	**7381**	29.9	2363	349	53.1
1959	19	5202	1090		1.9	0.9	**6314**	26.3	2071	229	46.8
1960	21	5148	2287		0.6	6.1	**7463**	29.4	2327	75	52.1
1961	51	6185	1733		1.1	0.4	**7970**	32.8	2583		58.4
1962	170	7025	184		2.7	0.1	**7382**	29.0	2300	101	51.7
1963	1002	7115	0		7.2	0.0	**8124**	33.2	2615	100	59.4
1964	1097	5690			3.0	0.2	**6791**	26.5	2104	55	47.3
1965			2		3.4		**5**	0.0	2	319	0.2
1966	2274				3.9		**2278**	9.7	753	644	17.3
1967	2418	14433			2.2		**16853**	73.6	5731	503	130.6
1968	2273	2			2.8	0.0	**2277**	9.1	692	652	15.7
1969	2700	6352			4.9	0.1	**9057**	31.9	2544	986	56.3
1970	2336				45.1	0.0	**2381**	10.5	806	711	18.5
1971	129	1319			5.1		**1453**	4.8	383	1199	8.6
1972	31	3078			5.1	0.1	**3114**	14.0	1083	1396	25.1
1973	3	558		1.4	5.6		**568**	2.5	197	1539	4.9
1974	15				4.8		**20**	0.0	4	1401	1.6
1975				1.4	5.9		**7**	0.1	2	1576	0.4
1976	12			1.3	4.8		**18**	0.1	4	1491	1.3
1977	15				5.4		**20**	0.0	5	1739	0.7
1978	28				2.5	0.1	**31**	0.1	6	732	1.2
1979	66				5.0		**71**	0.1	14	1498	0.6
1980	36				1.4	0.0	**38**	0.1	7	390	2.6
1981	0				5.7	0.0	**6**	0.0	2	1600	0.4
1982					6.7	0.9	**8**	0.1	1	1756	0.4
1983	23				7.0		**30**	0.1	6	1911	0.5
1984	733				7.5	0.0	**741**	3.2	253	899	6.1
1985	918				8.2	0.0	**926**	4.1	323	390	8.0
1986	1151				6.4	0.0	**1157**	5.2	405	622	9.7
1987	314				4.6		**318**	1.4	111	705	2.9
1988	123				3.1	4.8	**131**	0.6	45	478	1.3
1989	0				0.1		**0**	0.0	0	12	0.0
1990					0.1		**0**	0.0	0	10	0.0
1991											
1992											
1993					2.9		**3**	0.0	1		0.0
1994											
1995						0.0	**0**	0.0	0		0.0
1996						1.4	**1**	0.0	0		0.0
Total	**17966**	**83748**	**14568**	**4.1**	**184**	**1939**	**118408**	**477**	**37555**	**26494**	**858**

NOTE: Totals may not add due to rounding. Zero indicates value smaller than displayed significant figures.

GLOSSARY

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 waste. Chemical separation is also known as reprocessing.

Contaminants
Minor, unwanted components of a desired product. For purposes of this report, only radiological contaminants (i.e., fission products and transuranics) are considered.

Depleted Uranium
Uranium in any chemical form that contains less than 0.7 percent U-235 and more than 99.3 percent uranium-238.

Enriched Uranium
Uranium in any chemical form that contains more than 0.7 percent U-235.

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

Highly Enriched Uranium
Uranium in any chemical form that contains more than 20 percent U-235.

Irradiation
The exposure to ionizing radiation, or neutrons, usually in a nuclear reactor. Targets are irradiated to produce isotopes.

Isotope
Any of two or more forms of an element having the same chemical properties and the same atomic number, but different atomic weights (U-235, U-236, and U-238 are three isotopes of uranium).

Neptunium
A reactor-produced element having the atomic number 93. It is a silvery metal and slightly denser than lead.

Plutonium
A man-made 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.

Production Site
A site having facilities for, and the mission to, separate uranium from irradiated targets and or discharged nuclear reactor fuel.

Recycled Uranium
Uranium that is recovered from spent reactor fuel or irradiated targets using chemical separations processes, including REDOX and PUREX. For this report, recycled uranium is uranium that originated from the chemical reprocessing of spent nuclear fuels.

Technetium
A fission product element with the atomic number 43. The only known element with an atomic number of less than 93 that does not exist naturally on earth.

Transuranic Elements
All elements beyond uranium on the periodic table.

Uranium
A slightly radioactive, naturally occurring heavy metal element, atomic number 92, that is denser than lead. The isotopes in natural uranium are U-238, U-235, and U-234. It is the fuel used for nuclear reactors and the fundamental material of nuclear technology.

Uranium-236
An isotope of uranium that is generated in a nuclear reactor from U-235 by a neutron capture reaction.

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