Recycled Uranium

Establishing Confidence in Uranium Production and Shipment Data

July 2003

DOE/SO-0005

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for the
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Executive Summary

In August 1999, workers at the Paducah Gaseous Diffusion Plant raised concerns and initiated a lawsuit over health and safety related to possible exposure to contaminants, especially plutonium, in recycled uranium processed at the plant. In the fall of 1999, the Department of Energy (DOE) initiated an investigation of the production and use of recycled uranium in the DOE complex as shown in Figure 1. 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 46-year period, 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.

Because differences between shipper and receiver data presented were observed in the site reports published in 2000, the DOE tasked its Office of Plutonium, Uranium, and Special Materials Inventory (SO-62) to conduct a follow-on study to examine the original reports and correct and validate the recycled uranium material values. The first efforts of this follow-on study concern the production of recycled uranium. The results are published in "Recycled Uranium, United States Production, Enrichment, and Utilization" (SO-0003). This report reviewed, corrected, and validated the material accounting records providing a public record of U.S. production and initial shipment of recycled uranium and its contaminants.

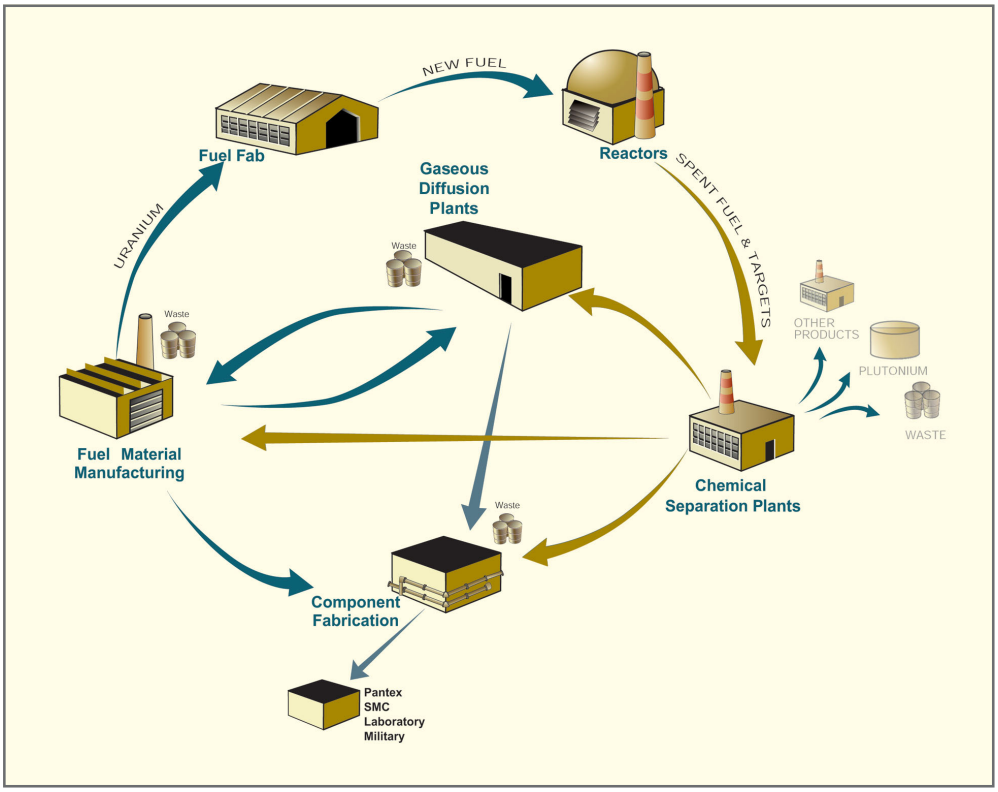

Figure 1 - Flow of recycled uranium in the DOE complex.

The report indicates that 138,604 metric tons of recycled uranium (MTU) was produced with approximately 85 percent (118,408 MTU) shipped to the enrichment and manufacturing sites (Figure 2). Approximately 15 percent remains in storage at the production sites.

With the publication of the report referenced above, SO 62 anticipated that there would be questions regarding the accuracy and reliability of the published numbers. To determine the uncertainty value, SO-62 asked for the assistance of the New Brunswick Laboratory (NBL) to quantify and establish confidence levels for the numbers published in the recycled uranium report. NBL is managed by SO-62 and has been the Department's recognized expert in measurement control for over 50 years. NBL has established and managed several measurement evaluation programs. These include the General Analytical Evaluation (GAE) Program (1952 to 1984), the Safeguards Analytical Laboratory Evaluation (SALE) Program (1970 to 1984), and the Safeguards Measurement Evaluation (SME) Program (1985 to present). The purpose of this report, then, is to establish a level of confidence to be assigned the numbers published in the recycled uranium report.

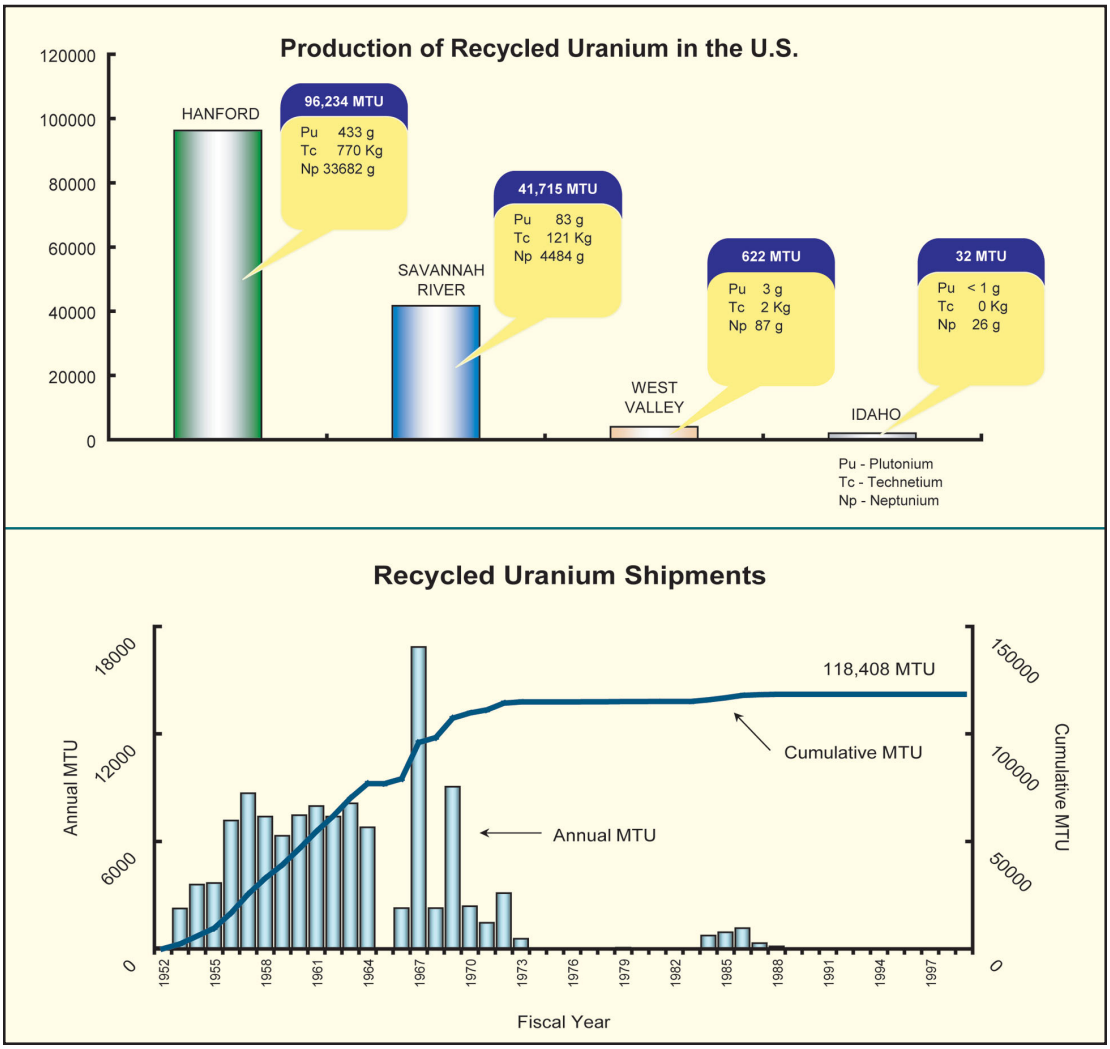

Figure 2 - Production and shipments of recycled uranium.

Introduction

In May 2003, the Office of Security issued a report, "Recycled Uranium: United States Production, Enrichment, and Utilization" (DOE/SO-0003), which dealt with the production and shipment of recycled uranium within the Department of Energy (DOE) complex. Recycled uranium was produced from the reprocessing of spent nuclear fuel at the DOE Hanford, Savannah River, and Idaho sites, as well as the commercial West Valley site. The recovered uranium was sent to other sites for enrichment and to make nuclear fuel for reactors and other components. Three primary sites received nearly all of the recycled uranium shipped from the fuel reprocessing plants. These sites were the Paducah and Oak Ridge K-25 Gaseous Diffusion Plants, and the Fernald Feed Materials Production Center. Other sites, like the Oak Ridge Y-12 facility and the Portsmouth Gaseous Diffusion Plant received small amounts of recycled uranium. These sites are shown in Figure 3.

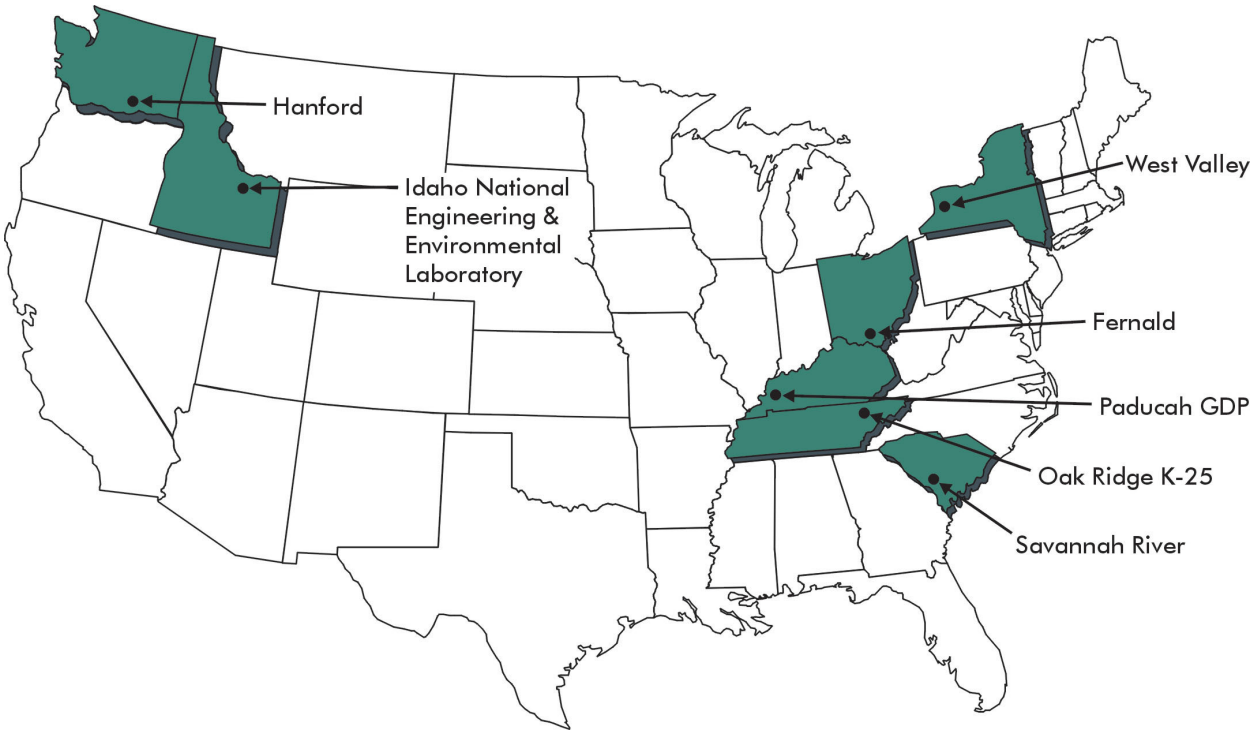

Figure 3 - Production sites and primary initial receiving sites for U.S. recycled uranium.

The recycled uranium report published by the Office of Security was a result of extensive analysis of nine site reports that encompassed the years 1952 through 1999, in which recycled uranium was transferred throughout the DOE complex. The DOE sites that processed, shipped, or received recycled uranium prepared these nine reports. The data from those nine reports was the basis for the May 2003 recycled uranium report, which provides an accurate materials' accounting and public record of U.S. production and shipment of recycled uranium and its contaminants.

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 nine 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 nonrecycled uranium in the dataset as well. The information presented in the May 2003 recycled uranium report resolves the data differences due to definitional and other differences that existed between shipper and receiver data in the previously issued site reports. The resolution of the recycled uranium data involved the use of the Nuclear Materials Management and Safeguards System (NMMSS)[1] database, as well as the utilization of process knowledge, in discussions and interactions with production and receiving site personnel. Original shipping and receiving reports were also compared to the NMMSS database to resolve discrepancies. The NMMSS database provided material type, composition, description, project codes, and information concerning the chemical form or the use of the uranium in question.

Establishing confidence levels in the data involved taking the total amount of shipments between sites and verifying it against measurement data from the individual sites.

The material control and accountability procedures used by DOE and its predecessor agencies dictate strict adherence to a set of guidelines and requirements for measuring nuclear materials; however, each site could choose its method of measuring. Gravimetry (net weight following total oxidation) was the primary method of measurement used by the various shipper receiver pairs; however, titrimetry (an analysis using an oxidation-reduction reaction of uranium in solution) was also used. Titrimetry was an extremely small, if not negligible contributor to the limits of error associated with these shipments. The systematic and random errors associated with the scales used to measure and record shipper receiver values varied from site to site and were probably the major contributors to the errors associated with these shipments. Hanford, the primary shipper and producer of recycled uranium, relied on the Davies-Gray method of titrimetry for assaying uranium. Conversations with personnel who were associated with the production and measurement of uranium at Hanford revealed that x-ray diffraction was used during the 1950s and early 1960s to assay uranium. Isotope dilution mass spectrometry was used at Idaho to assay all shipments and receipts of uranium.

Transfers of nuclear materials between facilities, such as the shipments and receipts of recycled uranium discussed in this report, are subject to the same measurement control and statistical analyses described above. The shipper and receiver both provide a system for measuring the same attribute of the nuclear material and, within statistically calculated limits of error, report their values for comparison. A large difference occurring in any given shipment that would fall outside the limits of error would cause an investigation by both the shipper and receiver as well as the government.

[1] NMMSS is the U.S. Government's information system that contains current and historic data on the possession, use, and shipment of nuclear materials. This centralized database contains information collected from government and commercial nuclear facilities and tracks and accounts for special nuclear, source, and byproduct materials as defined by the Atomic Energy Act of 1954.

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 contaminant quantities presented in the recycled uranium report were derived from the historical contaminant data included in the nine site reports. Because of the paucity of analytical data regarding recycled uranium contaminants, an analysis of the uncertainty associated with the recycled uranium contaminants in the recycled uranium report would not be meaningful.

Primary Shippers and Receivers of Recycled Uranium

Shippers

The Hanford Site, located in southeastern Washington State, produced plutonium for national defense. Nine production reactors were built and operated on the site, as well as five chemical separation plants, which processed the spent reactor fuel. Hanford shipped its first batch of recycled uranium to the Oak Ridge, Tennessee, K-25 Gaseous Diffusion Plant in 1952. Hanford was the largest producer of recycled uranium, producing nearly 70 percent (96,234 MTU) of the U.S. recycled uranium. The site shipped 95,566 MT of recycled uranium 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, with smaller quantities shipped to several other sites.

Nearly all of the remaining U.S. recycled uranium production was carried out at the Savannah River Site located in southwestern South Carolina. Over its history, Savannah River operated a fuel and target manufacturing facility, five production reactors, two chemical separation areas, and various waste management facilities. Savannah River recovered 41,715 MTU and 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. As of March 1999, the Savannah River site had about 19,526 MTU of mostly depleted recycled uranium in storage.

Idaho began operation in 1949 as the National Reactor Testing Station. The 890-square-mile reservation is in the southeastern Idaho dessert. 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 Idaho Chemical Processing Plant was a specialized plant designed to reprocess the unique fuels required by the various test reactors. Idaho recovered about 32 MTU of enriched uranium from a variety of experimental and test reactors.

The New York West Valley Service Center is located in southwestern New York and is the only private facility in the United States to reprocess spent fuel. The facility operated from 1965 through 1972. Throughout its operational history, West Valley received both commercial and government spent fuel. The 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. Approximately 0.9 MTU was composed of uranium-233 (U-233) produced from thorium. All of the West Valley uranium, except the U-233, was shipped to Fernald. The U-233 was sent to Y-12 and is currently stored at Oak Ridge.

Initial Receivers

The Paducah Gaseous Diffusion Plant has operated since 1952 and is located in southwestern Kentucky. Historically, the plant enriched uranium for government programs and commercial nuclear power plants from it natural uranium-235 (U-235) content of about 0.7 percent to about 2.0 percent. 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 that was shipped from Hanford in 1954. Starting in 1955, Paducah received recycled uranium from Savannah River production. A total of 83,748 MT of recycled uranium production was received at the Paducah plant.

The Oak Ridge K-25 Plant, located in northeastern Tennessee, used the gaseous diffusion process to produce enriched uranium. The K-25 Plant began enriching uranium in 1945. The first recycled uranium produced by the Hanford chemical separation facility was sent to the K-25 Plant for enrichment in 1952. The plant also received recycled uranium from the Savannah River Site starting in 1955. A total of 14,568 MT of recycled uranium production was received at the K-25 Plant.

The Fernald Environmental Management Project is located in southwestern Ohio. This DOE-owned property was formerly known as the Feed Materials Production Center. Production operations were active from 1952 through 1989 and supported defense program missions by producing various uranium products. Fernald received 17,966 MT of recycled uranium from the production facilities. Most of the recycled uranium (14,859 MTU, or 83 percent) came from Hanford as oxide. Savannah River shipped 2,486 MT of recycled uranium, and West Valley shipped 621 MT of recycled uranium to Fernald.

Methodology

The approaches to finding a level of confidence in the data published in the May 2003 report involved an examination of the measurement records for the amount of total uranium shipped, deriving the amount of recycled uranium contained in the total uranium (establishing definitional attributes), and examining other factors, such as timing of the data, that would impact the validity of the data.

As a result of a thorough review of the site reports by SO-62, several sets of data, organized by shipper-receiver pairs, were generated from data extracted from the site reports. The data set with the most consistently applied criteria is that for total uranium shipments between sites. Recycled uranium shipments are a subset of the total uranium shipments, but different sites applied different definitions to designate the uranium as recycled. Differences between site data were reconciled by SO-62 by applying a consistent definition of recycled uranium.

For many shipper-receiver pairs, annual total uranium shipment data were available with separately reported values from the shipper and receiver. The difference between each annual pair can serve as a measure of the uncertainty of the reported values. To be a valid shipper-receiver pair, a necessary condition is that the same underlying cumulative mass of uranium was measured and reported during a given year. Reasons to reject or suspect data included missing records, apparent year-end effects, and data reported in the wrong

year. In addition, some shipper-receiver pairs reconciled the reported values, so the difference between the pairs was lost. The reports from sites and NMMSS information helped determine valid data.

For some of the earliest shipments, there were large discrepancies between the reported values from shippers and receivers, apparently due to one of the sites having incomplete or nonexistent records. In other cases, year-end effects were seen (the shipper sends the shipment in one year, but the receiver does not report it until the following year).

Once valid data were identified, the statistical analysis proceeded. For each valid annual pair, a mean and variance can be calculated. The sum of the means over all years yields total uranium shipped, and the square root of the sum of the variances gives the standard deviation in the sum of the means.

This statistical analysis is not dependent on knowledge concerning the details of what measurements were made. Each of the two values that comprise the annual shipments for a shipper-receiver pair are the sum of many independent measurements. Each individual measurement has an associated uncertainty that will be "rolled up" into the associated annual value and is ultimately manifested in the difference between the two values of the pair. This difference is used to infer the associated overall uncertainty.

Results

Five shipper-receiver pairs had valid data. Table 1 presents the results for those shipper-receiver pairs with valid data. The Mean Sum is the sum of the yearly means. The standard deviation is the standard deviation of the sum of the means, calculated by taking the square root of the sum of the yearly variances; %RSD is the relative standard deviation expressed as a percent.

Table 1 - Uncertainties in total uranium shipments

Shipper-Receiver Pair	Mean Sum (kg)	s	By-year %RSD
Hanford-Fernald	17132609	9169.508	0.054
Hanford-Paducah	74479848	191916.6	0.258
Idaho-Portsmouth	4074.884	2.412332	0.059
SRS-Fernald	7077053	1207.538	0.017
SRS-K-25	10288840	3344.776	0.033

The Hanford-Paducah data show significant year-end effects. This results in relatively large yearly variances, which, when summed, result in the observed %RSD of 0.258%. However, these year-end effects tend to cancel out when averaged over all years. The difference between the shipper values and receiver values, summed over all years, is only 0.029% (see the right-most column of Table 2). This difference is comparable to those from the other shipper-receiver pairs with valid yearly data. It was noted during the data analysis that inclusion of only three points with suspected year-end effects caused the Hanford-Fernald %RSD to increase from 0.054% to 0.207%. In the case of the Hanford-Paducah data, the %RSD of the sum of the means, as calculated from yearly data, is about

an order of magnitude greater than the difference between the total shipper and receiver sums. This indicates that the data may not be independent year-to-year, which is consistent with year-end effects.

Since the overall Hanford-Paducah values agree to 0.029% and there is no apparent reason to believe Hanford performed measurements less accurately when shipping to Paducah as compared to Fernald, a value of 0.06% is assigned to Hanford-Paducah for the valid total uranium shipment relative standard deviation. Table 2 presents adjusted %RSDs for total uranium shipments.

Table 2 - Adjusted total uranium %RSDs

Shipper-Receiver (S-R) Pair	Mean Sum (kg)	%RSD	S-R % diff
Hanford-Fernald	17132609	0.054	-0.029
Hanford-Paducah	74479848	0.060	0.029
Idaho-Portsmouth	4074.884	0.059	0.043
SRS-Fernald	7077053	0.017	0.026
SRS-K-25	10288840	0.033	-0.017

Extrapolation From Total Uranium to Recycled Uranium

Two subsets of all shipments are of interest. The first subset is that of shipments with valid shipper-receiver values. The second subset is that of recycled uranium shipments. To apply the uncertainties determined for the first subset to the second, the following assumptions are made:

- measurements of, and accounting practices for, recycled uranium shipments were similar to those for other uranium shipments;
- a consistent methodology was used to designate recycled uranium; and
- errors are normally distributed.

With these assumptions, the relationship between the $\%RSD_{TU,V}$ of the valid total uranium shipments to the $\%RSD_{RU}$ for recycled uranium is:

$$\%RSD_{RU} = \%RSD_{TU,V} \times \sqrt{\frac{M_{TU,V}}{M_{RU}}} \qquad \textit{(Equation 1)}$$

where $M_{TU,V}$ is the mass of the total uranium shipped (sum of the yearly means) during years with valid data for a particular shipper-receiver pair and M_{RU} is the mass of recycled uranium. This adjustment resulted in the $\%RSD_{RU}$ being greater than or equal to the $\%RSD_{TU,V}$, and is, therefore, believed to be a statistically conservative estimate.

Effect of Incomplete Hanford-Fernald Data (Exclusion of Early Years)

About 20% of the total uranium shipped from Hanford to Fernald occurred in early years without good Fernald data. Shipper values were the only ones available, so comparison of shipper and receiver values could not be performed to derive uncertainty.

The General Analytical Evaluation (GAE) Program data were reviewed to see if any significant differences in measurement uncertainties existed between measurements of uranium trioxide (UO_3) in the 1950s as compared to the 1960s. The GAE Program was established by NBL to monitor the quality of uranium concentration, U-235 isotopic abundance, and impurity measurements. This program was active from 1952 until 1984 and, because Hanford participated in the GAE Program UO_3 analyses from 1954 to 1958, provided a means to evaluate measurement quality of UO_3 measurements at Hanford.

Hanford analyses exhibited biases of less than 0.04%. This is consistent with the residual %RSDs seen for total uranium and recycled uranium. While some small improvements in uranium concentration measurements may have occurred in the decades after the 1950s, the associated measurement biases do not appear to be the dominant source of uncertainties in the historical data.

Derivation of Uncertainties for Remaining Significant Recycled Uranium Shipper-Receiver Pairs

The shipper-receiver pairs in Table 3 account for about 85 percent of the recycled uranium shipments. Several other shipper-receiver pairs contribute the remaining 15 percent. All shipper-receiver pairs are shown in Table 4. Note that shipments are expressed in units of MTU.

Table 3 - Recycled uranium (RU) uncertainties based on yearly data

Shipper-Receiver (S-R) Pair	$M_{TU,V}$ (kg)	$\%RSD_{TU,V}$	valid years S-R % diff	M_{RU} (kg)	% of all RU shipments	inferred $\%RSD_{RU}$
Hanford-Fernald	17132609	0.054	-0.029	14858771	12.5	0.057
Hanford-Paducah	74479848	0.060	0.029	74490696	62.9	0.060
Idaho-Portsmouth	4074.884	0.059	0.043	4076	0.0	0.059
SRS-Fernald	7077053	0.017	0.026	2485625	2.1	0.029
SRS-K-25	10288840	0.033	-0.017	10291680	8.7	0.033

Table 4 - Recycled uranium (RU) pairs - all sites

Shipper-Receiver Pair	RU (MTU)	% of all RU shipments
Hanford-Fernald	14859	12.55
Hanford-Paducah	74491	62.91
Idaho-Portsmouth	4	0.00
SRS-Fernald	2486	2.10
SRS-K-25	10292	8.69
Hanford-K-25	4276	3.61
Hanford-Labs	0	0.00
Hanford-Other than K-25	17	0.01
Hanford-Others	1914	1.62
Hanford SRS	5	0.00
Hanford Y-12	4	0.00
Idaho-Others	<1	0.00
Idaho-Y-12	26	0.02
SRS-Minors	2	0.00
SRS-Other than K-25	<1	0.00
SRS-Paducah	9257	7.82
SRS-Y-12	153	0.13
WV-Fernald	621	0.52
WV-Y-12	<1	0.00
TOTAL	118408	100.00

Not all the shipper-receiver pairs in Table 4 account for a large enough percentage of the total recycled uranium shipments to influence the uncertainties in shipments. Table 5 presents those shipper-receiver pairs with significant shipments (% of total >0.5%). The first four pairs had uncertainties determined using valid shipper-receiver data (note that Idaho-Portsmouth is not listed since associated recycled uranium shipments were much less than 0.5% of all recycled uranium shipments).

Table 5 - Recycled uranium (RU) pairs-significant sites only (% of total >0.5%)

Shipper-Receiver Pair	RU (MTU)	% of all RU shipments
Hanford-Fernald	14859	12.5
Hanford-Paducah	74491	62.91
SRS-Fernald	2486	2.10
SRS-K-25	10292	8.69
Hanford-K-25	4276	3.61
Hanford-Others	1914	1.62
SRS-Paducah	9257	7.82
WV-Fernald	621	0.52
TOTAL	118196	99.82

Uncertainties in the shipments for the remaining significant recycled uranium sites may be inferred from the uncertainties observed for the initial four shipper-receiver pairs. Since no clear correlation of uncertainty with annual shipments is evident in the final values for the initial four shipper-receiver pairs, the correction for annual shipment size (similar to that of Equation 1) is not applied.

Hanford Shipments to Oak Ridge K-25

K-25 records were used for the 1952–1967 time period (Hanford did not report shipments to K-25 and the Oak Ridge Y-12 plant separately). Total receipts for K-25 and Y-12 have close agreement with Hanford starting in 1960. Also, K-25 records have excellent agreement with Savannah River records, which indicates accurate and full accounting by K-25. No recycled uranium was shipped between these sites from 1968 forward. Hanford uncertainties for shipments to Fernald and Paducah are on the order of 0.06%. SRS–K-25 uncertainties are about 0.03%. As a conservative estimate, the larger of these uncertainties of (0.06%) is assigned to the Hanford to K-25 shipments.

Hanford Shipments to Others

For Hanford-Others, 1953 and 1954 (only years with recycled uranium), are shipments of depleted uranium oxide to the Harshaw Chemical Company for preprocessing before shipment to K-25 and/or Paducah. An uncertainty of 0.06% is assigned, consistent with Hanford shipments to Fernald and Paducah. Harshaw, located near Cleveland, Ohio, converted the recycled uranium to uranium tetrafluoride and uranium hexafluoride and then shipped the material to K-25 or Paducah for further processing and enrichment.

Savannah River Site Shipments to the Paducah Gaseous Diffusion Plant

SRS values are used for SRS–Paducah shipments. An uncertainty of 0.03% is assigned to the shipments from SRS to Paducah. This value is consistent with the uncertainties for shipments from SRS to Fernald and K-25.

Shipments From the New York West Valley Service Center to Fernald

Fernald receipt data were used. Fernald receipt uncertainty from SRS is 0.03% and from Hanford is 0.06%. The more conservative value of 0.06% is used as an estimate for West Valley Fernald shipments.

Summary of Recycled Uranium Shipments

Table 6 summarizes the uncertainty determinations for shipper-receiver pairs with significant recycled uranium shipments.

Table 6 - Uncertainties for significant recycled uranium (RU) shipments

Shipper-Receiver Pair	% of all RU shipments	RU (MTU)	%RSD
Hanford-Fernald	12.55	14859	0.06
Hanford-Paducah	62.91	74491	0.06
SRS-Fernald	2.10	2486	0.03
SRS-K-25	8.69	10292	0.03
Hanford-K-25	3.61	4276	0.06
Hanford-Others	1.62	1914	0.06
SRS-Paducah	7.82	9257	0.03
WV-Fernald	0.52	621	0.06
TOTAL significant sites	99.82	118196	0.04
All RU shipments	100.00	118408	0.04

The %RSD for "TOTAL, significant sites" was calculated by taking the square root of the sum of the variances for each shipper-receiver pair. This is expressed in Equation 2.

$$\%RSD_{\text{TOTAL, significant sites}} = \frac{\left[\sum_{SignificantSites}\left(RU_i \times \%RSD_i \div 100\right)^2\right]^{\frac{1}{2}}}{\sum_{SignificantSites} RU_i} \times 100\% \qquad \textit{(Equation 2)}$$

RU_i and $\%RSD_i$ are the values for the "ith" shipper-receiver pair from the "RU (MTU)" and "%RSD" columns, respectively, in Table 6. Since the recycled uranium from the significant sites is 99.82% of all the recycled uranium shipped, the %RSD for all recycled uranium shipments is essentially equivalent to that from the significant sites. The %RSD for all shipments of 0.04% equates to an uncertainty of 47 MTU in the total recycled uranium shipments.

Total recycled uranium production was about 138,604 MTU. Uranium assay measurement methods for materials staying in inventory (about 15% of the total) were the same as those for uranium that was shipped (about 85% of the total), so the %RSD for the total recycled uranium produced should be about the same as for the shipped recycled uranium. Applying the value of 0.04% RSD to 138,604 MTU gives an uncertainty of 55 MTU.

Conclusions

For the over 50 years that recycled uranium was produced and shipped, measurements on the elemental and composition of uranium product materials were conducted for safeguards, quality control, and safety purposes. These measurements were generally performed by both the shipper and receiver. Based on an examination of site and NMMSS records and measurement control data available from the NBL, discrepencies between shipper and receiver data were not primarily caused by measurements, but from other sources such as nonexistent or missing records, difference in year-end reporting, or errors in reporting.

In summary, recycled uranium shipments were 118,408 ± 47 MTU. Recycled uranium production was 138,604 ± 55 MTU. The percent Relative Standard Deviation of 0.04% is consistent with the order of magnitude of the 2000 International Target Values for systematic error (bias) for gravimetry of uranium oxide of 0.05% and titrimetry of 0.1%. This level of performance has been achieved from the 1950s through the present.

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Acronyms and Abbreviations

DOE	U.S. Department of Energy
GAE	General Analytical Evaluation
MTU	metric tons of recycled uranium
NBL	New Brunswick Laboratory
NMMSS	Nuclear Material management and Safeguards System
RU	Recycled Uranium
SALE	Safeguards Analytical Laboratory Evaluation
SME	Safeguards Measurement Evaluation
SO-62	Office of Plutonium, Uranium, and Special Materials Inventory
U-233	uranium-233
U-235	uranium-235
UO_3	uranium trioxide

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