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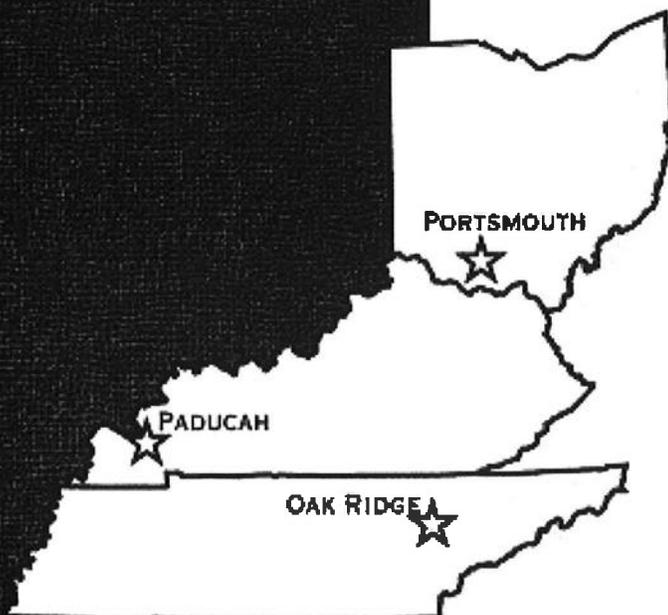


ENVIRONMENTAL MANAGEMENT &
ENRICHMENT FACILITIES

MANAGEMENT AND INTEGRATION
CONTRACT

**RECYCLED URANIUM
MASS BALANCE PROJECT
OAK RIDGE
GASEOUS DIFFUSION PLANT
(Currently Known as
East Tennessee Technology Park)
SITE REPORT**

June 2000



MANAGED BY
BECHTEL JACOBS COMPANY LLC
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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**RECYCLED URANIUM MASS BALANCE PROJECT
OAK RIDGE GASEOUS DIFFUSION PLANT
(Currently Known as
East Tennessee Technology Park)
SITE REPORT**

**Prepared for the
U. S. Department of Energy
Office of Uranium and Engineering Services**

**BECHTEL JACOBS COMPANY LLC
managing the
Environmental Management and Uranium Programs activities at the
East Tennessee Technology Park
under contract DE-AC05-98OR22700
for the
U.S. DEPARTMENT OF ENERGY**

**Haselwood Enterprises, Inc.
under subcontract 95K-HBG76V**

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LIST OF ACRONYMS

$\mu\text{g/gU}$	micrograms per gram of total uranium
^{99}Tc	technetium-99
AEC	Atomic Energy Commission
ASTM	American Society for Testing and Materials
CAM	continuous air monitor
CIP	Cascade Improvement Program
CROET	Community Reuse Organization of East Tennessee
CUP	Cascade Upgrade Program
DOE	U.S. Department of Energy
DOE-ORO	DOE Oak Ridge Operations
dpm	disintegrations per minute
ER	Environmental Restoration
ETTP	East Tennessee Technology Park
GDP	gaseous diffusion plant
HEU	highly enriched uranium
KANLIS	K-25 Analytical Laboratory Information System
LEU	low-enriched uranium
MBR	Material Balance Reports
MPC	Maximum Permissible Concentration
MTU	metric tons of uranium
MUF	material unaccounted for
NCRP	National Committee on Radiation Protection
NMC&A	Nuclear Materials Control and Accountability
NMMSS	Nuclear Materials Management and Safeguards System
Np	neptunium
NPDES	National Pollutant Discharge Elimination System
OEP	Occupational Exposure Potential
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORHASP	Oak Ridge Health Agreement Steering Panel
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PAL	Plant Action Level
PGDP	Paducah Gaseous Diffusion Plant
PORTS	Portsmouth Gaseous Diffusion Plant
ppb	parts per billion
ppm	parts per million
PPE	personnel protective equipment
Pu	plutonium
QA	Quality Assurance
RIS	Reporting Identification Symbol
RU	recycled uranium

LIST OF ACRONYMS (CONT.)

SRO	Savannah River Operations
TRU	transuranic
UCL	upper confidence limit
UF ₄	uranium tetrafluoride
UF ₆	uranium hexafluoride
UO ₂	uranium dioxide
UO ₃	uranium trioxide
wt %	weight percent

EXECUTIVE SUMMARY

I. INTRODUCTION

This report has been prepared to summarize the findings of the Oak Ridge Gaseous Diffusion Plant (ORGD¹) Mass Balance Project and to support preparation of associated U. S. Department of Energy (DOE) site reports. The project was conducted to support DOE efforts to assess the potential for health and environmental issues resulting from the presence of transuranic (TRU) elements and fission products in recycled uranium (RU) from reactor returns that was processed by DOE and its predecessor agencies. The U.S. Government used uranium in fission reactors to produce plutonium and tritium for nuclear weapons production. Because uranium was scarce relative to demand when these operations began almost 50 years ago, the spent fuel from U.S. fission reactors was processed to recover uranium for recycling. DOE's reconstruction of the historical flow and processing of RU has three fundamental elements:

- Determining annual mass flow of RU throughout the DOE system from the start of processing to March 31, 1999.
- Identifying the characteristics and contaminants (e.g., Pu, Np, and ⁹⁹Tc) in the major uranium streams.
- Conducting at appropriate sites mass balance activities sufficient to identify any significant implications for personnel exposure or environmental contamination.

The ORGD¹ Mass Balance Project represents an effort to collect, verify, analyze, and interpret available data to provide an overall accountability, or site mass balance, for ORGD¹ RU streams. In addition, data on ORGD¹ processes and activities and data on Pu, Np, and ⁹⁹Tc—the primary contaminants of concern in the RU stream—have also been collected, analyzed, and interpreted. Based on this information, the project team has attempted to identify all those activities that (1) created a likelihood of workers coming into contact with concentrated RU constituents through direct physical contact or via airborne dust and/or (2) caused reportable environmental releases of concentrated RU constituents.

The project team analyzed data on receipts, shipments, inventories, product, tails, releases, and other categories—along with available analytical data—in the context of documented historical information on ORGD¹ processes and activities. Understanding of GDP processes known to concentrate Pu, Np, and ⁹⁹Tc and of GDP processes and activities known to create potential for exposure to these RU constituents provided additional context for analysis. By correlating mass balance data, analytical data, health physics data, environmental sampling data, and historical information on ORGD¹ processes, the team was able to identify specific processes, locations, and time periods of importance for potential worker exposure or environmental contamination. These processes, locations, and time periods became the focus of

¹ Following the shutdown of ORGD¹ in 1987, the facility was known as the Oak Ridge K-25 Site. In 1997, it became the East Tennessee Technology Park (ETTP).

additional assessment to determine the situations that had the potential to create exposure hazards for workers and/or significant environmental contamination.

II. RECYCLED URANIUM AT ORGDP

Receipts

For purposes of this project, RU has been defined as any uranium that has been irradiated in a reactor and as a result contains TRU (e.g., Pu and Np) and fission products (e.g., ⁹⁹Tc). The methodology applied in this project for identifying ORGDP's involvement with the flow of RU materials involves: (1) the source site and (2) the ²³⁵U assay of the material. Sites identified as RU candidate source sites are the U.S. government facilities at Hanford and Savannah River that operated production reactors and used chemical separation processes to extract uranium from irradiated fuel, Harshaw Chemical Company, and foreign customers for U.S enrichment services. Secondary sites providing RU to ORGDP included Paducah Gaseous Diffusion Plant (PGDP), Portsmouth Gaseous Diffusion Plant (PORTS), and the Oak Ridge National Laboratory (ORNL).

ORGDP received a total of 18,654 MTU of RU through three primary pathways:

- **Receipts of 16,268 MT** of RU oxide provided as feed to ORGDP by Hanford, Savannah River, and Harshaw Chemical Company. This oxide was processed in the ORGDP feed production facility.
- **Receipts of 1,294 MT** of RU as UF₆ feed from commercial enrichment customers (primarily nuclear utilities in France, the United Kingdom, and Germany). From 1969 to 1988, 807 MTU was fed to the ORGDP cascade; 486 MTU was shipped to PGDP in 1986; and 1 MTU was returned to France in 1988.
- **Receipts of 1,092 MT** of RU as UF₆ feed from PGDP, ORNL, and PORTS (99.2% from PGDP) during 1953 to 1970. This material was fed into the ORGDP cascade.

Shipments

RU streams exited ORGDP via several pathways:

- Shipment to PGDP and PORTS of RU converted to UF₆ or UF₄.
- Shipment of RU fluorination tower waste ashes to PGDP (which subsequently shipped them to Fernald)
- Shipment of product enriched in the ORGDP cascade to the Y-12 Plant, PORTS, and to private-sector companies fabricating fuel for commercial enrichment customers.
- Shipment of tails from the ORGDP enrichment cascade to PGDP for additional "stripping" in the PDGP cascade.
- Shipment of RU from commercial enrichment customers to PGDP after ORGDP was placed on standby (without re-enriching the RU in the ORGDP enrichment cascade).
- Shipment of cylinder heels at ORGDP to PGDP after ORGDP was placed on standby.

ORGDP shipped a total of 12,141 MT of RU to the following sites:

- PGDP 11,629 MTU
- PORTS 301 MTU
- Y-12 Plant 189 MTU
- ORNL 8 MTU
- Savannah River 11 MTU
- Fernald 2 MTU
- Foreign 1 MTU

Feed and Material Unaccounted For

ORGDP fed 5,915 MT of RU into the ORGDP cascade. Cumulative losses and material unaccounted for (MUF) for RU material at ORGDP totaled 598 MTU. Current inventory at ORGDP is 0. The RU mass balance for ORGDP is summarized in Table ES-1 and Figure ES-1.

Table ES-1. ORGDP RU Mass Balance

Category	MT of RU
ORGDP shipments	12,141
Feed to ORGDP cascade	5,915
Cumulative losses and RU material unaccounted for (MUF)	598
Subtotal	18,654
ORGDP receipts	18,654

III. CONSTITUENTS (Pu, Np & ⁹⁹Tc) IN RU

The 18,654 MTU of RU received by ORGDP is estimated to have contained the following quantities of the RU constituents of concern:

- Pu: 71.5 g (based on data from RU receipts obtained from correspondence of the ORGDP Laboratory Superintendent). Of this 71.5 g, only 0.01 to 0.04 g is projected to have entered the ORGDP cascade. The overwhelming majority of Pu was concentrated in the ash from the feed plant, and a small fraction was retained as cylinder heels. The ORGDP mass balance for Pu is summarized in Figure ES-2.
- Np: 9 kg (based on ORNL composite sample analysis prior to 1957 and PGDP sample analysis from 1957 to 1967). Of this 9 kg, 0.8 kg is estimated to have entered the ORGDP cascade, along with up to 0.17 kg of Np that was fed to the ORGDP cascade in PGDP enriched product. Approximately 75% of the Np received by ORGDP in RU UO₃ is estimated to have remained in feed plant ash and cylinder heels. Almost 1.5 kg of Np was shipped to PGDP in UF₆ from the ORGDP feed plant. Analysis for Np performed by ORNL in 1955 and early 1957 on composite samples of Hanford and Savannah River RU show much higher concentrations of Np (0.78 ppm Np average) than subsequent analysis reported by Smith (0.24 ppm Np average) for the period from mid-1957 through 1967. This estimate

is based on using the ORNL analysis for estimated Np concentration during 1952 through mid-1957 and the Smith analysis for the period from mid-1957 through 1963, when shipments from Hanford and Savannah River to ORGDP ceased. The ORGDP mass balance for Np is summarized in Figure ES-3.

- ^{99}Tc : 135 kg (based on measurements performed from 1959 to 1973 on Tc content in RU from Hanford and Savannah River). Of this 135 kg, 45 kg is estimated to have entered the ORGDP cascade in the RU feed stream—along with up to 165 kg of ^{99}Tc contained in PGDP enriched product (based on PGDP data for 1972–1982 and ORGDP measurements of ^{99}Tc in PGDP product during 1962–1963). Approximately 70 kg of ^{99}Tc was shipped to PGDP in UF_6 from the ORGDP feed plant. In the ORGDP cascade, ^{99}Tc tended to accumulate at the top of the cascade or to migrate to the purge cascade points at the high end of the plant configuration, where it was trapped and/or vented. The ORGDP mass balance for ^{99}Tc is summarized in Figure ES-4.

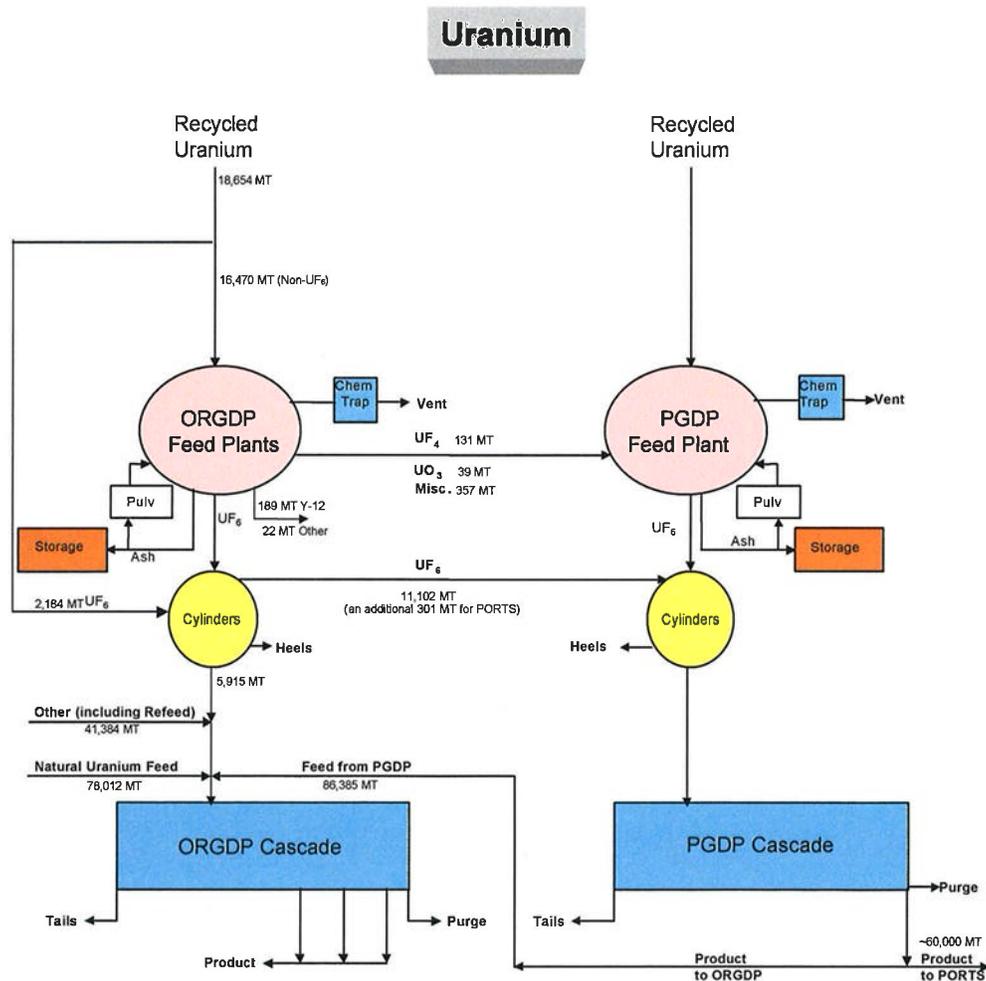
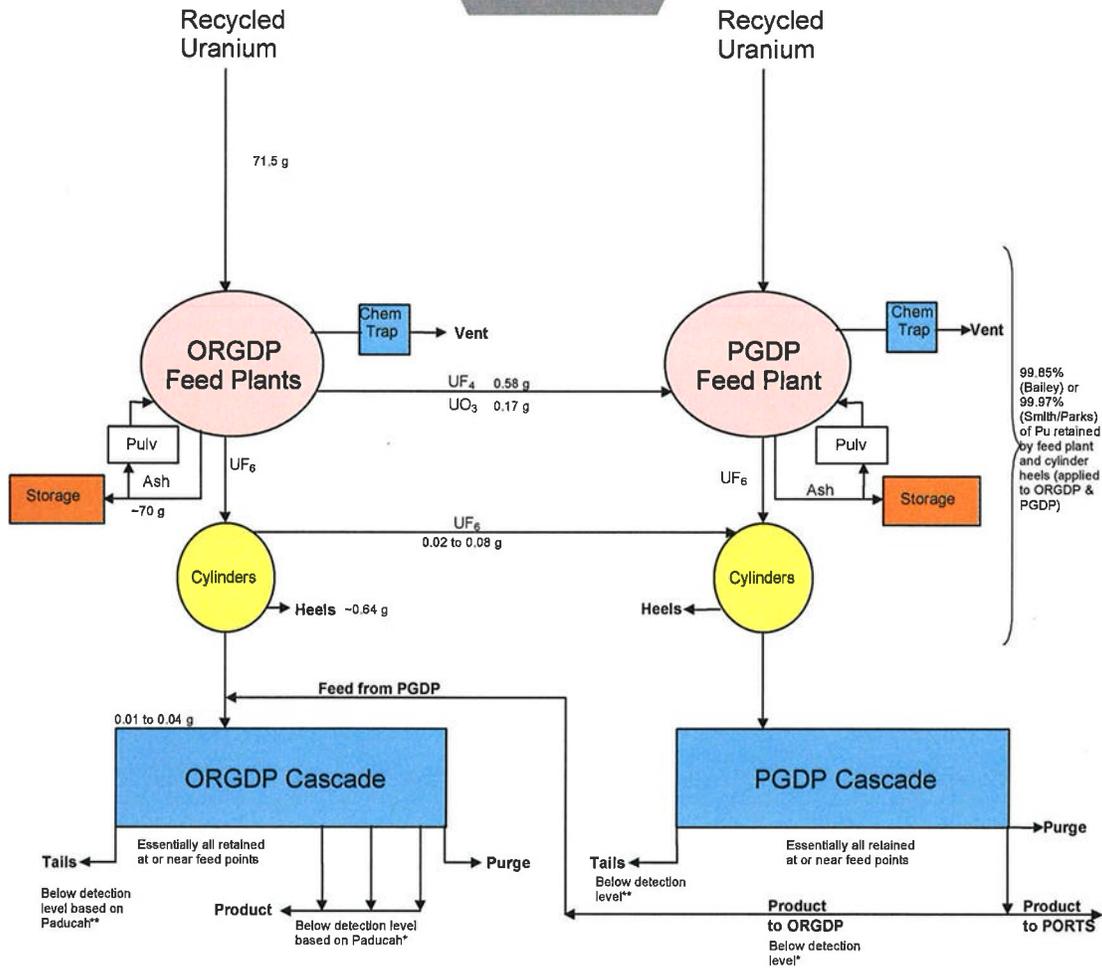


Fig. ES-1. Summary of Recycled Uranium Flow.

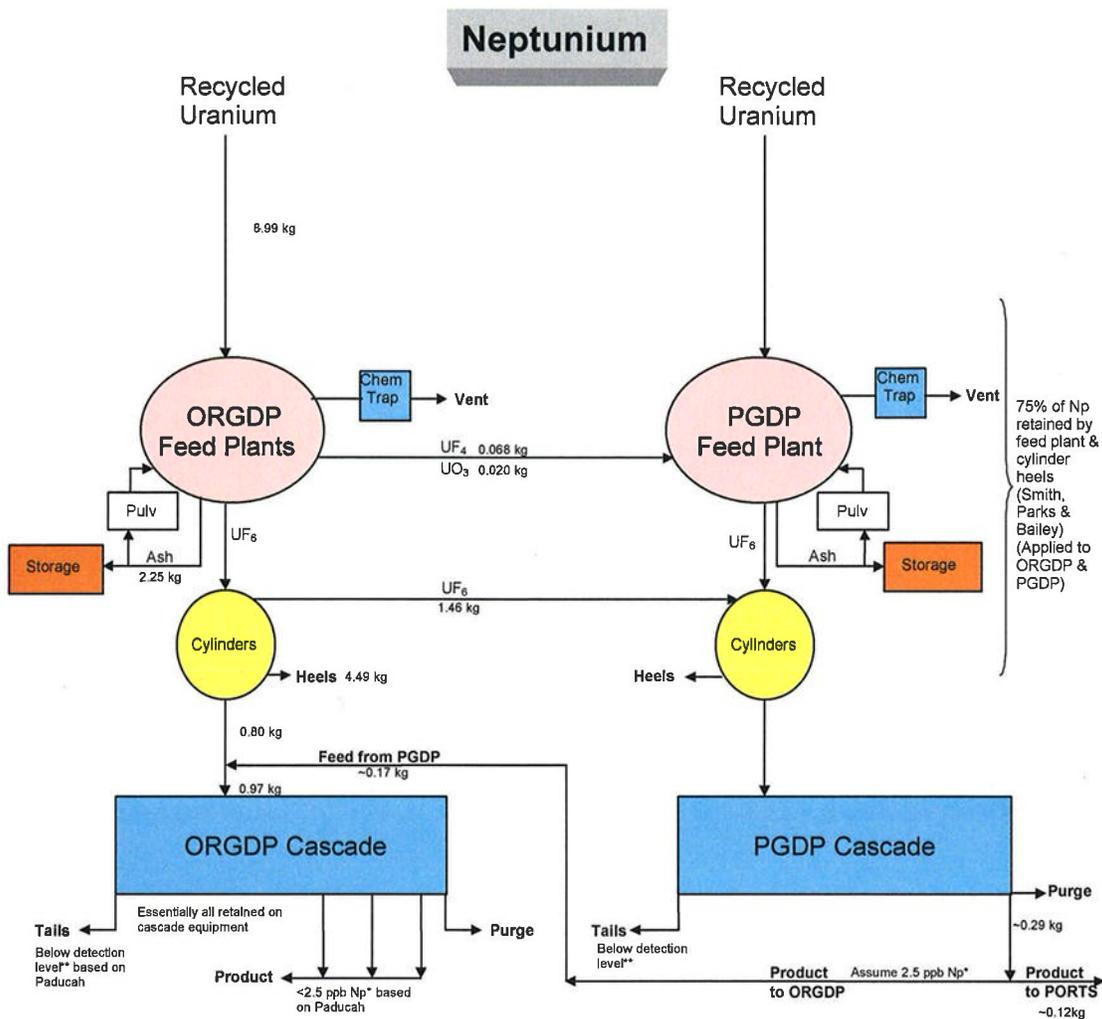
Plutonium



**Three product cylinders measured in 1973. Sixty product cylinders measured between 1975 - 1982; all were below detection level of 0.05 ppb initially and 0.01 ppb after 1980 except two cylinders, one showing 0.06 ppb and one showing 0.02 ppb (Smith).*

***Two tails cylinders measured in 1973 <.01 ppb Pu. Routine measurements since 1975 show <0.01 ppb Pu detection level (Smith).*

Fig. ES-2. ORGDP Mass Balance for Plutonium.

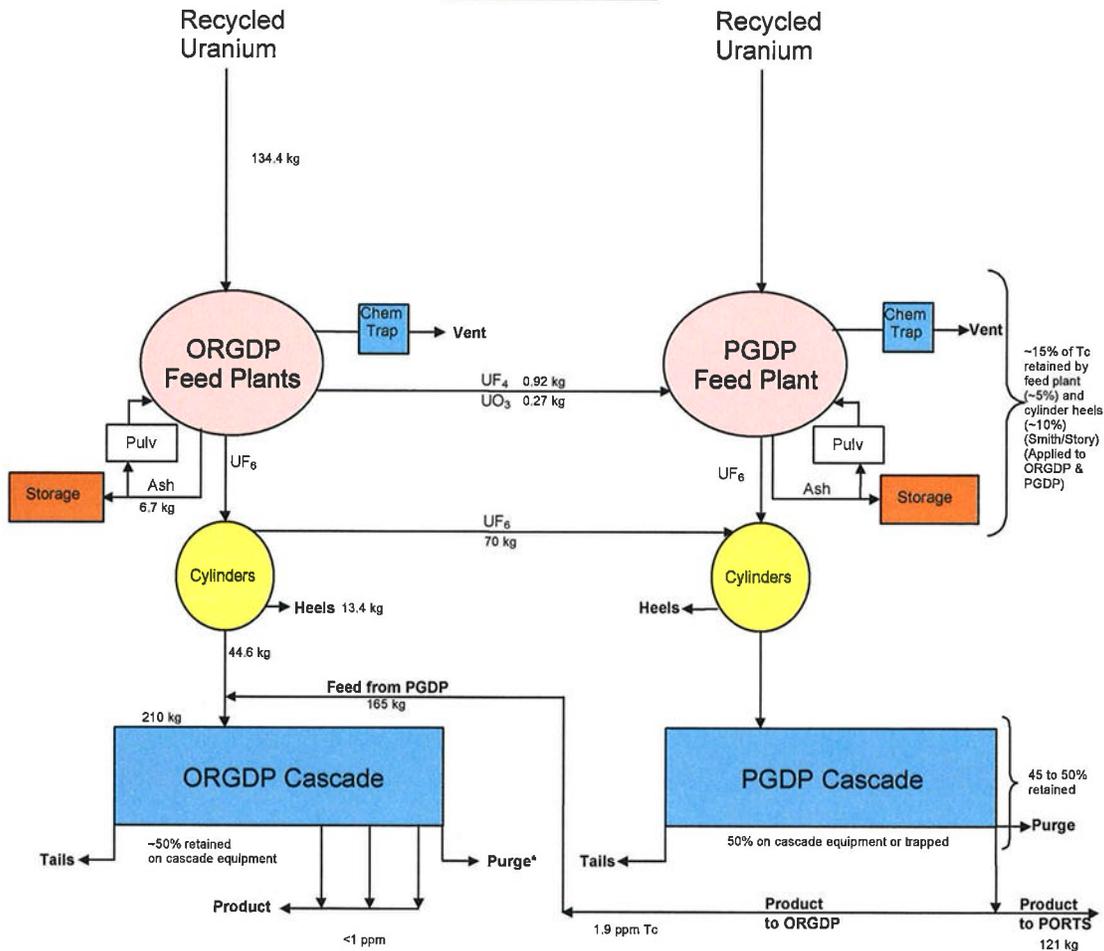


*60 product cylinders analyzed for Np at Paducah; a few exceeded 5 ppb detection level; highest measurement 27 ppb; most cylinders showed undetectable levels of Np; i.e., <1 and 5 ppb detection levels used (Smith). Assume average Np concentration at Paducah was half of 5 ppb detection level.

**40 tails cylinders analyzed for Np at Paducah; all were below 1 & 5 ppb detection levels (Smith).

Fig. ES-3. ORGDP Mass Balance for Neptunium.

Technetium



**Most of the remaining Tc from the ORGDP cascade (up to ~110 kg) is projected to be in purge cascade equipment, i.e., the K-311-1, K-310-3 system and the K-402-8, K-402-9 system or in the trapped material. A significant quantity of Tc was removed from the purge system by trapping, but the specific quantity is not reported. Very little Tc is expected to have been included in the Product, certainly <1 ppm. Tc in the tails stream is expected to be below detectable levels.*

Fig. ES-4. ORGDP Mass Balance for Technetium.

IV. POTENTIAL FLOW PATHS OF RU WITHIN ORGDP

Once an RU stream entered ORGDP, RU constituents of concern had the potential to reach various facilities and equipment via pathways associated with:

- Oxide conversion to UF₆ for feed
- Cascade buildings and operations
- Uranium recovery operations
- Analytical laboratories

The potential pathways associated with each of these groups of operations are described in the following sections.

Oxide Conversion to UF₆ for Feed Pathways

The process of converting RU oxide to UF₆ for feed for the ORGDP enrichment cascade involved the following potential pathways:

- Unpacking, feeding, and sampling of UO₃
- Collecting ash for uranium recovery and cleaning fluorination tower filters
- Uranium recovery from ash
- Maintenance and repair of fluorination tower and associated equipment

Cascade Buildings and Operations Pathways

ORGDP enrichment cascade operations involved the following potential pathways:

- Feeding UF₆ from cylinders to cascade
- Inadvertent releases of UF₆ within cascade buildings or from piping
- Withdrawal of product
- Withdrawal of tails
- Venting process gas to atmosphere
- CIP/CUP and other equipment removal

Uranium Recovery Operations Pathways

Uranium recovery operations involved the following potential pathways:

- Cleaning heels from UF₆ feed cylinders
- Decontamination of equipment
- Processing of wastes for uranium recovery
- Handling of scrap metal from equipment
- Removal and storage of pond sludge
- Thermal drying and repackaging of pond sludge
- Recovery of uranium deposits from process equipment

- Servicing cascade chemical traps
- Discharge of wastes associated with recovery processes to holding ponds

Analytical Laboratories

Because of the protocols and processes involved in analytical laboratory analysis at ORGDP, these operations created no significant pathways for RU.

V. PROCESSES OR FACILITIES THAT INVOLVED POTENTIAL WORKER EXPOSURE TO RU CONSTITUENTS

Processes and facilities that involved potential worker exposure to RU constituents coordinate closely with the pathways for the flow of RU within ORGDP described in Section IV. Table ES-2 summarizes the activities that were rated by the ORGDP Site Team as “High” in occupational exposure potential—and that consequently have significant implications for potential personnel exposure. For each activity, the table includes information on location, time frame, and RU constituents of concern. (A complete summary of activities at ORGDP with potential for worker exposure to RU is provided in Table 2.4-1.)

Table ES-2. Activities Rated High in Exposure Potential

Location	Activity	Time Frame	Constituents	Occupational Exposure Potential
1. Oxide Conversion				
K-1131 K-1420	1A. Unpacking, feeding of UO ₃ to process, operation and pulling samples * Exposure potential would have been high for brief periods in Jan-Apr 1953 when Pu ranged as high as 40 ppb in material from Hanford	1952-1961 1960-1963	Estimated levels in UO ₃ 520 ppb Np 4.4 ppb Pu 7,800 ppb Tc 170 ppm ²³⁶ U	Moderate*
K-1131 K-1420	1B. Collecting ash for uranium recovery and cleaning of tower filters	1952-1961 1960-1963	Estimated levels in ash 13,000 ppb Np 440 ppb Pu 40,000 ppb Tc 170 ppm ²³⁶ U	High
K-1231 K-1410	1C. U recovery from ash, processes included ash pulverizer	1952-1963 1952-1962	Estimated levels in ash 13,000 ppb Np 440 ppb Pu 40,000 ppb Tc 170 ppm ²³⁶ U	High
K-1131 K-1410	1D. Maintenance and repair of fluorination tower and associated equipment	1952-1961 1952-1962	Estimated levels 13,000 ppb Np 440 ppb Pu 40,000 ppb Tc 170 ppm ²³⁶ U	High

VI. PROCESSES OR FACILITIES THAT INVOLVED POTENTIAL ENVIRONMENTAL CONTAMINATION

Process knowledge and a review of documentation narrowed activities that involved potential environmental contamination by the RU constituents of concern to two activities:

- Venting of ^{99}Tc to the atmosphere from the ORGDP enrichment cascade
- Discharges of RU constituents in sludge primarily from the K-1420 decontamination facility to the K-1407-B and -C holding ponds

VI. CONCLUSIONS

Potential Personnel Exposure

The ORGDP Site Team's analysis of ORGDP activities that would have involved potential worker exposure to the RU constituents of concern identified three activities that the team rated "High" in occupational exposure potential and one other activity that was rated high for a brief period over four months in 1953 (Table ES-2). These activities represent the set of ORGDP processes that the Site Team believes involve significant implications for personnel exposure to RU constituents.

With the exception of the unpacking, feeding, and sampling of UO_3 (which only presented "High" occupational exposure potential during a brief period), the occupational exposure potential resulted primarily from hazards posed by fluorination tower ash. An examination of the activities with significant implications indicates that they occurred at the following four locations during the designated time frames:

- K-1131 feed facility (1952–1961)
- K-1231 ash pulverization and uranium recovery facility (1952–1963)
- K-1410 decontamination and uranium recovery facility (1952–1962)
- K-1420 feed facility (1960–1963)

Although both K-1131 and K-1420 performed feed facility functions, K-1131 processed much greater quantities of RU during 1952–1961 than the relatively small portion of K-1420 devoted to feed production did during 1960–1963.

Early in its existence, ORGDP implemented a worker protection program that included worker radiological protection. This program incorporated elements such as personnel protective equipment, personnel monitoring, environmental monitoring, work location surveys, work-time limits on jobs with penetrating radiation, excretion rate limits, periodic examinations of personnel, and Plant Action Level limits. The inhalation of radioactive materials was recognized as the most important source of possible exposure at ORGDP. Consequently, administrative controls were primarily designed to guard against associated hazards.

Worker protection measures in place at ORGDP likely provided substantial mitigation to the risks introduced by the activities rated as "High" in occupational exposure potential. However, dose assessment studies may be warranted as a follow-on activity to provide a more detailed assessment of worker exposure.

1.0 OAK RIDGE GASEOUS DIFFUSION PLANT MASS BALANCE PROJECT

1.1 PROJECT OVERVIEW

This report has been prepared to summarize the findings of the Oak Ridge Gaseous Diffusion Plant (ORGD¹) Mass Balance Project and to support preparation of associated U. S. Department of Energy (DOE) site reports. The project was conducted to support DOE efforts to assess the potential for health and environmental issues resulting from the presence of transuranic (TRU) elements and fission products in recycled uranium (RU) from reactor returns that was processed by DOE and its predecessor agencies. The U.S. Government used uranium in fission reactors to produce plutonium and tritium for nuclear weapons production. Because uranium was scarce relative to demand when these operations began almost 50 years ago, the spent fuel from U.S. fission reactors was processed to recover uranium for recycling.

Uranium that has been irradiated in reactors contains TRU elements [e.g., plutonium (Pu) and neptunium (Np)] and fission products [e.g., technetium-99 (⁹⁹Tc)]. Following chemical processing to recover uranium for reuse, trace quantities of Pu, Np, and ⁹⁹Tc continue to be present in the RU stream. These contaminants make the RU stream more radioactive than natural uranium. The processing and re-enrichment of RU thus may potentially introduce health and environmental consequences beyond those associated with the uranium stream.

In response to these concerns, DOE initiated an effort to identify all situations in which the processing of RU by DOE and its predecessor agencies could have created exposure hazards for workers and/or significant contamination to the environment. The first step in this process involves the "mass balance review." The mass balance review attempts to determine how much RU was generated by the U.S. Government during a period of approximately 47 years and to determine how it was distributed, processed, and used. DOE's reconstruction of the historical flow and processing of RU has three fundamental elements:

- Determining annual mass flow of RU throughout the DOE system from the start of processing to March 31, 1999.
- Identifying the characteristics and contaminants (e.g., Pu, Np, and ⁹⁹Tc) in the major uranium streams.
- Conducting at appropriate sites mass balance activities sufficient to identify any significant implications for personnel exposure or environmental contamination.

The DOE mass balance review includes U.S. Government sites that were sources for RU (i.e., that processed irradiated fuel to recover uranium for recycling); sites that re-enriched the RU stream in the fissile ²³⁵U isotope; sites that manufactured weapons components; and other affected sites. As the first U.S. gaseous diffusion plant (GDP) for enriching uranium in the ²³⁵U isotope for weapons and for commercial nuclear fuel, ORGD had significant involvement

¹ Following the shutdown of ORGD in 1987, the facility was known as the Oak Ridge K-25 Site. In 1997, it became the East Tennessee Technology Park (ETTP).

with the flow of RU materials from and to other sites. ORGDP's involvement with other sites included:

- Receiving RU from U.S. Government facilities at Hanford and Savannah River and from Harshaw Chemical Company, following use of chemical separation processes to extract uranium from irradiated fuel.
- Receiving RU from other U.S. GDPs—the Paducah Gaseous Diffusion Plant (PGDP), which shipped RU material as UF_6 feed to ORGDP, and the Portsmouth Gaseous Diffusion Plant (PORTS), which provided much smaller quantities of RU as UF_6 feed.
- Receiving RU from commercial enrichment customers (primarily nuclear utilities in France, the United Kingdom, and Germany).
- Receiving partially enriched UF_6 product from PGDP that contained certain RU constituents (although this PGDP-enriched product was technically not RU).
- Converting RU received to uranium tetrafluoride (UF_4) and to uranium hexafluoride (UF_6) for use as GDP feed.
- Shipping RU converted to UF_6 or UF_4 to PGDP and PORTS.
- Shipping RU fluorination tower waste ashes from the UF_6 conversion process to PGDP (which subsequently shipped them to Fernald).
- Shipping product enriched in the ORGDP cascade to the Y-12 Plant, PORTS, and to private-sector companies fabricating fuel for commercial enrichment customers.
- Shipping tails from the ORGDP enrichment cascade to PGDP for additional “stripping” in the PGDP cascade.
- Shipping RU from commercial enrichment customers to PGDP for storage after ORGDP was placed on standby (without re-enriching the RU in the ORGDP enrichment cascade).
- Shipping cylinder heels to PGDP after ORGDP was placed on standby.

ORGDP began gaseous diffusion enrichment production in 1945. The subsequent processing of RU, which began in 1952, impacted a broad range of processes and activities in facilities and locations across the ORGDP site. Facilities with significant involvement in RU processing included UF_6 feed production facilities; a waste ash pulverization and uranium recovery facility; decontamination and uranium recovery facilities; facilities fed by waste streams from decontamination facilities; other facilities performing more limited uranium recovery and decontamination activities; and the ORGDP enrichment cascade, which operated in a variety of different configurations over time.

In 1985, with an overcapacity of enrichment capabilities, ORGDP was placed on standby status. The plant was officially shut down in 1987. Recently, DOE has initiated a program of reindustrialization at the site, which in 1997 became known as the East Tennessee Technology Park (ETTP). ETTP also serves as the base of operations for environmental activities at facilities managed by DOE Oak Ridge Operations (DOE-ORO).

The ORGDP Mass Balance Project represents an effort to collect, verify, analyze, and interpret available data to provide an overall accountability, or site mass balance, for ORGDP RU streams. In addition, data on ORGDP processes and activities and data on Pu, Np, and ^{99}Tc —the primary contaminants of concern in the RU stream—have also been collected, analyzed, and interpreted. Based on this information, the project team has attempted to identify all those activities that (1) created a likelihood of workers coming into contact with concentrated

RU constituents through direct physical contact or via airborne dust and/or (2) caused reportable environmental releases of concentrated RU constituents.

1.2 PURPOSE AND SCOPE

The purpose of the ORGDP Mass Balance Project is to support DOE's efforts to identify all situations in which the U.S. Government processing of RU could have created exposure hazards for workers and/or significant contamination to the environment. Following guidance provided in DOE's *Historical Generation and Flow of Recycled Uranium in the DOE Complex: Project Plan*, the ORGDP project team has focused on:

- Describing the amounts, characteristics, and constituents of the incoming and outgoing RU streams at ORGDP.
- Understanding the historical processes, product specifications, and process activities that concentrated the primary RU constituents of concern (Pu, Np, and ⁹⁹Tc).
- Determining the facilities and processes that could cause worker exposures or lead to measurable environmental contamination.
- Performing annual mass balances for RU and for Pu, Np, and ⁹⁹Tc to the degree existing mass and analytical data permit.

The project has identified and reviewed RU streams at ORGDP from the initial introduction of RU into the plant until March 31, 1999. At ORGDP, these streams encompassed a broad spectrum of material forms, including uranium dioxide (UO₂), uranium trioxide (UO₃), UF₆, UF₄, feed conversion ash, scrap, and a wide variety of other associated wastes. The RU flow has been traced from receipt by ORGDP until ultimate disposition by the plant. Efforts have also been made to identify all other DOE sites with which ORGDP interfaced via RU streams and to determine how the plant worked with them.

To place emphasis on the RU flows that most warrant attention, the project team has followed the guidance of the DOE *Project Plan* and identified the RU flows that posed no significantly increased hazard. These RU streams contained Pu, Np, and ⁹⁹Tc constituents that would have provided an incremental radiological dose of significantly less than 10% of the dose provided by the uranium itself. These streams also represented final product or waste forms, with no additional processing anticipated. DOE has deemed such end products to be outside the scope of the mass balance project. The process for identifying these RU streams, which include ORGDP enrichment cascade product and tails streams, is documented in this report.

1.3 PROJECT IMPLEMENTATION STRATEGY

An interdisciplinary project team was formed to conduct the ORDGP Mass Balance Project. Team members included individuals with extensive experience in DOE uranium enrichment operations; uranium processing; nuclear materials control and accountability; health and safety at DOE facilities; nuclear engineering; the nuclear fuel cycle; statistical analysis; and data and information management. Guided by information provided in the DOE *Project Plan* (e.g., the Question Set and the Site Report Outline), the team developed a strategy and process for identifying, collecting, organizing, and analyzing available data relevant to the project. Leads were established for major project areas (e.g., site historical overview, RU mass flow, mass balance activities, and constituents in RU), and team members were designated to research and abstract information on specific topics. Formal team meetings were held twice each week to track progress and discuss project issues.

The project team searched a variety of data collections and libraries at ETTP and other Oak Ridge Complex locations to identify and retrieve data. Major data sources consulted and analyzed included:

- Nuclear Materials Control and Accountability (NMC&A) Material Balance Reports, including shipping, receiving, and inventory records.
- Nuclear Materials Management and Safeguards System (NMMSS) data.
- ORGDP historical site reports, including quarterly plant reports and engineering progress reports.
- ORGDP reports describing facilities and production processes.
- Plant records, including employment and health physics records.
- ORGDP production records.
- ORGDP analytical laboratory records.
- Correspondence between shippers and receivers.
- Historical DOE and contractor reports addressing RU.
- More recent (i.e., post-1990) health physics reports on the site.
- More recent environmental survey reports on the site.
- Interviews with ORGDP personnel or with personnel with direct experience with enrichment operations.

Where NMC&A data was unavailable, attempts were made to obtain NMMSS data to fill the gaps. Team members worked with representatives of other DOE sites with which ORGDP interfaced via RU streams to verify shipping and receiving data and reconcile differences between sites. Any unresolved data discrepancies will be turned over to the DOE Working Group Team for assistance with resolution.

In addition to consulting the ORGDP analytical laboratory records, the team found it necessary to glean analytical data from a wide variety of sources, including the ORGDP historical quarterly reports and health physics reports. Correspondence between shippers and receivers also provided a record of comparisons of sets of analytical data, the first set developed by the site shipping RU and the second by the site receiving the material. In addition, analytical data has been compared and shared with other appropriate DOE sites.

For some areas that presented gaps in data that could not at present be filled by research, the project team developed estimates for quantities of RU and/or constituents. These estimates are based on extrapolations from actual data and represent (1) application of known data from similar material and/or circumstances or (2) application of known data from a specific time period over a longer or a shorter period of time. All such estimates and their bases are specifically identified in this report.

The project team analyzed data on receipts, shipments, inventories, product, tails, releases, and other categories—along with available analytical data—in the context of documented historical information on ORGDP processes and activities. Understanding of GDP processes known to concentrate Pu, Np, and ⁹⁹Tc and of GDP processes and activities known to create potential for exposure to these RU constituents provided additional context for analysis. By correlating mass balance data, analytical data, health physics data, environmental sampling data, and historical information on ORGDP processes, the team was able to identify specific processes, locations, and time periods of importance for potential worker exposure or environmental contamination. These processes, locations, and time periods became the focus of additional assessment to determine the situations that had the potential to create exposure hazards for workers and/or significant environmental contamination.

The ORGDP project team has made an effort to identify and resolve discrepancies between the findings presented in this report and information found in other DOE site reports and previous DOE historical reports. This report attempts to identify major discrepancies and describe their resolutions.

2.0 SITE HISTORICAL OVERVIEW

2.1 SITE DESCRIPTION

2.1.1 Background

2.1.1.1 Gaseous Diffusion and the Need for Uranium Enrichment

In natural uranium, the fissile ^{235}U isotope accounts for only 0.711 weight percent (wt %) of the total uranium; the ^{238}U isotope accounts for more than 99%. Both nuclear weapons production and commercial nuclear power generation require higher concentrations of the fissile ^{235}U . The process of increasing the ^{235}U concentration in a uranium stream—and decreasing the concentration of ^{238}U —is known as uranium enrichment. ORGDP enriched uranium as UF_6 gas via the gaseous diffusion process for military purposes from 1945 to 1964 and for commercial purposes from 1965 until the plant was placed on standby in 1985.

In the gaseous diffusion process, a UF_6 feed stream having both ^{235}U and ^{238}U molecules is pumped into a barrier consisting of numerous porous tubes. The less massive $^{235}\text{UF}_6$ diffuses through the barrier slightly faster than the $^{238}\text{UF}_6$. The slightly enriched UF_6 stream thus created is fed to many subsequent stages of equipment, and the process is repeated until the desired level of ^{235}U enrichment is achieved. The series of connected stages is referred to as the enrichment cascade. The product produced by the gaseous diffusion enrichment process is UF_6 enriched in the ^{235}U isotope. The by-product or waste stream, which is referred to as depleted UF_6 , or “tails,” contains less ^{235}U than is found in nature.

All uranium fed into the gaseous diffusion enrichment cascade must be in the form of UF_6 . The uranium feed is derived from two primary sources:

- Natural uranium that is mined as a uranium bearing ore and processed to an oxide, typically near the mine, and subsequently converted to UF_6 at a feed plant.
- Recycled uranium (RU) that has been used in plutonium or tritium production, research, or in commercial nuclear power reactors and has been processed to recover the uranium for reuse. RU contains trace quantities of TRU elements and fission products [generally at the level of parts per million (ppm) to parts per billion (ppb) in relation to the uranium].

2.1.1.2 Origins of ORGDP

ORGDP had its origins as one of three nuclear production facilities built in East Tennessee during 1942–1943 in support of the Manhattan Project. These facilities were constructed on approximately 90 square miles of undeveloped land west of Knoxville, Tennessee. Initially known as the Clinton Engineer Works military reservation, the area became known as Oak Ridge after World War II. The three Manhattan Project production facility sites were code-named Y-12 (site of an electromagnetic plant for uranium enrichment), X-10 (site of an experimental

plutonium pile and chemical separation facilities), and K-25 (the site of the gaseous diffusion plant). The first gaseous diffusion enrichment cascade was Building K-25; the names K-25 and ORGDP were synonymous throughout much of the plant's history. The K-25 enrichment cascade officially began operations in February 1945. In April 1945, construction began on K-27, a second gaseous diffusion facility built to provide low-level enrichment.

2.1.2 ORGDP Site

Located on a 1,500-acre tract approximately 11 miles west of the city of Oak Ridge, Tennessee, ORGDP eventually added three more gaseous diffusion buildings (K-29, K-31, and K-33) and encompassed more than 100 different facilities (Fig. 2.1-1). The plant ultimately became capable of enriching uranium up to 93% ^{235}U for defense purposes. Decreasing requirements for highly enriched uranium (HEU) for defense purposes resulted in the shutdown of ORGDP HEU facilities in 1964. As the U.S. Government began providing low-enriched uranium (approximately 2 to 5% ^{235}U) for commercial nuclear power reactors in the United States and other countries, ORGDP became an integral part of that effort.



Fig. 2.1-1. The ORGDP Site. The former Oak Ridge Gaseous Diffusion Plant and K-25 Site is now the East Tennessee Technology Park (ETTP).

The plant was officially shut down in 1987. Following the shutdown, the site became known as the Oak Ridge K-25 Site and served as the base for environmental management activities at the five sites managed by DOE-ORO. In 1997, the site became known as ETTP. With the initiation of DOE's reindustrialization program at the site, inactive ETTP facilities are subleased to private-sector companies by the Community Reuse Organization of East Tennessee (CROET), a private, not-for-profit organization. The Bechtel Jacobs Company LLC serves as the management and integration contractor for DOE-ORO environmental management activities that continue to be based at the site.

2.1.3 ORGDP Evolution

Except for a brief period in 1945 when Building K-25 was the only gaseous diffusion facility producing enriched uranium, the ORGDP gaseous diffusion buildings have operated as an integrated unit. For example, when K-27 came on line, K-25 and K-27 operated much like a single plant or enrichment cascade. Over ORGDP's operating history, the plant's five gaseous diffusion buildings (K-25, K-27, K-29, K-31, and K-33) were linked together in a large number of different configurations. Once PGDP and PORTS began operations, the three DOE GDP sites worked together as an integrated operation (Fig. 2.1-2). To optimize use of resources, feed and product of different assays were shipped among the sites. Generally, PGDP shipped uranium that it had enriched to a lower level to ORGDP and PORTS for further enrichment. ORGDP provided some material it had enriched to PORTS for additional enrichment. And both ORGDP and PORTS enriched material for shipment to commercial customers and to other U.S. Government facilities using enriched uranium.

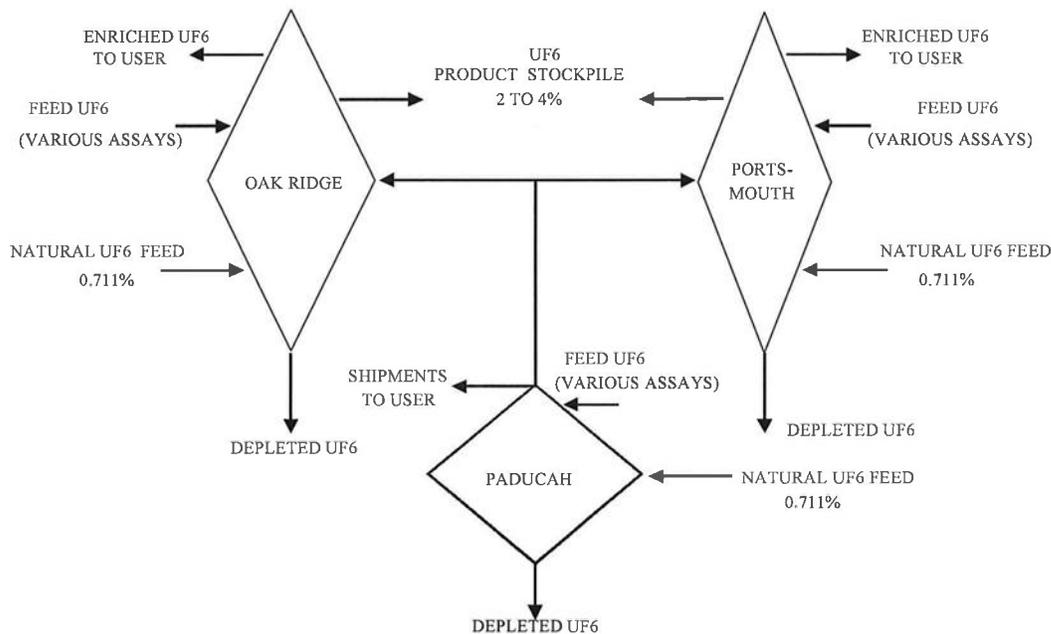


Fig. 2.1-2. DOE Gaseous Diffusion Complex.

Because process buildings at a site were connected, and feed and product moved among the GDP sites, contaminants had many potential pathways to reach various parts of the facilities. For example, ^{99}Tc introduced into a gaseous diffusion cascade in feed tends to travel up the cascade over time because it is lighter than ^{235}U . One might thus anticipate finding ^{99}Tc anywhere in the system above the feed point where the material was introduced. In addition, contaminants may have found pathways to buildings not directly involved in the GDP processes. For example, equipment may have been removed from a processing building and transferred to a non-processing building for repair. Although one can identify many potential pathways for contaminating various facilities at the site, the level of contamination that may be present is also very significant.

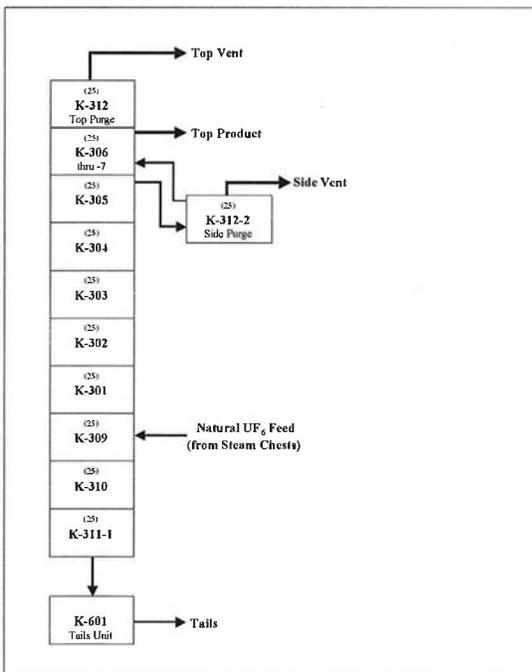
The following sections provide descriptions of the major configuration changes for the ORGDP cascade. Fig. 2.1-3 shows the locations of the principle facilities that are discussed. In reviewing these descriptions, one should view the configurations presented as the “base case” for a specific time period. Other configurations may also have been used. Factors influencing configuration variations include:

- When cells were taken off line for maintenance, the cascade would be reconfigured around the cells for the period they were out of service.
- The top product assay for any period was almost certainly not the only assay produced. Any assay below the top product assay would have been possible at any given time.
- Feed at various assays would have been fed at corresponding assay points in the cascade to avoid mixing different assays (and losing separative work).



Fig. 2.1-3. DOE Gaseous Diffusion Complex RU Facility Locations.

2.1.3.1 August 1945 to January 1946 (Fig. 2.1-4)



The original cascade configuration was established in August 1945 when all stages of the K-25 building were placed on stream. The normal (.711% ²³⁵U) feed point was in the K-309 section and was accessed via a series of steam chests. The K-601 building was the tails withdrawal facility. The top product withdrawal point was in the K-306-7 unit. The K-312 purge units, located in the cascade above the product withdrawal point, were used to separate light molecular gases (e.g., N₂, O₂) from UF₆. A side purge point was established at the top of K-305-12 to eliminate most purge gases from entering the K-306 section. K-312-3 was used as a top purge. The K-310 section and the K-311-1 section served as the tails-stripping sections of the cascade.

All feed entered into the cascade during this period was natural UF₆.

2.1.3.2 January 1946 to 1948 (Fig. 2.1-5)

In early 1946, Building K-27 construction was completed, and its units were placed on stream as quickly as feasible. The optimum K-25/K-27 cascade configuration that was established involved overlapping the stripping sections of K-25 with those of K-27 (with the K-25 stripping section K-309 at the top and the K-311-1 unit at the bottom of the stripping section). The normal feed location was in K-27 in the K-402-3 or K-402-4 units, depending on the cascade gradient. During this period, Building K-631 was placed in operation and became the tails withdrawal point. The product was shipped to Y-12 for further enrichment by the electromagnetic process. In January 1947, the product assay of ORGDP was increased from 30%U²³⁵ to 93% U²³⁵ and the Y-12 Plant electromagnetic process subsequently shut down.

All feed entered into the cascade during this period was natural UF₆.

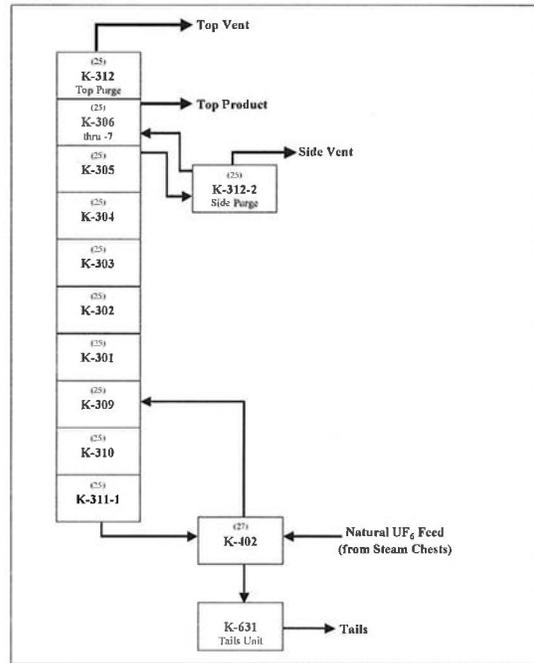


Fig. 2.1-5. Schematic Process Flow for ORGDP Cascade, 1946 – 1948.

2.1.3.3 1948 to 1951 (Fig. 2.1-6)

In order to produce 93% U²³⁵ efficiently, the ORGDP enrichment cascade had to be lengthened. This modification resulted in a significant change to the K-25/K-27 cascade configuration. To lengthen the cascade, the K-25/K-27 overlap was eliminated, and all stages were placed in series. The bottom of the cascade was K-311-1 (in Building K-25), and the tails went from this unit to Building K-631. K-631 remained the tails withdrawal point until the entire ORGDP was shut down. Above K-311-1 in the cascade was K-402 (in Building K-27) where feed from Building K-131 was introduced. Unit K-310 (in Building K-25) was fed from K-402, and the rest of the cascade above this point was in K-25. At the top of the cascade, the product withdrawal station and purge locations remained the same as in the previous period.

All feed entered into the cascade during this period was natural UF₆.

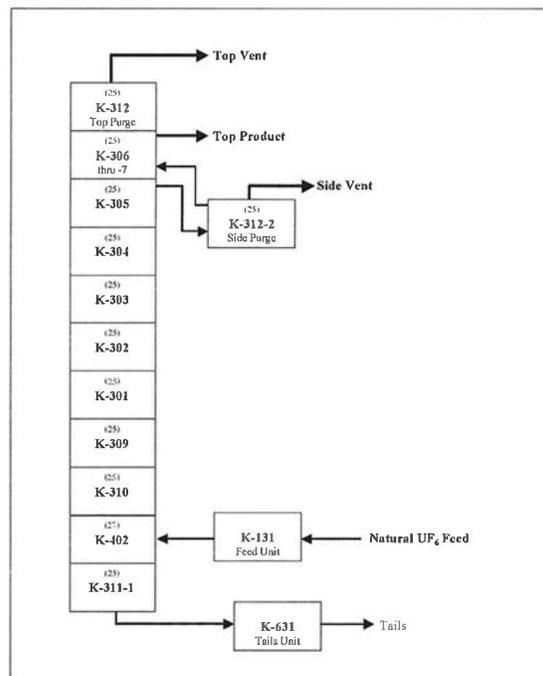


Fig. 2.1-6 Schematic Process Flow for ORGDP Cascade, 1948 – 1951.

2.1.3.4 1951 to 1952 (Fig. 2.1-7)

With demand for enriched U^{235} increasing at a rapid rate, the U.S. Government embarked on a large expansion program that included not only additions to ORGDP, but also the construction of GDPs near Paducah, Kentucky, and Portsmouth, Ohio. The third major processing building added to ORGDP was Building K-29, which was located east of K-27. The K-29 cascade was inserted into the existing cascade between the K-402-1 and K-402-2 units of K-27. There were thus units in K-27 on either side of the K-29 units. This configuration necessitated major process gas piping changes in K-27. The K-311-1 unit in K-25 remained in the bottom position of the cascade, below the K-402-1 unit in K-27. Tails still went to K-631. At the top of the K-402 units in K-27 were the K-309 units in Building K-25. The cascade feed point was shifted to the K-29 stages were thus in the tails-stripping section of the plant.

The addition of 300 K-29 stages to the cascade resulted in a further increase in light gas contaminants leaking into the cascade and the higher concentration of light gases in the upper stages of Building K-25—up to the side purge withdrawal point in K-305-12. Such concentrations can result in the loss of sensitivity in detecting air in-leakage to the cascade. Because of this concern, the side purge point was shifted from K-305-12 to K-304-5.

All feed entered into the cascade during this period was natural UF_6 .

2.1.3.5 1952 to 1954 (Fig. 2.1-8)

During 1952 to 1954, the U.S. Government's GDP expansion proceeded at a rapid pace. PGDP was brought on stream in this period. The overall optimum cascade configuration was an overlap between the PGDP and ORGDP sites. PGDP was used for the low-assay range of the enrichment process. PGDP fed normal material, as well as ORGDP tails shipped from ORGDP to PGDP. PGDP produced product above normal assay and was used as feed to ORGDP at the K-602 unit of ORGDP's new Building K-31, which was brought on line in the period because of increasing feed volumes. Normal feed was also fed into the K-602 unit.

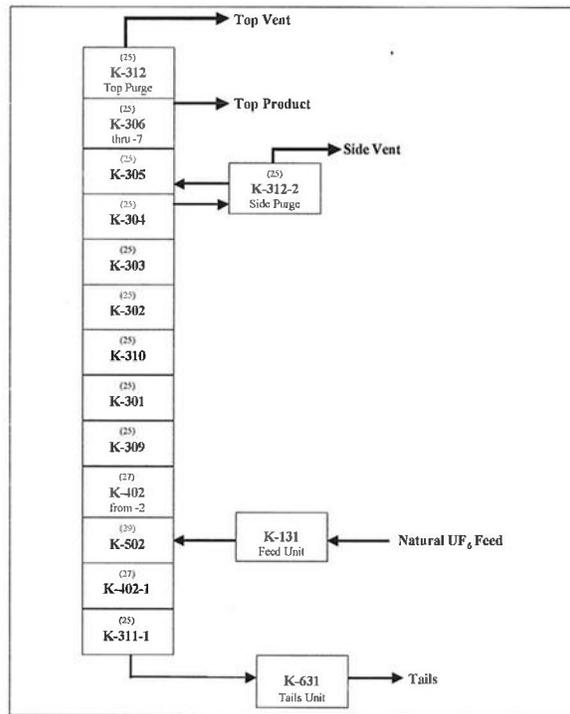


Fig. 2.1-7. Schematic Process Flow for ORGDP Cascade, 1951 – 1952.

During this period and beyond (1952-1961) ORGDP operated the on-site fluorination plant at K-1131 for both virgin and RU feed. (This facility is described in more detail elsewhere in this report.)

The K-31 stages were placed in the cascade between the K-29 stages (with K-502 at the bottom of K-29) and the K-27 stages (with K-402-1 at the top of K-27, but now the bottom of the overall cascade). The tails withdrawal point continued to be at K-631, with tails going to PGDP, as previously mentioned. The K-312-2 side purge unit was no longer adequate and was replaced by a new side purge at K-311-1 in K-25 (connected between K-309 in K-25 and K-402 in K-27). The K-312 unit continued as the top purge, and top product withdrawal continued to be at K-306 (both in K-25).

In 1952, RU was first received at ORGDP. In 1953, the first RU was fed into the ORGDP cascade.

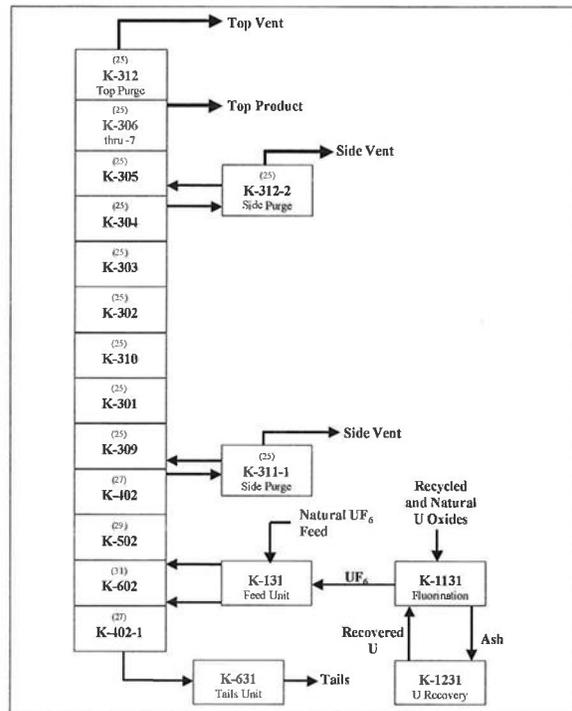


Fig. 2.1-8. Schematic Process Flow for ORGDP Cascade, 1952 - 1954.

2.1.3.6 1954 to 1957 (Fig. 2.1-9)

As the GDP expansion continued, Building K-33 was brought on stream. K-33 was integrated into the cascade between the K-602 units in Building K-31. Some of the K-602 units were now in the tails-stripping group. The area below K-602-1 was the bottom of the cascade, with tails withdrawal still performed in K-631. Normal feed and PGDP product feed to ORGDP was shifted to K-33 at the appropriate points in the cascade. The feed room constructed at K-33 proved to be much more convenient than the K-131 location.

During this period, many gas cooler leaks were experienced because of design problems. A K-101 coolant removal unit was placed in operation, with a cascade pigtail arrangement in K-303-1 for concentrating the coolant (C-816) that leaked into the cascade. The stages in K-303-1 (in Building K-25) were equipped with special barrier that permitted the coolant to

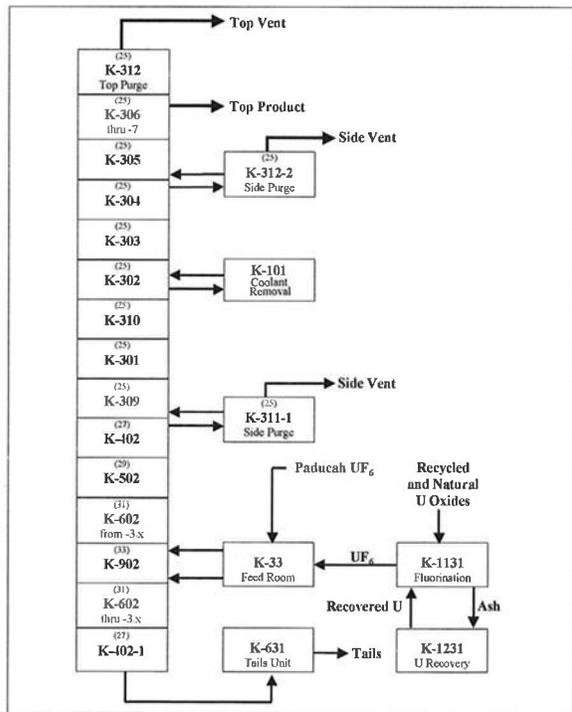


Fig. 2.1-9. Schematic Process Flow for ORGDP Cascade, 1954 - 1957.

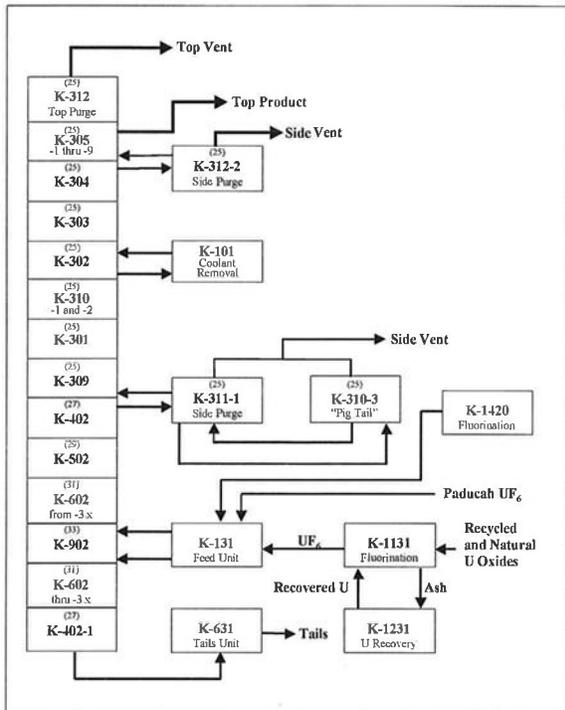


Fig. 2.1-11. Schematic Process Flow for ORGDP Cascade, 1959 – 1961.

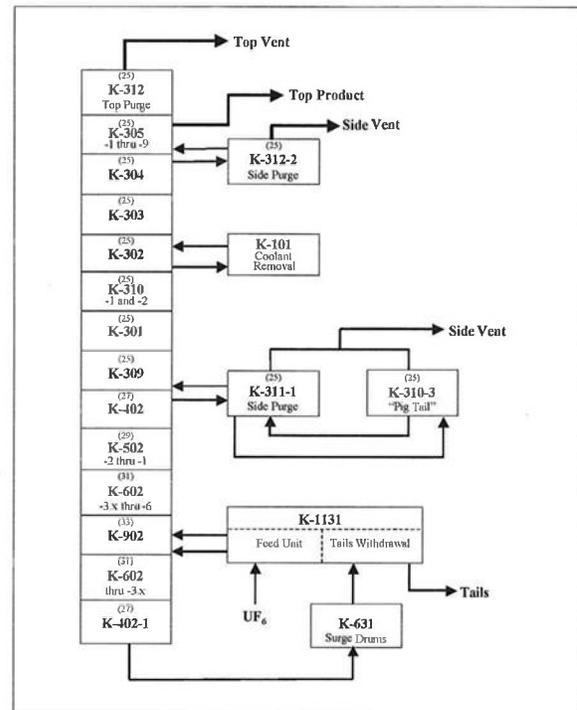


Fig. 2.1-12. Schematic Process Flow for ORGDP Cascade, 1962 – 1964.

2.1.3.9 1962 to 1964 (Fig. 2.1-12)

During 1962 to 1964, the cascade configuration remained unchanged from the previous period. The significant operational change involved the shutdown of the tails withdrawal facility in Building K-631. Tails withdrawal was shifted to Building K-1131 after the UF_6 feed production operations there were suspended. Tails were now withdrawn directly into cold traps before they were liquefied and drained in 14-ton cylinders. Also, the K-131 feed operation was terminated and transferred to Building K-1131. ORGDP feed and tails removal operations were now located in a single building.

Reactor returns were processed by ORGDP during the period, and ORGDP continued to receive product from PGDP for use as feed.

2.1.3.10 1964 to 1985 (Fig. 2.1-13 and Fig. 2.1-14)

In 1964, Buildings K-25 and K-27 were shut down—with the exception of the K-311-1 purge cascade and its K-310-3 pigtail operation (in K-25). In 1968, the K-502-3 unit in Building K-29 was shut down, and in 1977, the K-311-1 and the K-310-3 pigtail were replaced by the K-402-9 purge and the K-402-8 pigtail. The top product during the period was withdrawn from the K-413 unit. Feed and tails withdrawal in Building K-1131 continued. The bottom of the cascade was now the K-602-1 unit (in Building K-31), which tied directly into the K-631 surge drums floating on line prior to the tails withdrawal.

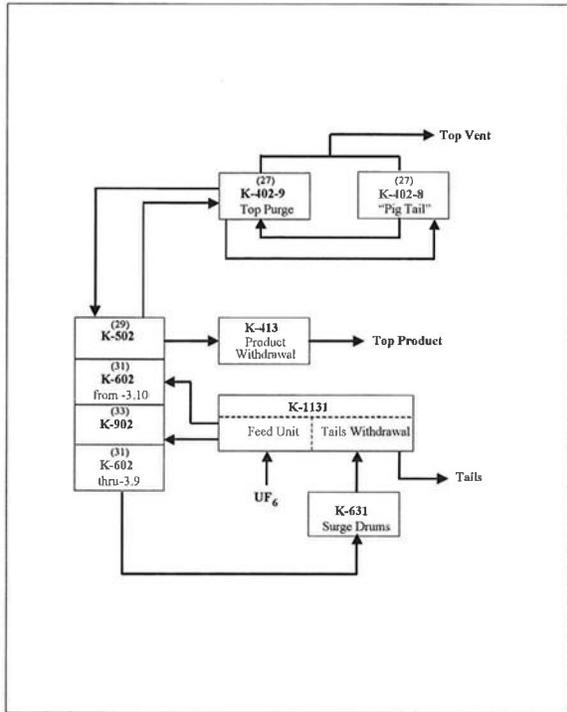


Fig. 2.1-13. Schematic Process Flow for ORGDP Cascade, 1964 – 1977.

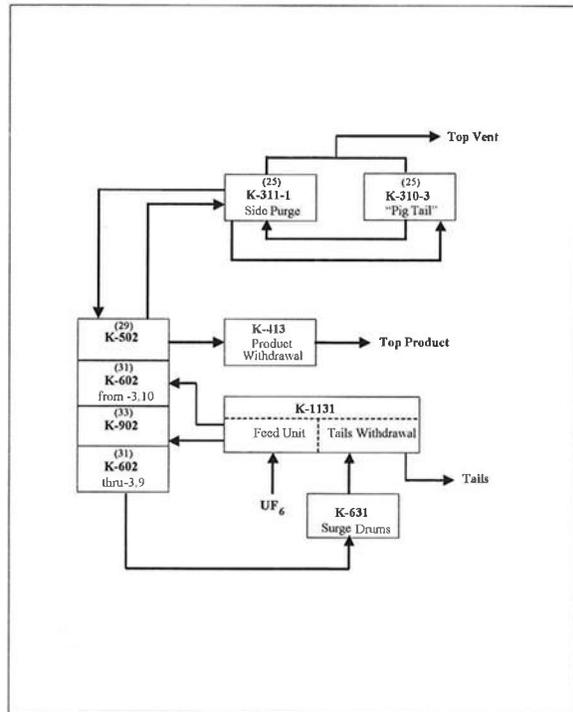


Fig. 2.1-14. Schematic Process Flow for ORGDP Cascade, 1977 – 1985.

Reactor returns were processed by ORGDP through 1984, and ORGDP continued to receive product from PGDP for use as feed. In June 1985, ORGDP was placed on standby; in 1987, the plant was permanently shut down.

2.1.3.11 Mixing of Process Equipment

There are good indications that there was very little mixing of equipment from point to point in the cascade during ORGDP's operational era. Some small parts, such as mechanical seals, could be interchanged relatively freely after reconditioning. However, because of differences in equipment sizes, compressors and converters could not be used outside their original buildings. In fact, because of special modifications, large equipment often could not be moved between units and, in some cases, could not be moved between enrichment cells.

Certain facilities that did serve the entire site could be contaminated with mixed material from all parts of the enrichment process. These facilities would include maintenance and decontamination facilities (e.g., Buildings K-1401, K-1410, and K-1420). Even within one cascade building, some equipment (such as the wet air pump, its associated seal exhaust, and the building exhaust ventilation system) served more than one unit and could be contaminated with RU material from throughout the building.

With exceptions cited in the preceding paragraph, contamination at a given point in the process buildings generally should be representative of a specific point in the enrichment process, with minimal influence of materials from other points in the process.

2.1.3.12 Improvement Programs

As previously described, the original facilities at ORGDP, PGDP, and PORTS were built and placed in operation in the late 1940s and the early to mid-1950s. Beginning circa 1956, an improvement program was undertaken to incorporate significant improvements in the separation membrane. In addition, because improvements in compressor technology had also been achieved, in the period from 1956-1962, essentially all of the compressors and converters in the low-assay portion of the cascade were replaced with higher-performance equipment. By the early 1970s, more improvements were developed that justified additional equipment change-out actions known as the Cascade Improvement Program/Cascade Upgrade Program (CIP/CUP), which continued until 1981 at ORGDP. Thus, there were large-scale equipment change-out programs collectively known as CIP/CUP in the low-assay diffusion cascades—in addition to the many exchanges of failed equipment over the course of the years. During 1951–1985, a total of 5,324 compressors, 2,983 converters, and 43,257 seals were replaced at ORGDP. This high amount of activity over many years created potential for RU contamination and exposure.

2.2 ORGDP OPERATIONS INVOLVING RU

Table 2.2-1, “ORGDP Cascade Evolution, 1945–1985” shows by time period ORGDP cascade buildings in operation and the feed, tails withdrawal, top product withdrawal, and purge points. RU was introduced into the ORGDP cascade beginning in 1953. The combination of the site evolution and the introduction of RU leads to a focus on the following operations as possible contamination points.

Table 2.2-1. ORGDP Cascade Evolution, 1945 – 1985

Period	Processing Buildings in Operation	Feed Point	Tails Withdrawal	Top Product Withdrawal	Purge Locations
Aug 1945 - Jan 1946	K-25	K-309 (K-25)	K-601 Bldg.	K-306-7 (K-25)	K-312 Top Vent K-303-12 Side Vent K-312-3 Spare Purge (all K-25)
Jan 1946 - 1948	K-25, K-27	K-402 (K-27)	Same as above	Same as above	Same as above
1948 - 1951	same	Bldg. K-131 to K-402 (K-27)	Same as above	Same as above	Same as above
1951 - 1952	K-25, K-27, K-29	Bldg. K-131 to K-502 (K-29)	Same as above	Same as above	Same as above
<i>No RU prior to 1953</i>					
1952 - 1954	K-25, K-27, K-29, K-31	Bldg. K-131 to K-602 (K-31)	Same as above	Same as above	K-312 Top Vent K-304-5 Side Vent K-311-1 Side Vent K-310-3
1954 - 1957	K-25, K-27, K-29, K-31, K-33	K-33 Feed Room	Same as above	Same as above	Same as above
1957 - 1959	Same as above	Same as above	Same as above	K-305-12 (K-25)	K-312 Top Vent K-311-1 Side Vent K-310-3
1959 - 1962	Same as above	Same as above	Same as above	K-305-1 thru -9 (K-25)	Same as above
1962 - 1964	Same as above	K-1131 Bldg.	K-1131 Bldg.	Same as above	Same as above
1964 - 1985	K-29, K-31, K-33	Same as above	Same as above	K-502 (K-29)	K-311-1 Top Purge and K-310-3 (1977) K-402-8 and K-402-9 (After 1977)

2.2.1 UF₆ Feed Preparation

UF₆ is required as feed for input into the cascade for enrichment. UF₆ feed enrichments ranged from depleted to natural to enriched wt % ²³⁵U. Over the life of ORGDP, UF₆ feed came from a variety of off-site sources, including PGDP, commercial natural UF₆ producers (including Allied Chemical in Illinois and, later, Kerr McGee in Oklahoma), foreign reactor returns, and re-feed of tails. ORGDP also had the capability to produce UF₆ feed on site.

At the Hanford and Savannah River Plant plutonium processing facilities, after the irradiation of uranium fuel in reactors to produce plutonium and tritium, chemical processes were used to recover as much Pu as possible from uranium and separate both Pu and uranium from fission products and impurities. Because the chemical separation processes were not 100% efficient, the resulting RU that was shipped primarily to PGDP or ORGDP as “purified” UO₃ had trace quantities of the TRU element ²³⁷Np and the fission product ⁹⁹Tc.

Following experimental operations in 1948, Building K-1131 (which was originally built in 1945 as a dry air plant for the K-25 cascade) was converted to a UF₆ preparation facility (Fig. 2.2-1), with production starting in 1952. From 1952 to 1960, ORGDP operated K-1131 as the on-site feed plant for both natural and RU UO₃ feed.

At the K-1131 feed plant, natural or recycled uranium (which was received as UO₃) was hydrogen reduced to UO₂. The UO₂ was hydrofluorinated to produce UF₄. The UF₄ was fluorinated in a flame tower reactor to produce UF₆ as feed for the gaseous diffusion process. The UF₆ was collected in large cylinders for transport to the K-131 cascade feed building. In 1960, the K-1420 building became involved in fluorination activities in addition to other activities related to decontamination and uranium recovery.

With the RU, no significant separation of the transuranics and fission products occurred during the reduction or hydrofluorination steps (UO₃ to UO₂ and UO₂ to UF₄). Transuranics, and to a lesser extent, fission products, were concentrated during the conversion of UF₄ to UF₆. Most of the Pu and a smaller fraction of the incoming Np formed nonvolatile compounds and were deposited with the ash. On the other hand, most of the feed ⁹⁹Tc was fluorinated to a volatile specie and was collected with the uranium in the UF₆ feed cylinders.

Metal canisters for ash collection and particulate filters to filter the UF₆ 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 the solids were size reduced in an ash pulverizer located at the west end of the building. The processed ash was

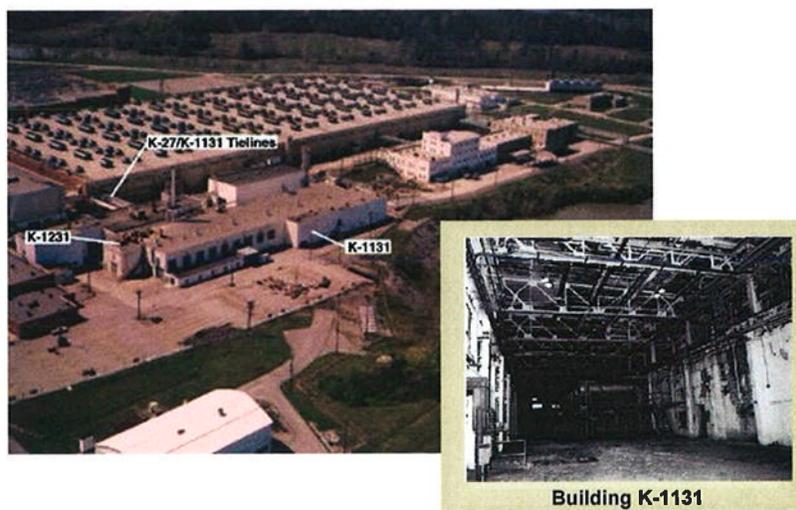


Fig. 2.2-1. K-1131 and K-1231 Exteriors and K-1131 Interior (Inset).

subsequently recycled to the fluorination tower. Some ash recovery activities were also conducted in K-1420. After successive re-feedings into K-1131 towers until it was no longer practical to recover the remaining uranium, the spent ash was discarded. Historical information indicates that the spent ash was packed and shipped to PGDP.

ORGD operated K-1131 as the on-site feed plant until 1961. Fig. 2.2-2 presents K-1131 feed production totals as recorded in the *ORGD Quarterly Reports* for each quarter reported from 1952 to 1963.¹

Beginning in 1960 (or possibly earlier), as a part of its ORGD decontamination and uranium operations, Building K-1420 also accepted oxides for processing from off-site sources, including Hanford and Savannah River. The K-1420 processing included fluorination to UF₆ and associated ash recovery and disposal operations. Building K-1131 was decommissioned during the late 1990s.

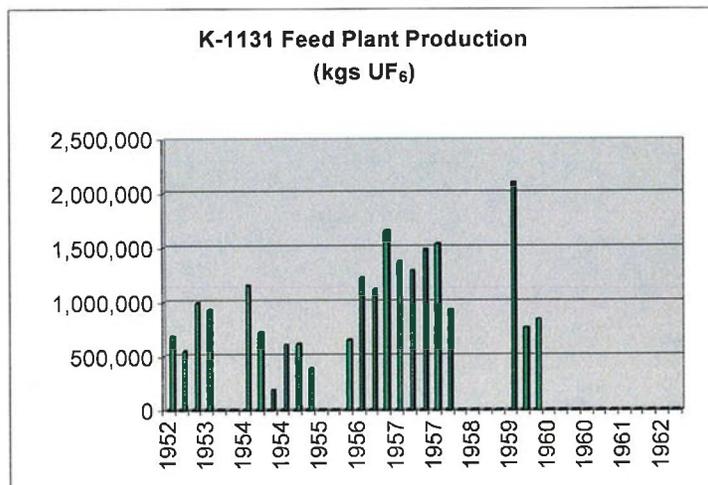


Fig. 2.2-2. K-1131 Feed Plant Production

2.2.2 Feed Input

In the enrichment process, 2.5-, 10-, and 14-ton cylinders of UF₆ coming from one of the ORGD feed production facilities [K-1131 (until 1961) or K-1420] or from off site were placed in large steam-heated autoclaves. The autoclaves were used to liquefy the feed UF₆ to allow efficient generation of UF₆ vapor for feeding to the cascade. Beginning in 1952, UF₆ feed was delivered to one of three feed facilities located in either K-131, K-33 feed room, or K-1131. The feed facilities in turn fed various stages in the cascade, typically including units in buildings K-27, K-29, K-31, and K-33. Both the UF₆ feed building and feed point varied over time.

2.2.3 Cascade Operation

In the enrichment process, gaseous UF₆ diffuses through a porous barrier containing millions of holes, each smaller than two-millionths of an inch. Because of the molecular weight difference between ²³⁵UF₆ and ²³⁸UF₆, slightly more ²³⁵U atoms diffuse through the barrier than ²³⁸U atoms. The slightly enriched UF₆ goes up the cascade where the process is repeated thousands of times to reach the desired product enrichment. UF₆ depleted in ²³⁵U atoms goes down the cascade where it is eventually removed as depleted UF₆ (commonly called “tails”) from the cascade. The actual location in the cascade where feed is introduced into the cascade is

¹ *ORGD Quarterly Reports*, 1952 to 1963

the “feed point,” which varied depending on the enrichment of the UF_6 feed and how the cascade was configured. These feed points are described in Section 2.2.2.

ORGDP started with a single processing building, K-25, and at its peak had five large processing buildings operating together as a UF_6 enrichment cascade. Each of the buildings was broken down into sections, and each section was broken down into cells. The cells were in turn broken down into stages where the actual enrichment process occurred. Each stage consisted of a converter vessel, a gas compressor, a motor, a control valve system and associated piping.

Converters (Fig. 2.2-3) contained the barrier material and a gas cooler or heat exchanger to control the stage temperature. Compressors were used to pump the UF_6 gas through the barrier

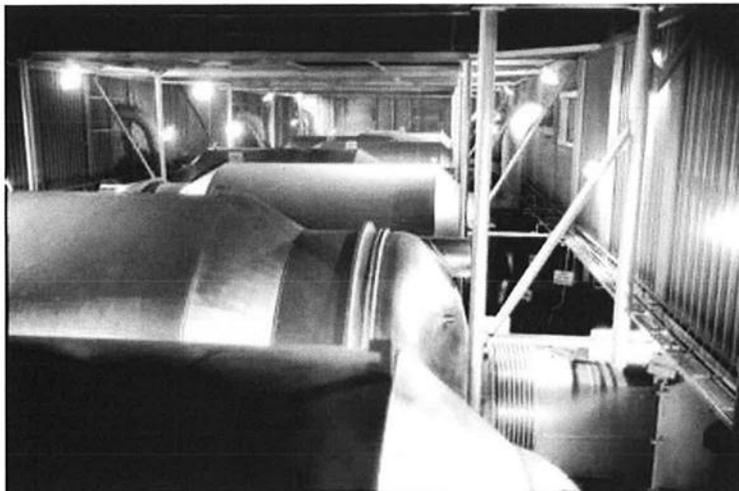


Fig. 2.2-3. ORGDP Converters

at optimum conditions. For maintenance, large block valves were used between successive groups of eight to ten stages to allow isolation of the equipment from the rest of the operating cascade. There were also the CIP/CUP major equipment upgrades in the 1970s, when, for practical purposes, the cascade was “rebuilt.” Of course, significant auxiliary systems were required to operate the cascade (such as the power generation and distribution system and the cooling towers to dissipate waste process heat).

The cascade had side and top purge cascades. The purpose of the side purge was for the removal of intermediate molecular weight gasses, such as coolant vapor and chlorine fluorides. The top purge was used to remove the lighter gasses from the cascade.

2.2.4 Tails Withdrawal

As previously described, UF_6 depleted in ^{235}U atoms went down the cascade where it was eventually removed as tails from the cascade. The UF_6 tails were placed in large steel cylinders, cooled, and placed in various tails storage yards, K-1066A through L, at ORGDP for long-term storage. For the period of concern (after RU was first fed to ORGDP) tails were withdrawn from one of two locations in the cascade, Building K-601 and Building K-1131.

2.2.5 Product Withdrawal

Beginning in 1953 (when RU was first introduced into the cascade), the UF_6 top product was withdrawn from the K-25 building (at locations K-306-7, K-305-12, and K-305-1 through K-305-9). The UF_6 at enrichments up to 93% ^{235}U was placed in 5-in. cylinders and stored in cages on the operating floor near where it was withdrawn from the cascade until shipment to Y-12. After the K-25 high enrichment building was shut down, the assay of the top product was lowered to <5 wt % ^{235}U . This product was withdrawn in K-29 (at location K-502).

Beginning in 1969, DOE predecessor agencies began offering toll enrichment services for use by nuclear utilities in the United States and abroad. For a fee, customers provided natural

UF₆ feed and took enriched UF₆ product at assays typically in the range of 2 to 4 wt % ²³⁵U. Product was withdrawn at the point in the cascade corresponding to the desired product enrichment. The UF₆ was withdrawn into large cylinders and was later transferred to 2.5-ton cylinders at Building K-1423 for delivery to commercial nuclear fuel fabricators.

2.2.6 Support Operations

During the life of ORGDP, many support operations were necessary. The principal on-site support operations that were involved with and were possibly impacted by RU streams are discussed in the following sections.

2.2.6.1 Decontamination and Uranium Recovery in Building K-1420 and Related Facilities

A key facility for supporting on-site operations and maintenance by providing radiological decontamination and uranium recovery was Building K-1420 (Fig. 2.2-4). This facility was designed and built in 1954 and utilized throughout the operational life of ORGDP. Equipment from every process building, except the feed building K-1131, was decontaminated and serviced in this facility. During the 1970s, Building K-1420 was upgraded and used for decontamination of major gaseous diffusion equipment being upgraded as part of CIP/CUP. Process



Fig. 2.2-4. Building K-1420 Exterior.

facilities in K-1420 included equipment for converter conditioning and recovery, mercury recovery, Miller's fluorinated lubricating oil reclamation, classified parts disassembly and cleaning, cascade process equipment cleaning and decontamination, uranium recovery (including fluorination), and laboratory functions. K-1303, a smaller building, was used in the late 1940s and early 1950s before K-1420 was placed in service for activities involving decontamination of enrichment process equipment from Building K-25 and recovery of fluorinated lubricating oil.

Following disassembly and/or decontamination activities, decontamination solutions were processed in K-1420 to recover the uranium. Aqueous waste effluents from the various chemical recovery operations were pumped to the K-1407-A Neutralization Pit and on to the K-1407-B Holding Pond. Later, contaminated sludge was dredged from K-1407-B and stored in the K-1407-C retention basin. In 1988, sludge was removed from the K-1407-B and K-1407-C ponds and either fixed in concrete or stored as wet sludge in 85-gal drums in an open storage yard adjacent to K-1417. In later years, effluents from K-1420 operations were discharged to the Central Neutralization Facility for pH adjustment, filtration, and release to Poplar Creek under NPDES permit.

Prior to 1976, discarded contaminated diffusion plant equipment and sensitive process components disassembled in K-1420 were likely buried in the classified burial ground located between Building K-25 and the K-1407-B Pond.

In 1961, K-1131 feed plant operations ceased, and K-1420, in addition to other activities, initiated limited feed plant capabilities. Major equipment in the uranium recovery system was designed to recover and concentrate uranium from liquid wastes generated by decontamination systems, enrichment process gas traps, and laboratory operations. The system produced uranyl nitrate that was converted to uranium oxides. The uranium oxide (or UF_4 from building K-1131) was converted to UF_6 feed. It is also known that various uranium materials from offsite were converted to UF_6 in K-1420. The feed was delivered to a flame tower reactor where fluorine was introduced. The resulting fluorination reaction produced UF_6 , which was filtered and collected in cold traps.

K-1420 operations also involved removing heels from UF_6 cylinders, cleaning the cylinders, and processing the heels material. It is unclear whether this activity included recovering heels from feed cylinders.

2.2.6.2 K-1410 Decontamination and Uranium Recovery

Building K-1410 was built in 1944 and operated through 1979. For many years this facility was used for receiving, emptying, and refilling spent chemical traps from the K-25 building. Records show that from 1946 to 1962, K-1420 was used exclusively for decontamination and maintenance of uranium-contaminated feed plant equipment from K-1131 and for recovery of uranium from feed plant ash (see also Section 2.2.1 concerning treatment of ash in Building K-1231). Filtered process equipment wash water was discharged directly to Poplar Creek. Contaminated sludges, residues, oil, rags, and spent chemical trap media, as well as contaminated UF_6 cylinders were buried in the K-33 contaminated waste burial ground located northwest of building K-33. Building K-1031, located adjacent to K-1410, was used as a general storage area for the chemical operations conducted in K-1410. During 1963-1979, the building was used for nickel plating and now is generally referred to as the K-1410 Plating Facility.

2.2.6.3 K-770 Scrap Metal Yard

The K-770 Scrap Metal Yard is in the former ORGDP powerhouse area on the east bank of the Clinch River, upstream of the confluence of Poplar Creek. It was originally built in the 1940s for the storage of fuel oil in a tank farm. Scrap metal storage began in the 1960s. The scrap includes various metals from equipment used at ORGDP and is contaminated with radioactive materials, including uranium and ^{99}Tc . The scrap metal inventory has been sorted according to metal type and size reduced. At least one on-site campaign was conducted several years ago to demonstrate recycle potential by smelting different types of scrap.

2.2.6.4 K-1401-N Converter Re-Tubing Area

During the 1970s, Building K-1401-N was constructed to support the CIP program. Facilities were provided to install, test, and assemble barrier in process converters. In other parts of the building, other process equipment from the cascade (i.e. UF_6 compressors and process valves) was refurbished. The process equipment was generally decontaminated in K-1420 prior to being transferred to K-1410. However, some chemical cleaning was conducted in K-1401,

consequently, chemical and radiological contamination may be present. Corrosive solutions used to clean equipment were transferred to the K-1407-A Neutralization Facility for disposal.

2.2.6.5 K-1421 Incinerator

The K-1421 Incinerator was operated from the mid-1950s until circa 1986. There were upgrades to the facility over time to meet changing performance and environmental standards. The incinerator was used to burn low-level contaminated combustible waste such as gloves, coveralls, wood, paper, plastic, and waste oil sludge. The incinerator was in an area of high radioactive contamination. There are reports that floor drains connected to either the K-1407-A Neutralization Pit or the K-1407-B Holding Pond. Low level contaminated ash was collected for uranium recovery at K-1420.

2.3 CONCENTRATING PROCESSES

2.3.1 Feed Operations

At the K-1131 feed plant (and later K-1420), when RU feed was fluorinated in the flame tower from UF_4 to UF_6 , most of the Pu and a smaller fraction of the Np components contained in the RU were largely converted to relatively involatile compounds. These compounds were concentrated in the ash collected on the reactor off-gas filters and in the bottom of the flame tower. On the other hand, only a small percentage of the ^{99}Tc formed involatile compounds and stayed in the ash, while the balance of the RU ^{99}Tc was fluorinated as a volatile specie and collected overhead with the uranium.

Because Pu and Np were concentrated in the ash, the operations of removing, recycling, and packaging ash from the reactor and cleaning filters presented a significant potential for worker exposure. Periodically, personnel in breathing apparatus disconnected the filter and ash collectors, emptied the ash collectors, and replaced the filters.

Although the majority of the TRU elements went into the ash and filters associated with the fluorination operation, smaller quantities of Pu and Np, plus the majority of the ^{99}Tc , remained with the UF_6 and was collected in feed cylinders. Both PuF_6 and NpF_6 are slightly more reactive with the steel walls of the feed cylinder relative to UF_6 , forming less volatile compounds that tended to stay in the feed cylinders during the subsequent UF_6 vapor feed operation.

After UF_6 was vaporized and was fed to the cascade, small quantities of uranium and any nonvolatile materials remained in the UF_6 feed cylinders. This material is referred to as cylinder heels. The nonvolatile material contained small quantities of Pu, Np, and ^{99}Tc . The emptied cylinders may have been refilled without heels removal, reused elsewhere in the ORGDP cascade, or sent to PGDP. The cylinders with heels may have been buried as contaminated waste or sent to Building K-1420 for cylinder cleaning and uranium recovery. However, former ORGDP employees familiar with K-1420 operations stated in discussions with members of the Site Team that they did not recall washing feed cylinders at K-1420 during the time RU was being processed. Only 2.5-ton cylinders that were used by the fuel fabricators in the commercial sector were washed at K-1420. Records concerning the disposition of ORGDP feed cylinder heels are incomplete.

2.3.2 Cascade

Minute quantities of Pu and small but measurable amounts of volatile Np and ^{99}Tc compounds were introduced into the cascade via the UF_6 feed stream. Residual amounts of Pu and Np fed to the cascade would have been removed from the feed stream by the barrier and other metal surfaces as solid deposits in the process equipment near the feed points. Most of the contaminated equipment would likely have been removed during the CIP/CUP efforts. Nickel removed from the barrier was smelted in a facility in K-1037 and shipped to PGDP.

^{99}Tc chemistry is considerably more complex than uranium or the TRU compounds. Multiple fluoride and oxyfluoride ^{99}Tc compounds are likely under the widely varying operating conditions of the cascade. Because of its lower molecular weight, any volatile ^{99}Tc compounds would tend to migrate up the cascade. Less volatile compounds accumulated as various surface deposits in the upper stages of the plant. The ^{99}Tc solids tended to redistribute in the process equipment as temperature and gas composition changes were made to optimize the enrichment stages. At ORGDP, the purge unit was above the product withdrawal point, and the purge unit had a ^{99}Tc trapping system.

2.3.3 Tails

It is possible, but not believed to be likely, that tails withdrawn from the cascade and placed in cylinders for long-term storage may have contained very small to negligible quantities of Pu, Np, and ^{99}Tc . The vast majority of the tails produced over the lifetime of the plant remain in storage, as previously described. Because there is a DOE program in progress to consider ways to beneficially use the depleted uranium, there is a need for a good understanding of tails contamination levels.

2.3.4 Product

HEU produced at K-25 during the period of time when RU was being fed to the cascade was shipped to the Y-12 Plant. The UF_6 product may have contained very small to negligible amounts of Pu and Np. Measurable quantities of ^{99}Tc are possible in the HEU product because ^{99}Tc was present in larger quantities in the UF_6 feed and volatile compounds (i.e., TcF_6 and TcO_3F) are not as reactive as the TRU compounds.

Low-assay product was shipped to fuel fabricators to produce commercial nuclear fuel. There was an American Society for Testing and Materials (ASTM) specification that was used for this product. This UF_6 was withdrawn at a lower enrichment point in the cascade than the HEU. The low-assay product may also have contained very small to negligible quantities of ^{99}Tc . Measurable quantities of Pu or Np are unlikely to have been present.

2.3.5 Support Operations

Support operations, especially those involving equipment maintenance and/or decontamination, would have presented the more significant scenarios for possible worker exposure to RU constituents. In particular, maintenance work associated with the fluorination tower reactor, ash collection, and solid transfer equipment would have offered the greatest opportunity for personnel exposure to Pu and Np. By their very nature, decontamination operations may have resulted in the removal and concentration of Pu, Np, and ^{99}Tc . Depending

on the operation and the material, solution, equipment, or waste involved, personnel performing support work in K-1420, K-1421, K-1410, and K-1303 would have experienced increased potential for exposure.

Uranium recovery and waste processing operations could have involved exposure to two different sources of concentrated ⁹⁹Tc. When the purge gases flowed through the chemical traps prior to venting, ⁹⁹Tc concentrated in the reactive NaF and MgF₂ media. Personnel collecting and emptying the traps and disposing of the waste solvent would have experienced increased potential for exposure. Also, personnel doing maintenance work associated with the upper cascade enrichment stages, including the purge cascade would have increased potential for exposure to ⁹⁹Tc.

Solvent extraction activities in K-1420 for uranium recovery also resulted in the concentration of ⁹⁹Tc in the raffinate stream and in sludge formed from raffinate treatment. From K-1420, this sludge was sent to the K-1407-A Neutralization Pit. The K-1407-B holding pond was used as a settling basin for metal hydroxide sludge precipitated after neutralization in the K-1407-A pit. The aqueous contents of K-1407-B were at times discharged to Poplar Creek. Sludge was also dredged from K-1407-B and stored in the K-1407-C retention basin. All sludge from both K-1407-B and K-1407-C was eventually dredged and stored, and both facilities were filled, capped, seeded, and posted as underground radioactive contamination areas. The personnel performing the sludge removal work may have been exposed to higher levels of ⁹⁹Tc and possibly traces of Pu and Np.

2.4 ACTIVITIES WHERE WORKERS WERE LIKELY TO BE IN CONTACT WITH RU THROUGH DIRECT PHYSICAL CONTACT OR AIRBORNE DUST

In its review of ORGDP facilities and processes, the ORGDP Site Team identified a number of activities that, based on available data, would be expected to present the greatest potential for workers to be exposed to the RU constituents of interest. Table 2.4-1 presents a list of these activities and the locations in which they occurred, along with the time frame, constituent level, and level of occupational exposure potential. In the table, activities are grouped by four major categories: (1) oxide conversion for UF₆ feed, (2) cascade buildings and operations, (3) uranium recovery operations, and (4) analytical laboratory analysis.

A discussion of the methodology used to perform constituent level calculations and to develop the ratings for the category "Occupational Exposure Potential" in Table 2.4-1 is provided in Appendix A.

Table 2.4-1. Activities Involving Potential Worker Exposure

Location	Activity	Time Frame	Constituents	Occupational Exposure Potential
1. Oxide Conversion				
K-1131	1A. Unpacking, feeding of UO ₃ to process, operation and pulling samples	1952-1961	Estimated levels in UO ₃	Moderate*
K-1420	* Exposure potential would have been high for brief periods in Jan-Apr 1953 when Pu ranged as high as 40 ppb in material from Hanford	1960-1963	520 ppb Np 4.4 ppb Pu 7,800 ppb Tc 170 ppm ²³⁸ U	

Location	Activity	Time Frame	Constituents	Occupational Exposure Potential
K-1131 K-1420	1B. Collecting ash for uranium recovery and cleaning of tower filters	1952-1961 1960-1963	Estimated levels in ash 13,000 ppb Np 440 ppb Pu 40,000 ppb Tc 170 ppm ²³⁶ U	High
K-1231 K-1410	1C. U recovery from ash, processes included ash pulverizer	1952-1963 1952-1962	Estimated levels in ash 13,000 ppb Np 440 ppb Pu 40,000 ppb Tc 170 ppm ²³⁶ U	High
K-1131 K-1410	1D. Maintenance and repair of fluorination tower and associated equipment	1952-1961 1952-1962	Estimated levels 13,000 ppb Np 440 ppb Pu 40,000 ppb Tc 170 ppm ²³⁶ U	High
2. Cascade Buildings and Operations				
Cascade feed points	2A. Feeding UF ₆ from cylinder to the cascade	1952-1985	Estimated levels in UF ₆ 130 ppb Np 0.004 ppb Pu 6,600 ppb Tc 170 ppm ²³⁶ U	Moderate
Cascade buildings	2B. Inadvertent releases of UF ₆ within cascade buildings or from piping between cascade buildings	1952-1985	Estimated levels in UF ₆ 31 ppb Np 0.001 ppb Pu 2,300 ppb Tc 87 ppm ²³⁶ U	Moderate
Product withdrawal points	2C. Withdrawal of product from cascade into cylinders	1952-1985	Estimated levels in UF ₆ <5 ppb Np 0 ppb Pu 1,800 ppb Tc 395 ppm ²³⁶ U	No significant
Tails withdrawal points	2D. Withdrawal of tails from cascade into cylinders	1952-1985	Estimated levels in UF ₆ 0 ppb Np 0 ppb Pu 0 ppb Tc 40 ppm ²³⁶ U	No significant
Cascade purge locations	2E. Venting process gas to atmosphere from operating cascade through process stack	1952-1985	Estimated levels in UF ₆ <5 ppb Np 0 ppb Pu 2x10 ⁴ ppb Tc 400 ppm ²³⁶ U	Moderate
Cascade feed points	2F. CIP/CUP and other work involving removal of converters, compressors, and valves associated with cascade feed points	1952-1985	Estimated levels 130,000 ppb Np 4 ppb Pu 1,000 ppb Tc 170 ppm ²³⁶ U	Moderate
Cascade purge locations	2G. CIP/CUP and other work involving removal of converters and compressors, and valves associated with the purge cascade	1952-1985	Estimated levels <5 ppb Np 0 ppb Pu 7,500 ppb Tc 395 ppm ²³⁶ U	Moderate

Location	Activity	Time Frame	Constituents	Occupational Exposure Potential
Cascade buildings	2H. CIP/CUP and other work involving equipment removal and maintenance activities other than near feed point or purge cascade	1952-1985	Estimated levels <5 ppb Np 0 ppb Pu <1,000 ppb Tc 100 ppm ²³⁶ U	No significant
3. Recovery Operations				
K-1410 K-1420	3A. Cleaning of heels from UF ₆ cylinders	1955-1979 1954-1993	Estimated levels in heels 26,000 ppb Np 4 ppb Pu 70,000 ppb Tc 170 ppm ²³⁶ U	Moderate
K-1303 K-1410 K-1420	3B. Decontamination of equipment associated with feed point and recovery of uranium	1952-1955 1952-1979 1954-1993	Estimated levels 130,000 ppb Np 4 ppb Pu 1,000 ppb Tc 170 ppm ²³⁶ U	Moderate
K-1303 K-1410 K-1420	3C. Decontamination of equipment associated with purge cascade and recovery of uranium	1952-1955 1952-1979 1954-1993	Estimated levels <5 ppb Np 0 ppb Pu 7,500 ppb Tc 395 ppm ²³⁶ U	Moderate
K-1303 K-1410 K-1420	3D. Decontamination of equipment associated with other than near feed point or purge cascade	1952-1955 1952-1979 1954-1993	Estimated levels <5 ppb Np 0 ppb Pu <1,000 ppb Tc 100 ppm ²³⁶ U	No significant
K-1037 K-1303 K-1410 K-1420 K-1421	3E. Uranium recovery from and/or processing of contaminated oils, cleaning solutions, and other wastes	1952-1981 1952-1955 1952-1979 1954-1993 1954-1986	Estimated levels in solutions <5 ppb Np 0 ppb Pu 1,000 ppb Tc 100 ppm ²³⁶ U	Moderate
K-770 Scrap Metal Yard	3F. Handling of scrap metal from equipment	1960s- present	Estimated levels on metal 0 ppb Np 0 ppb Pu 1,000 ppb Tc 100 ppm ²³⁶ U	Low
K-1407-B K-1407-C K-1419	3G. Removal, transfer, and/or storage of sludge from facility treating constituents concentrated in sludge	1952-1988 1973-1988 1987-1988	Estimated levels in sludge 2 ppb Np 0.02 ppb Pu 41,000 ppb Tc 100 ppm ²³⁶ U	Moderate
RUBB Buildings	3H. Thermal drying/repackaging of pond sludge for offsite disposal	1991-1992	Estimated levels in deposits 2 ppb Np 0.02 ppb Pu 200 ppm Tc 100 ppm ²³⁶ U	Moderate

Location	Activity	Time Frame	Constituents	Occupational Exposure Potential
Cascade buildings and associated piping	3I. Recovery of uranium deposits from process equipment associated with cascade feed points following shutdown of ORGDP	1987-present	Estimated levels on metal 130,000 ppb Np 4 ppb Pu 1,000 ppb Tc 170 ppm ²³⁶ U	Moderate
Cascade buildings and associated piping	3J. Recovery of uranium deposits from process equipment associated with purge cascade following shutdown of ORGDP	1987-present	Estimated levels in traps <5 ppb Np 0 ppb Pu 7,500 ppb Tc 395 ppm ²³⁶ U	Moderate
Cascade buildings and associated piping	3K. Recovery of uranium deposits from process equipment other than feed points and cascade purge following shutdown of ORGDP	1987-present	Estimated levels in traps <5 ppb Np 0 ppb Pu 1,000 ppb Tc 100 ppm ²³⁶ U	No significant
K-1031	3L. Service cascade chemical traps	1952-1962	Estimated levels in traps 5 ppb Np 0 ppb Pu 1x10 ⁶ ppb Tc 395 ppm ²³⁶ U	Moderate
K-1410		1952-1962		
K-1420		1960-1985		
4. Analytical Labs				
Analytical laboratories K-1004A, B, C, D, J K-1006	4A. Analytical laboratory sampling	1952-1985	Estimated levels in samples 13,000 ppb Np 440 ppb Pu 40,000 ppb Tc <395 ppm ²³⁶ U	No significant

2.4.1 Descriptions of Activities Presenting Occupational Exposure Potential

The following sections provide more information on the activities listed in Table 2.4-1. For ease of correlation with the information in Table 2.4-1, the same alphanumeric system used to group activities in the table (i.e., 1A, 1B, etc.) is employed for these next sections

1. Oxide Conversion for UF₆ Feed

1A. Unpacking, Feeding, and Sampling of UO₃

Oxide in the form of UO₃ was delivered to the K-1131 feed plant in hoppers. (K-1420 also had oxide conversion capabilities—initially to recover enriched uranium from decontamination solutions. K-1420 subsequently received and converted RU oxide for use as feed, but on a much smaller scale than K-1131.) The UO₃ powder was fed directly into sequential reactors and hoppers to achieve conversion to UF₆. The design of the UO₃ hoppers featured a heavy steel frame that supported a box-like container with a funneled bottom. The hoppers arrived funnel

up, with a flanged cover on the funnel end. This cover was replaced with a flapper valve assembly before the hopper was inverted into the feed position. The inverted hopper was placed on the feed point of the conversion system, and the valve was opened to permit material transfer. Although the oxide was in powder form, because of the particle size and density, the potential for the oxide to become airborne was not high. The resulting hazard was thus determined to have a "Moderate" occupational exposure potential. However, in the period of January 1953 through April 1953, receipts were recorded for shipments of oxide from Hanford containing up to 40 ppb of Pu (a significantly higher level than noted for receipts during any other time). At that level, the occupational exposure potential would be rated "High" for that relatively short period of time.

1B. Collecting Ash and Cleaning Tower Filters

In the UF_4 to UF_6 conversion step, any unreacted or partially converted residual uranium solids (referred to as ash) were collected in a receiver can located below the fluorination reactor. The ash container, which was approximately 2 ft in diameter, with a capacity of approximately 30 gal, was exchanged as a routine part of operations. Ash also collected on the tower reactor filters, which carried similar exposure potential. Because of the increased concentrations of Pu and Np in this material and the inherent potential of the fine ash to become airborne, ash provided one of the more significant pathways for worker exposure during these operations. The potential for any loose ash to become airborne or spilled represented a "High" exposure potential for the employee because of the constituent levels (concentrated transuranics with some fission product), the nature of the ash collection process, the physical properties of the ash, and the frequency with which these operations had to be performed.

1C. Uranium Recovery from Ash

During the earlier part of ORGDP's operating history, the shortage of uranium feed and the poor reactivity of the RU feed made it desirable to recover the uranium value in ash from the UF_4 to UF_6 conversion process. In an attempt to recover essentially all of the uranium, the ash was collected, pulverized, and re-fed through the conversion process. When beneficial reclamation of the uranium from the ash was no longer feasible, the residual ash was containerized and stored. Most of the spent ash (which contained approximately 99% of the incoming Pu, 25% of the incoming Np, and 5% of the incoming ^{99}Tc) was eventually shipped to PGDP. As with ash collection and filter cleaning activities, the exposure potential associated with manual operations for recovering uranium from ash was determined to be "High."

1D. Maintenance and Repair of Fluorination Tower

Maintenance and repair activities occasionally associated with the fluorination tower carried considerable potential for worker exposure to finely divided uranium solids concentrated in Np and Pu. Equipment failures or breakdowns often necessitated the disassembly of equipment containing significant quantities of in-process material. The tower reactor for UF_4 -to- UF_6 conversion would sometimes plug, requiring mechanical disassembly and potential exposure to solids for personnel manually removing the obstructions. Feed screws would sometimes jam with uranium slag and require similar remedial actions. In addition, the UF_6 gas would also sometimes freeze in the outlet line and need to be manually cleared. Although these activities

occurred less frequently than handling the ash receiver, their nature contributed substantially to the potential for exposure. As a result, the occupational exposure potential was determined to be "High."

2. Cascade Buildings and Operations

2A. Feeding UF₆ from Cylinders to Cascade

Although the majority of incoming ⁹⁹Tc entered UF₆ feed cylinders with the UF₆ produced at a feed plant, only a small fraction of Np and an even smaller fraction of Pu entered into the feed cylinders. In the feed process, the UF₆ cylinder was placed into a large autoclave to liquefy the UF₆ contents under its own vapor pressure and promote efficient high volume vapor transfer to the cascade. Beginning in 1952 (which was when RU was first introduced into the ORGDP cascade in production quantities), UF₆ feed was delivered to the cascade in various years from one of three buildings (K-131, K-33 Feed Room, or K-1131). The feed buildings fed to various stages of the cascade—depending on the cascade configuration—but typically including cells in buildings K-27, K-29, K-31 and K-33. UF₆ and all of the various minor volatile metal fluorides present in the feed cylinder had a tendency to react with the cylinder wall steel to form non-volatile reduced metal fluorides. PuF₆ is the most reactive (i.e., most easily reduced) of the feed components while UF₆ is the least reactive. Because of the higher reactivity of PuF₆ and NpF₆, essentially all of the Pu and much of the Np remained in the empty feed cylinder as non-volatile fluorides as the uranium was removed. Although the constituent levels and potential for becoming airborne were appreciable, the duration of the physical activities associated with the UF₆ feed operation was very brief. Potential for exposure existed only when process feed line connections were being made or broken. Consequently, the exposure potential was judged to be only "Moderate."

2B. Inadvertent Releases of UF₆ within Cascade Buildings or from Piping

Although not routine, releases in the process equipment and/or associated piping and cascade instrumentation were not uncommon. Based solely on the constituent level, the potential for exposure could be significant. However, because the cascade was operated at pressures below atmospheric, the potential for airborne hazards was low. Breaches in the system resulted in an inflow of ambient air rather than a release of process gas into the building. Furthermore, the duration of such an event would be very short, as it would be obvious to the control room personnel and would result in prompt reconfiguration of the affected cell to isolate it from continued gas flow. The exposure potential associated with releases from the diffusion cascade was rated as "Moderate."

2C. Product Withdrawal

All of the PuF₆ and most of the NpF₆ entering the diffusion cascade with the UF₆ feed gas was rapidly reduced by the active metal surfaces of the cascade and immobilized in the feed gas piping and converters as non-volatile fluorides. These compounds tended to accumulate around the cascade feed points. Most of the ⁹⁹Tc proceeded up the cascade with the enriched UF₆. The ORGDP cascades were always operated with the benefit of a purge cascade, which served to remove light gases (air and nitrogen seal gases) and intermediate molecular weight gases

(Freon 114 and various fluorination gases) to promote efficient collection of enriched UF₆ product. UF₆ was extracted at various points in the cascade below the top purge units for light gases and downstream of the side purge equipment for intermediate gases. ⁹⁹Tc tended to collect between the top purge and the UF₆ product withdrawal point as an intermediate molecular weight gas. Some ⁹⁹Tc was vented to the atmosphere with the light gases, and some was withdrawn with the UF₆ product. But the majority of the ⁹⁹Tc tended to accumulate in the purge cascade equipment. However, the product was relatively free of any transuranic compounds. The potential exposure duration to the cascade product was very brief and only existed when connections were being made or broken. As a result, the exposure potential was rated as “No Significant” potential.

2D. Tails Withdrawal

As the ORGDP cascade configuration changed throughout the history of the plant, the feed point was moved to various locations. In all instances, however, tails were withdrawn at a point well below the feed point. Because Np and Pu were primarily retained on the surfaces of the equipment at the feed points and ⁹⁹Tc migrated upstream, the tails were relatively free of RU constituents. In addition, the potential exposure duration was very brief because the potential only existed when process gas connections were being made or broken. The exposure potential was thus rated “No Significant” potential.

2E. Venting Process Gas to Atmosphere

Gas exhaust from the ORGDP cascade was ultimately vented to the atmosphere. The purge cascade design and operating parameters caused any UF₆ that entered the side or the top purge cascade to be rejected downstream and separated from the vent gases. Because Pu and Np plated out on equipment near the feed point, they were not significant constituents in the vent gases. Depending on the operating profile of the cascade, however, some ⁹⁹Tc passed through the purge cascade and was vented to the environment. The balance of the ⁹⁹Tc tended to collect in the purge equipment. In the early 1960s, chemical traps were placed at the top of the purge cascade to minimize ⁹⁹Tc emissions. (Prior to that time, some fraction of the total ⁹⁹Tc fed to the enrichment plant was vented.) The efficiency of the trap (typically around 80%) was very dependent on routine maintenance and change-out. Records indicate that this maintenance program was marginal at times. As a result, ⁹⁹Tc was vented throughout the operation of the cascade, but to a lesser extent after the early 1960s. Certainly, the ⁹⁹Tc constituent level in the diffusion plant exhaust was significant at times, and airborne potential was high under these circumstances, as the most likely ⁹⁹Tc species (TcO₃F and TcF₆) were volatile at discharge. The exposure duration, however, would be very brief. The process stack was well above the roof of the cascade buildings and removed from normal personnel traffic—thus minimizing the possibility of workers being directly exposed to the vent gases. The exposure potential was calculated to be “Moderate.”

2F. CIP/CUP and Other Equipment Removal at Feed Points

Process equipment throughout the ORGDP cascade routinely required maintenance and repair. If this work involved the converter, compressor, or valve components near the feed points, workers were likely to encounter Pu and Np solid deposits or, possibly, dust. Typically,

contaminated equipment was removed from the cascade, openings were covered in the field, and the equipment was transported to a decontamination facility as a precursor to working on the component. Seal replacement was performed in the field, but repair/replacement was typically accomplished as an enclosed package and not as components. In addition to removing equipment for routine maintenance, ORGDP implemented two major upgrade programs during the late 1970s: the Cascade Improvement Program (CIP) and the Cascade Upgrade Program (CUP). Together, these two programs constituted a virtual rebuilding of the cascade. Although workers likely encountered Pu and Np when working near the feed points in such operations, the actual duration of exposure at these locations would be expected to have been relatively low. Accordingly, the exposure potential for these activities was determined to be "Moderate."

2G. CIP/CUP and Other Equipment Removal at Purge Cascade

Workers removing converter, compressor, or valve components in the various purge areas of the cascade for CIP/CUP or routine maintenance or repair were likely to encounter ⁹⁹Tc. However, the actual duration of exposure during field removals at these locations would be expected to have been relatively low. Thus, the exposure potential for these activities was determined to be "Moderate."

2H. CIP/CUP and Other Equipment Removal at Other Points

Workers removing converter, compressor, or valve components for CIP/CUP or routine maintenance or repair in areas of the cascade other than near the feed points or the purge areas were unlikely to encounter significant quantities of the RU constituents of concern. Because Pu and Np were basically concentrated near the feed points and ⁹⁹Tc was concentrated at the purge areas, these constituents posed little or no hazard at other locations in the cascade. Workers would be expected to encounter only uranium residues. Therefore, the exposure potential for this activity was rated "No Significant" potential.

3. Uranium Recovery Operations

3A. Cleaning Heels from UF₆ Feed Cylinders

Some cleaning of heels from potentially RU-contaminated feed cylinders may have taken place at ORGDP. (Records regarding ORGDP feed cylinder heels are incomplete.) Because uranium compounds are water-soluble, the cylinder cleaning was typically accomplished by rinsing with water. Pu and Np formed compounds that reacted with the steel cylinder walls upon contact and were not as water-soluble as the uranium. These compounds were only partially removed when the cylinders were cleaned. Rinsing and spraying the cylinder with water had the advantage of entrapping the material and reducing the potential for it to become airborne. The airborne potential was judged to be moderate. Even with concentrations of transuranics and fission products in the heel of the cylinder, this activity was rated "Moderate" for exposure potential because of low exposure duration.

3B. Decontamination of Equipment from Feed Point

When ORGDP cascade process equipment was replaced or repaired as part of upgrade programs, such as CIP/CUP, or routine maintenance or repair, the equipment was decontaminated to protect workers and to recover uranium. Because decontamination work involved access to internal surfaces of the process equipment, there was potential for workers to be exposed to associated contamination. In decontaminating equipment from locations near the feed points (which varied over the life of the cascade), workers would have encountered elevated levels of Pu and Np. Because upgrade programs were extensive and continued over a number of years and maintenance and repair were ongoing activities, the associated exposure duration would be expected to be significant. Consequently, the exposure potential was rated "Moderate."

3C. Decontamination of Equipment from Purge Cascade

In decontaminating equipment from the purge cascades (which varied over the life of the cascade) and chemical traps, workers would have encountered elevated levels of ⁹⁹Tc. Because upgrade programs were extensive and continued over a number of years and maintenance and repair were ongoing activities, the associated exposure duration would be expected to be significant. Consequently, the exposure potential was rated "Moderate."

3D. Decontamination of Equipment from Other Points

As noted in Sect. 2.4.4.2 and 2.4.4.3, workers decontaminating equipment as part of upgrade programs or routine maintenance or repair would have encountered elevated levels of Pu and Np in equipment from near the feed points and elevated levels of ⁹⁹Tc in equipment from the purge cascades and chemical traps. For work on equipment from locations other than these areas, the overall exposure potential is reduced significantly. Accordingly, the occupational exposure potential was determined to be "Low."

3E. Processing of Wastes for Uranium Recovery

During the earlier part of ORGDP's operating history, the shortage of uranium feed made it desirable to recover the uranium value in decontamination solutions and other waste streams. As uranium became more plentiful, recovery efforts were reduced substantially and more uranium was discarded in various waste streams. Because recovery streams came from throughout the cascade, contamination by the RU constituents of concern was diluted. Oils were distributed from large reservoirs, and waste products such as paper and wipes were collected in gross quantities. Consequently, levels of RU constituents would have been expected to be low. As the waste streams tended to be liquid or wet, airborne potential would also have been low. However, because these activities were conducted routinely and on a large scale throughout the history of ORGDP cascade operations, the exposure duration would have been high. The exposure potential was thus rated "Moderate."

3F. Handling of Scrap Metal from Equipment

The decontamination of equipment being repaired or replaced typically resulted in the elimination of any loose surface contamination—leaving only residual amounts of fixed contamination on equipment. The scrap metals from equipment repairs and/or replacements were placed into the K-770 scrap metal yard on the ORGDP Site, where many metals remain today in contaminated storage. In addition, some metal was melted for volume reduction. Because of the removal and/or reduction of contamination, the elimination of loose material, and the level of activity for this type of work, the exposure potential was determined to be “Low”.

3G. Removal and Storage of Pond Sludge

Spent solutions from ORGDP decontaminating processes were discharged into precipitation and holding ponds at the site. Several years after the shutdown of the ORGDP enrichment facilities, an effort was undertaken to dredge the sludge from these ponds, mix it with concrete, and place it into storage in large steel drums. During the end of that effort, however, many drums were filled with raw sludge without the concrete component. Although the level of constituents would have been appreciable, the form of the material was a true sludge with significant water content and little potential to become airborne. The exposure potential was rated as “Moderate.”

3H. Thermal Drying and Repackaging of Pond Sludge

Raw pond sludge containing transuranics and fission products and stored in steel drums at ORGDP eventually corroded the drums and necessitated remedial action circa 1991–1992. The approach selected called for removing the sludge from the drums, thermally drying it, and repackaging it into new containers. Although the thermal drying operation provided significant potential for generating airborne hazards, the exposure duration was brief because of the short time frame of this effort. These factors, in combination with the sludge constituent levels, resulted in an exposure potential rating of “Moderate” for this activity.

3I. Recovery of Uranium Deposits Near Feed Points Following Shutdown

Years after the ORGDP cascades were shut down, concerns with criticality safety related to deposits of enriched uranium in the process equipment arose as the process buildings continued to age and became more susceptible to roof leaks. As a result, the Deposit Removal program was implemented to identify the location of the deposits, quantify the amounts and assays of the material, and remove those deposits that posed a significant criticality hazard. This material was placed into storage containers following removal.

During the CIP/CUP efforts, essentially all accumulations of Pu, Np, and ⁹⁹Tc in the cascade were removed from the converters and compressors as a result of the upgrade programs. Even constituents located in the piping and/or valves would have been reduced as a result of purge procedures performed prior to taking the equipment off-line for the upgrade work.

Post-CIP/CUP and until 1984, RU as UF₆ was received from PGDP and foreign sources and some was fed to the ORGDP. This material would have introduced small quantities of Np and ⁹⁹Tc into the cascade. Essentially all of the Pu and much of the Np would have remained in the

empty feed cylinder as non-volatile fluorides. The small quantities of Np that were fed to the cascade would have concentrated at the feed points and the ⁹⁹Tc would have proceeded up the cascade and concentrated around the purge equipment.

Information from the Deposit Removal Program indicates no significant issues with TRU or ⁹⁹Tc in the deposits. The nature of the work, which used manual and mechanical methods to remove and collect deposits, could have generated airborne material over the short period of time the operation was conducted. The exposure potential was determined to be "Moderate."

3J. Recovery of Uranium Deposits Near Purge Cascade Following Shutdown

As discussed previously, Pu and Np introduced into the cascade would have plated out near the feed points. Material near the purge cascade contained volatile and semi-volatile ⁹⁹Tc that had proceeded up the enrichment cascade and accumulated in the purge area. The ⁹⁹Tc would have presented some hazard during Deposit Removal activities performed in the area of the purge units. Given the fact that the Deposit Removal work had the potential for generating airborne material, the exposure potential was determined to be "Moderate."

3K. Recovery of Uranium Deposits from Other Points Following Shutdown

As noted in Sect. 2.4.4.9 and 2.4.4.10, workers performing Deposit Removal work following shutdown may have encountered low levels of Np and much lower levels of Pu near the feed points and elevated levels of ⁹⁹Tc near the purge cascades. For Deposit Removal work in locations other than these areas, the overall exposure potential was rated as "No Significant" potential.

3L. Service Cascade Chemical Traps

MgF₂ traps were used to capture and remove ⁹⁹Tc at the upper end of the cascade. ⁹⁹Tc also accumulated in NaF traps used to remove uranium from the side purge. Because of the nature of the sorbent material, the removal and replacement of the trap material was an operation that presented a high potential for material contaminated with ⁹⁹Tc to become airborne. Although the ⁹⁹Tc level and airborne potential were high, consideration of the infrequent performance of such operations resulted in an exposure potential rating of "Moderate."

4. Analytical Laboratory Analysis

Samples of oxide feed received at ORGDP were sent to the ORGDP analytical labs for analysis. These samples would have been containerized in lidded vials and carefully labeled with their origin. Typically, lab samples were in the range of a few grams and did not represent very large quantities of material. Once in the laboratory, samples were handled very carefully to preserve sample quality and prevent any cross contamination. Protocol for lab cleanliness and sample preservation was pristine. Although the samples had the potential to contain appreciable quantities of RU constituents, they were carefully handled within a ventilated laboratory hood. The exposure potential was thus rated as "No Significant" potential.

2.4.2 Worker Radiological Protection Programs

A search for documents that might provide information on the ORGDP worker protection program resulted in the discovery of several reports, audits, data summaries, and other documents. These materials provided a general summary of this ORGDP program for the time frame during which RU material was being processed. Based on the information reviewed, it is clear that receipt of RU was anticipated at the plant and that planning was accomplished to deal with the health and safety issues involved in processing this material. This RU awareness was confirmed in conversations with retired personnel who were directly involved in the operations and processes key to RU.

ORGDP monthly reports for Pu reported total U mg, total Pu mg, and ppb Pu/U.² Urinalysis data reporting Pu results were available from 1945 through the entire period of time RU material was processed. Sampling reports for K-1131 as early as 1953 also reported ppb Pu/U. It is not clear that Np or Tc were initially recognized as constituents.

A good deal of effort at ORGDP was spent on correlating surface contamination to potential airborne contamination in K-1131 based on data from 1957 through 1960. The 1960 report "Uranium Alpha Surface Contamination, Airborne and Urinary Excretion Rates" included urinalysis, air sampling, surface and respirator usage information.³

A document published in 1957 entitled "Radiation Protection Practices at the Oak Ridge Gaseous Plant"⁴ provided an extensive summary of information on worker protection practices. The following sections summarize the contents of this document. The various program elements described were also present in the 1973 document *Nuclear Materials Management Manual*⁵ that was reviewed as part of this effort.

2.4.2.1 Basic Plant Methods

The ORGDP Safety Program, of which the radiation-protection aspects of plant operation constituted a part, placed the primary responsibility for accident prevention on the line organization. Medical, health physics, and industrial hygiene staff groups were responsible for assisting in the evaluation of the potential hazards to personnel resulting from plant operations and for making appropriate recommendations to control those hazards. Service organizations and facilities were provided to assist the line and staff groups in meeting those responsibilities.

Plant acceptable limits for radiation and radioactive contamination levels, which were in accord with the recommendation of nationally recognized groups in that field, were established at values well below any known injury level for continuous personnel exposure, and efforts were made to prevent employee exposure to conditions exceeding those limits. The National Bureau of Standards Handbooks 59 and 69 offered criteria for penetrating and internal radiation exposures, respectively.

² *Monthly Plutonium Report*, Union Carbide Nuclear Company, Oak Ridge Gaseous Diffusion Plant, 1953–1961.

³ N. B. Schultz, et al., "Correlation of Uranium Alpha Surface Contamination, Air-Borne Concentrations, and Urinary Excretion Rates," KR-150, Union Carbide Nuclear Company, Oak Ridge Gaseous Diffusion Plant, June 22, 1961.

⁴ H. F. Henry, et al., "Radiation Protection Practices at the Oak Ridge Gaseous Plant", KSA-81, Union Carbide Nuclear Company, Oak Ridge Gaseous Diffusion Plant, April 3, 1957.

⁵ *Nuclear Materials Management Manual*, K-P-4086, Rev. 4, Union Carbide Nuclear Company, Oak Ridge Gaseous Diffusion Plant, 1973.

Personnel protective equipment was provided to employees as necessary, and adequate clinical facilities were available on-site. The evaluation of plant conditions and individual problems was based on thorough programs of clinical examinations and both personnel and environmental monitoring. The aid and advice of authorities in the field was made available as necessary or desirable.

2.4.2.2 Roles and Responsibilities

Responsibility for the protection of the employee against radiation health hazards rested with the line organization to the same extent that line organization personnel were responsible for operation and production. Supervisors formulated and administered rules and regulations for each area or major operation under their authority. Responsibilities included:

- Monitoring the extent and intensity of radiation or radioactive contamination in the work area.
- Providing employees with the appropriate personnel protective equipment and enforcing the use of that equipment.
- Establishing work-time limits on jobs with penetrating radiation.
- Decontaminating facilities in excess of Plant Action Level (PAL).
- Identifying/tagging contaminated equipment and facilities where radiation hazards were present.
- Reporting any new and/or potentially hazardous processes or materials to the Health and Safety staff groups.
- Maintaining a personnel monitoring program as necessary, making available hand-counting facilities and other radiation instruments, obtaining records of data from these devices, and initiating requests for provision of film badge and film ring monitoring services.
- Handling all cases of exposure in excess of the PAL, including accident reporting and investigation.
- Forwarding copies to the Safety, Fire and Radiation Control organization of established rules and regulations, surveys of hazards, personnel monitoring results, and information concerning radiation and radioactive contamination.

The employee was expected to follow rules and regulations pertaining to job hazards for his location and assignment, monitor his person and work area as required, and notify his immediate supervisor of any known exposure to radioactive materials or conditions exceeding the allowable radiation or contamination values.

Staff Groups were comprised of the Safety, Fire and Radiation Control Department and the Medical Department (which combined medical and industrial hygiene). Their responsibilities with regard to radioactive materials included the following functional activities:

- Evaluation of environmental health hazards and recommendation of the corresponding PAL values for personnel exposure.
- Independent monitoring and audit of facilities and equipment to determine the effectiveness of measures employed to control toxicological, contamination, and radiation hazards.
- Provision of film devices, processing those devices, and maintenance of personnel monitoring records.

- Treatment of occupational illnesses and injuries.
- Determination of clinical effects that might be related to exposure to radioactive and/or chemically toxic materials and recommending job placement of employees to avoid aggravation of pre-existing pathology.
- Maintaining liaison with authorities in the field and advising the line organization of new developments affecting PALs, improvements in detection methods or protective devices, and treatment of possible injuries/illnesses.
- Continual review of overall plant program and making recommendations to the line organization.

The Service Organizations included Plant Engineering, Shipping and Receiving, Stores, Tool Stores, Works laboratory, Decontaminating Agencies, Process Utilities, Instrument Maintenance and Laundry. Each of these disciplines provided service that was necessary in the daily routine of the operation.

2.4.2.3 Plant Limits

Plant Limits were established for internal exposure, alpha contamination (personnel and environmental), beta-gamma (external penetrating and contamination), and shipping contaminated materials.

Internal exposure specified the permissible body burden for continuous exposure to internal alpha emitters and included U-normal, ^{233}U , and ^{239}Pu , with limits given for soluble and insoluble forms. Excretion rate limits were also specified.

The alpha personnel contamination PAL was specified for masks and respirators (transferable and surface), hands, body, clothing, and shoes in $\text{dis}/\text{min}/\text{cm}^2$. The alpha environmental contamination PAL was provided for air and water in terms of uranium and plutonium. A Contamination Index was utilized for floors, tables, and other work surfaces. This index was an indicator that averaged the intensity of surface and transferable contamination over a given work location or surface area and under conditions where surface contamination might be a concern. This index was a measure of the relative hazard of various locations.

Beta-gamma external penetrating radiation limits were based upon the type of radiation and the particular body organ, and expressed as mr or mrep per 2-week badge period. The beta-gamma contamination PALs were specified for personnel contamination and for environmental conditions (air, surface, and water).

Acceptable activity levels were also defined for shipping non-contaminated material and contaminated scrap, which could be offered for public disposal, if the contamination did not exceed those values.

2.4.2.4 Plant Regulations and Practices

Personnel Practices. Employees working with radioactive materials were given complete examinations at the time of employment, at termination, and periodically during employment. They also received more frequent partial examinations, including blood counts and urinalysis. Employees working with plutonium-bearing materials ($> 1 \text{ ppm Pu in U}$) were examined at least once every 6 weeks.

Health records, including exposure histories, were maintained as part of the complete plant exposure records. These records included the results from film badges, film rings, pocket

chambers and dosimeters, personnel involvement in releases of radioactive materials, the clinical results of that involvement, routine hand-counting results and hand/clothing spot checks. Medical advisory services were available to each employee.

Exposures to conditions in excess of the PAL were handled in accordance with plant procedures for the reporting and investigation of accidents. Measurements exceeding the PAL were determined by the results of shift length air samples, positive urinary findings, material releases, film meters (rings or badges), pocket chambers or dosimeters, or hand counts.

Radiation exposures (total body and hand) were reported for each two-week badge period. The values were compared to the respective PAL to determine any necessary follow-up. If the values were less than the PAL, no specific action was taken. Employees with results that exceeded the PAL by 10X were considered injured and were provided medical attention. Exposures that fell between the PAL and this higher limit resulted in work restrictions for the affected employee. During the restrictions, interim limits were set for the employee at less than half of the PAL. Restrictions remained in effect until the film badge results fell below the PAL, after which the employee could be returned to his previous assignment. If exposure results during the restriction exceeded the interim limits, the employee would be further restricted from any work involving penetrating radiation until the values fell below the PAL. In addition, a quarterly accumulated radiation exposure limit was also used for personnel monitoring and determining any associated work restrictions that might be necessary.

Urinalysis results that showed positive chemical values or alpha counts resulted with a recall for a follow-up submittal and analysis. Evidence of potential over-exposure resulted in the removal of the employee from contact with the radioactive materials until normal values were established. Additionally, four successive positive urinary values required obtaining a weekend sample (24 hours away from plant operations) to determine if radioactive materials were being stored in the body. Any evidence of detectable Pu or a significant fraction of the maximum permissible uranium body burden resulted in the removal of the employee from contact with such materials.

General Operational Practices. The confinement of radioactive contaminants within closed systems and shielding of penetrating radiation sources or fields to levels within the prescribed PAL was fundamental to control measures. As a result, design drawings for new facilities and modifications were forwarded to Staff and Service groups for formal comments. Field audits were made on a random basis to ensure that installations were made in accordance with those drawings.

Employees working with radioactive materials or in areas where it was not feasible to provide design features to prevent possible exposures were provided with personnel protective equipment (PPE) and protective devices as necessary. They were instructed in the hazards that might be encountered, and specific administrative controls were designed by the line organization to provide adequate protection.

The spread of radioactive materials was minimized by the decontamination of areas and equipment and through process design that included measures such as stainless-steel wall sheets, catch pans, strippable coatings, and vent hoods/booths. In addition, change facilities were provided that afforded separate storage for company issued clothing/PPE (that might be contaminated) from the employees' personal clothes. Good housekeeping was also emphasized as a daily measure to avoid the spread of contamination and included routine monitoring as a guide for decontamination efforts.

Work Involving Contamination and Radiation. The inhalation of radioactive materials was recognized as the most important source of possible exposure at ORGDP and, consequently, administrative controls were designed primarily to prevent this from occurring.

When attempts to maintain the alpha airborne contamination below the PAL were not successful, respiratory protection was worn. The air was monitored continuously or intermittently depending on the probability of airborne material and the degree of surface contamination associated with the operation.

Where the probability of air contamination existed and the concentration of airborne materials was unknown, it was assumed to be above the PAL until determined differently.

Surface contamination was recognized a potential source of airborne contamination and was controlled accordingly. The Contamination Index was derived as an indicator of the level of protection that would be required. Based upon four ranges of the value of this index, measures were implemented for employee protection. The first range denoted an uncontaminated surface. The second level denoted a slight level of contamination, but not to a level where a potential hazard is indicated. The supervisor made available radiation monitoring instruments and advised the employee of the same.

An index at the third level resulted with a continuous air-monitoring program (possibly supplemented with periodic surveys), a routine industrial check for the employee with the requirement to have open wounds tightly bandaged during work, mandatory respiratory protection on certain jobs (including company clothing) and no smoking or eating in the work location without thorough hand washing. Smoking and eating in the work location were prohibited as conditions warranted.

The fourth and highest level also required respiratory protection, company-issued clothing (including coveralls, shoes and head covers).

Penetrating radiation hazards were controlled by limiting the amount of working time in the immediate area, isolation by distance (including remotely operated handling devices), and shielding (e.g., heavy aprons and lead impregnated gloves).

Transfer of Equipment. Property transfer forms included a space to identify the contamination status of the particular item and helped to prevent the spread of contamination from one area to another. In addition, radiation tags on shipped items were used to denote penetrating radiation or alpha contamination. Any shipment had to meet the applicable requirements of the Atomic Energy Commission, Interstate Commerce Commission, U.S. Coast Guard, Civil Aeronautics Board and the U.S. Post Office Department.

Items were released to commercial channels only if they met the appropriate limits for non-contaminated items. Uranium contaminated scrap could be sold to commercial channels if it was in a condition that it could be adequately monitored and it met the appropriate limits. With special authorization from the plant superintendent, limited quantities of scrap contaminated in excess of those levels, but from which enriched uranium had been recovered as completely as possible, could be released for remelting, based upon the alpha activity.

There were strict practices for the receipt of contaminated materials, as well as the shipment of the same from plant to plant. Storage of these materials had to be segregated from those that were not contaminated.

Waste Disposal. Burnable waste was incinerated, beta-gamma contaminated waste was delivered to another installation for burial, and contaminated liquid waste was disposed of in accordance with plant specifications. Contaminated metals meeting contamination levels for

release could be sold. Other unburnable waste was delivered to the contaminated scrap metal yard.

2.4.2.5 Area Surveys

Three types of area surveys were employed at ORGDP: the Work Location, the Equipment, and the Audit survey.

The Work Location survey was performed by the operating group. The group routinely monitored the entire work area in locations where radioactivity was suspected or known to exist. Monitoring included alpha and beta-gamma surface and wipe activity, beta-gamma penetrating radiation levels, and the extent of airborne radioactive contaminants. Monitoring was performed with instrumentation that was the responsibility of the operating group.

Equipment surveys included temporary jobs in which process and related systems were opened and could possibly cause contamination of adjoining clean areas. When ordering maintenance work on this type of equipment, the operating group arranged for the purging and preparation of the systems for entry. The group advised the maintenance group of the type and extent of hazard involved and monitored to determine activity levels. A system of Hazardous Work Permits provided a positive control for all entries into the contaminated process system.

Audit surveys were scheduled on a non-routine basis, performed by the staff groups, and then reported to the line organization. These surveys included a large variety of monitoring activities/spot checks to provide an independent assessment of the radiological and hazardous conditions present in the workplace.

2.4.2.6 Personnel Monitoring

Monitoring for personnel contamination and possible exposure was accomplished through several methods.

Film badges or film rings were requested by supervisors for those employees routinely assigned to work in areas where penetrating radiation was likely to be encountered. Supervisors would also request the termination of this service when it was no longer required. Used film was processed biweekly, with quarterly summaries submitted to the supervisor.

In all areas where process equipment was used, visitor badges were maintained for use by visitors or by employees assigned to that area on an intermittent basis. These badges were processed the same manner as badges for the regular employees.

Local supervision assigned pocket chambers and dosimeters to employees, with a listing of all employees recorded on IBM records. Readings were obtained, and the results were recorded daily. Each week the IBM records were forwarded for inclusion in the plant exposure record, and the results of readings were summarized in the quarterly reports to the appropriate supervisors.

Employees were expected to perform hand counts during the course of their work as the need arose and prior to eating or leaving the plant. The recorded results were forwarded for inclusion in the plant exposure record.

Spot checks were made periodically to determine the extent of on-the-job contamination. A listing of the employees working with radioactive materials was furnished to the Medical Department by the supervisor. The type of work and exposure was evaluated, and employees were scheduled for periodic clinical examination, accordingly.

All employees working with radioactive materials were placed on a routine urinalysis program. Personnel whose job assignments posed higher potential for exposure were subject to an increase in frequency in the submittal of their urinalysis samples.

2.5 ENVIRONMENTAL IMPACT OF RU CONSTITUENTS

Process knowledge and a review of documentation narrowed activities that involved potential environmental contamination by the RU constituents of concern to two activities: ⁹⁹Tc vented to the atmosphere from the cascade and discharges of RU constituents in sludge from K-1420 to the K-1407-B and -C holding ponds. Quarterly news releases on environmental radioactivity levels at the Oak Ridge Gaseous Diffusion Plant from 1959 through 1964 report data gathered from air monitoring (for atmospheric contamination by long-lived fission products and alpha-emitting materials), water monitoring, and gamma measurements.⁶

2.5.1 Air Monitoring

Atmospheric contamination by long-lived fission products and fall-out occurring in the general environment of East Tennessee were monitored by two systems of monitoring stations during 1959–1964. One system consisted of seven stations that encircled all the plant areas and provided data for evaluating the impact of all DOE Oak Ridge operations on the immediate environment. A second system consisted of eight stations encircling the Oak Ridge area at distances of from 12 to 120 miles. Sampling was accomplished by passing air continuously through filter paper. The data collected were accumulated and tabulated in average $\mu\text{c}/\text{cc}$ of air sampled. Figures 2.5-1 and 2.5-2 show the locations of both the perimeter and remote continuous air monitoring stations.

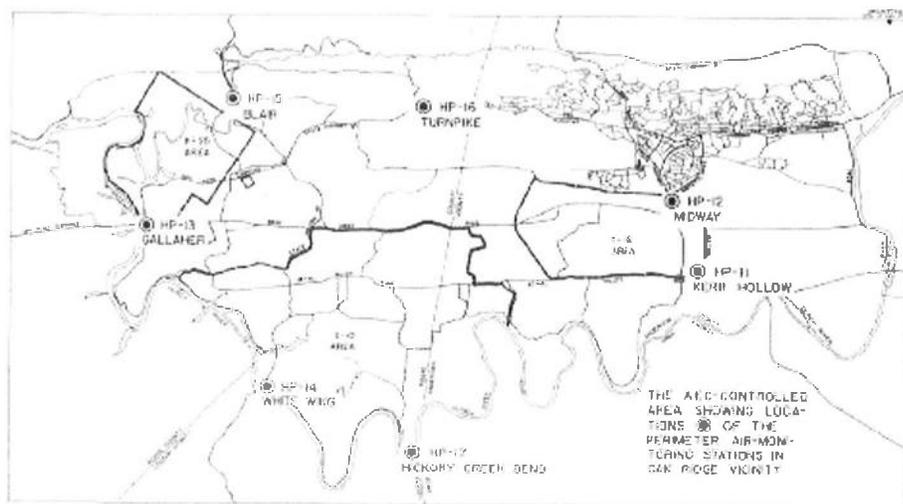


Fig. 2.5-1. Station Sites for Perimeter Air Monitoring System.

⁶ News Releases, "Environmental Radioactivity Levels, the Oak Ridge Gaseous Diffusion Plant," Oak Ridge Gaseous Diffusion Plant, January 1959 through June 1964.

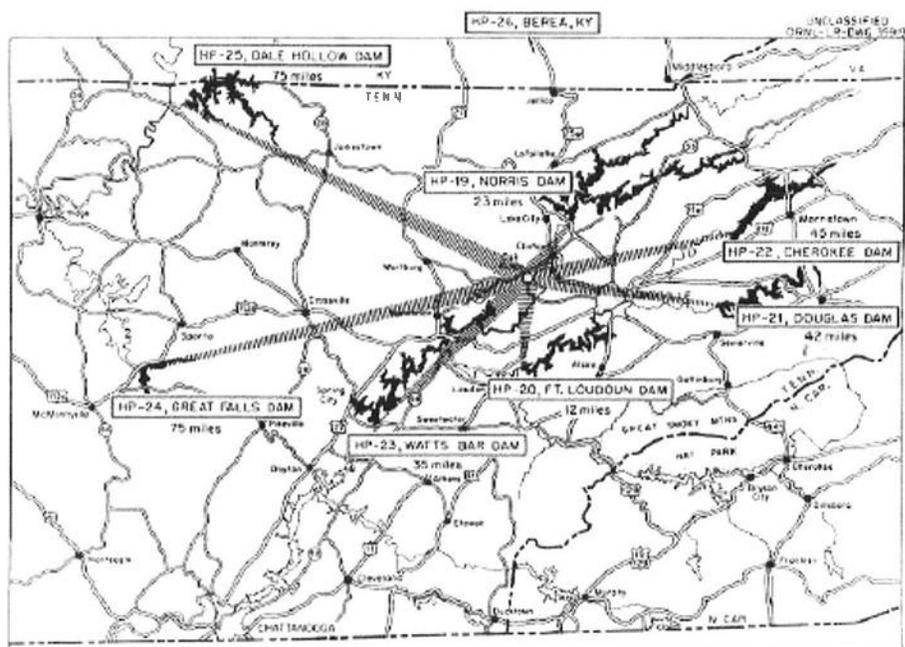


Fig. 2.5-2 Station Sites for Remote Air Monitoring System.

Summaries of the data for the perimeter and remote stations are shown in Tables 2.5-1 and 2.5-2.

Table 2.5-1. Continuous Air Monitoring Data – Perimeter Stations
Long-Lived Gross Beta Activity of Particulates in Air

Year	Period	Number samples (range)	Max*	Min*	Average*	% of MPC**
1959	year	49-52	81.31	0.08	15.76	1.6
1960	Q1	13	2.99	0.24	1.08	0.11
1960	Q2	13	4.22	0.21	1.63	0.16
1960	Q3	14	2.86	0.07	0.85	0.09
1960	Q4	13	1.80	0.04	0.46	0.05
1961	Q1	13-14	1.65	0.0	0.6	0.06
1961	Q2	13-14	8.51	0.18	1.19	0.12
1961	Q3	14	157.0	0.07	20.9	2.1
1961	Q4	13	73.0	16.0	35.0	3.5
1962	Q1/Q2	26-74	90.0	22.0	41.0	4.1
1962	Q3/Q4	26-74	81.0	11.0	30.0	3.0
1963	Q1/Q2	26-181	131.0	27.0	60.0	6.0
1963	Q3/Q4	26-180	69.0	3.0	20.0	2.0
1964	Q1/Q2	26-180	35.0	4.0	13.0	1.3

* Units of $10^{-13} \mu\text{c/cc}$

** Maximum Permissible Concentration (MPC) is taken to be $10^{-10} \mu\text{c/cc}$ as recommended in NBS Handbook 69

**Table 2.5-2. Continuous Air Monitoring Data – Remote Stations
Long-Lived Gross Beta Activity of Particulates in Air**

Year	Period	Number Samples (Range)	Max*	Min*	Average*	% of MPC**
1959	year	26-52	100.52	0.14	13.97	1.4
1960	Q1	13	2.73	0.12	1.14	0.11
1960	Q2	10-13	3.11	0.08	1.65	0.17
1960	Q3	11-13	2.39	0.16	0.8	0.08
1960	Q4	12-13	2.66	0.12	0.49	0.05
1961	Q1	13-14	1.18	0.0	0.55	0.06
1961	Q2	13-14	2.22	0.2	0.95	0.1
1961	Q3	14	220.0	0.07	23.6	2.4
1961	Q4	13	88.0	15.0	41.0	4.1
1962***	Q1/Q2	26	97.0	20.0	49.0	4.9
1962	Q3/Q4	26	159.0	11.0	36.0	3.6
1963	Q1/Q2	25-26	114.0	35.0	63.0	6.3
1963	Q3/Q4	25-26	91.0	4.0	24.0	2.4
1964	Q1/Q2	25-26	48.0	4.0	17.0	1.7

* Units of 10^{-13} $\mu\text{c}/\text{cc}$

** Maximum Permissible Concentration (MPC) is taken to be 10^{-10} $\mu\text{c}/\text{cc}$ as recommended in NBS Handbook 69

*** The Berea, Kentucky remote station provided no samples after 1961

The highest percent Maximum Permissible Concentration (MPC) values for the perimeter and remote monitoring stations for the period were in the first half of 1963 and were reported as 6% and 6.3%, respectively. The news release for that period states that: "Although these values are approximately two times greater than the average for the last half of 1962, they are no greater than the average of those measured in other areas of the United States and reported by the U.S. Public Health Radiation Surveillance Network for the period January through May 1963."

Beginning in 1961, atmospheric contamination by uranium was determined by taking periodic air samples at eight locations on a five-mile radius from the ORGDP. An average of 16 random, 10-minute samples were taken each quarter. Beginning in the fourth quarter, 1961, the analysis performed changed from uranium concentration to gross alpha, and the sampling methodology changed from random to continuous. The results are shown in Table 2.5-3.

Table 2.5-3. ORGDP Air Monitoring Data

Year	Period	Number of Samples	Direction from Plant				Average*	% MPC _a
			North*	East*	South*	West*		
1961	Q1	16	0.0	0.33	0.25	0.75	1.03	5.0
1961	Q2	16	0.5	0.75	1.8	1.4	1.3	6.5
1961	Q3	10	0.75	0.5	0.35	0.25	0.45	2.3
1961**	Q4	592	3.0	1.6	2.6	1.8	2.4	12.0
1962	Q1/Q2	2279	1.7	1.6	1.7	1.6	1.6	8.0
1962	Q3/Q4	2431	2.8	3.6	3.0	4.6	3.3	17.0
1963	Q1/Q2	2346	1.7	1.7	2.3	3.5	2.2	11.0
1963	Q3/Q4	1418	2.5	5.0	2.5	***	4.0	20.0
1964	Q1/Q2	1595	3.0	4.5	4.0	***	3.5	18.0

* Units of 10^{-13} $\mu\text{c}/\text{cc}$

** Beginning in Q4 1961, the analysis changed from uranium concentration to gross alpha and the sampling methodology changed from random to continuous

*** Sampling locations changed from N, E, S, & W to N, NE and SW.

The highest value for the approximate 5-year period was 20% of the MPC for air (MPC_a) for populations in the neighborhood of a controlled area.

2.5.2 Water Monitoring

Liquid wastes originating at ORGDP and the Y-12 Plant were discharged to Poplar Creek, which flows into the Clinch River. Releases were controlled to enable resulting average concentrations in the Clinch River to comply with the maximum permissible levels for populations adjacent to DOE facilities as recommended by the National Committee on Radiation Protection (NCRP). Water was sampled at a number of locations in the Clinch River, beginning at a point of entry of wastes into the river (mile 20.8) and ending at Center's Ferry near Kingston, Tennessee (mile 4.5). The average concentration of radioactivity at these two points was then calculated. The average concentration of TRU alpha emitters at mile 20.8 was also calculated. Stream-gauging operations were carried on continuously by the U.S. Geological Survey to obtain dilution factors for calculating the probable concentrations of wastes in the river. The average activity in Poplar Creek was also reported in 1959 and 1960. These results for the five-year period are shown in Table 2.5-4 as percentages of the MPC for water (MPC_w) for populations in the neighborhood of a controlled area.

Table 2.5-4. ORGDP Water Monitoring Data

Year	Period	% MPC _w (Clinch River)*		% MPC TRU alpha emitters (Clinch River)	% MPC activity (Poplar Creek)
		Mile 20.8	Mile 4.5		
1959	year	25.4	22.3	0.03	0.03
1960	Q1	26.9	16.4	0.002	0.02
1960	Q2	23.2	7.9	0.001	0.03
1960	Q3	12.6	4.9	0.001	0.04
1960	Q4	22.0	17.0	0.0004	
1961	Q1	33.0	13.0	0.0007	
1961	Q2	21.0	7.0	0.0005	
1961	Q3	6.3	3.1	0.003	
1961	Q4	8.8	5.5	0.0001	
1962	Q1/Q2	8.2	6.2	0.0002	
1962	Q3/Q4	6.4	3.9	0.0003	
1963	Q1/Q2	5.6	3.4	0.0002	
1963	Q3/Q4	3.3	4.0	0.0002	
1964	Q1/Q2	3.5	2.0	<0.001	

*The fraction of the total beta activity comprised by each isotope was determined from analysis of long-lived radionuclides contained in the effluent and a weighted average maximum permissible concentration for water (MPC_w) for the mixture of radionuclides is calculated on the basis of the isotopic distribution using the MPC values of each isotope as recommended by the NCRP. The average concentration of gross beta activity in the Clinch River was compared to the calculated MPC_w values. The concentration of uranium was compared with the specific MPC_w value for uranium.

There were no instances of water release at ORGDP boundaries above the long-term MPC concentrations.

2.5.3 Gamma Measurements

External gamma radiation levels were measured monthly at a number of locations in the Oak Ridge area. These locations included Solway Gate, Y-12 Plant East Portal, Newcombe Road in Oak Ridge, Gallaher Gate, and White Wing Gate. Measurements were taken with a Gieger-Muller tube at a distance of three feet above ground, with the results tabulated in mr/hr. These results are shown in Table 2.5-5.

Table 2.5-5. External Gamma Radiation Levels (mr/hr)

Year	Period	Average
1959	year	0.024
1960	Q1	0.017
1960	Q2	0.020
1960	Q3	0.020
1960	Q4	0.020
1961	Q1	0.015
1961	Q2	0.020
1961	Q3	0.019
1961	Q4	0.020
1962	Q1/Q2	0.027
1962	Q3/Q4	0.031
1963	Q1/Q2	0.028
1963	Q3/Q4	0.023
1964	Q1/Q2	0.014

The news releases state that "These average levels were the same as average background levels obtained throughout the United States by the U.S. Public Health Service Radiation Surveillance Network, employing similar methods and detection instruments."

A historical compilation of radionuclide release data was published in the 1986 *Oak Ridge Gaseous Diffusion Plant Historical Uranium and Radionuclide Release Report*, K/HS-95. This report documented releases from 1946 through 1984 and included data on the radionuclides associated with RU feed material, including transuranics and fission products. These data are presented in Section 4.7 of this report.

A joint task force was assembled by DOE in 1985 to study past and current practices related to processing of RU materials. From the data reviewed, the task force did not disclose any instance in which the environment or the safety or health of plant workers or the public were jeopardized or compromised. The primary recommendation for gaseous diffusion plant operations from this study was to develop formal specifications on maximum permissible levels of contaminants in enrichment feed materials. This study is documented in the DOE's 1985 *Report of the Joint Task Force on Uranium Recycle Materials Processing*.⁷

An Oak Ridge Dose Reconstruction Project was initiated in 1994 as follow-up to the Oak Ridge Dose Reconstruction Feasibility Study, which recommended a closer examination of the past uranium emissions and potential resulting exposures. The initial feasibility study performed

⁷ D. Egli, et al., *The Report on the Joint Task Force on Uranium Recycle Materials Processing*, DOE/OR-859, U.S. DOE Oak Ridge Operations, September 1985.

screening calculations to identify those operations and materials that warranted detailed investigation in terms of potential off-site exposures to the individuals that have lived in the areas surrounding the Oak Ridge Reservation (ORR). At the close of the feasibility study, the Tennessee Department of Health and the Oak Ridge Health Agreement Steering Panel (ORHASP) recommended that a detailed project—including dose reconstruction—be performed. The results of a portion of this project were documented in the July 1999 Task 6 report entitled *Uranium Releases from the Oak Ridge Reservation—a Review of the Quality of Historical Effluent Monitoring Data and a Screening Evaluation of Potential Off-Site Exposures*.⁸

The Task 6 component of the project involved further evaluation of Oak Ridge uranium operations and effluent monitoring records to determine if uranium releases from the ORR likely resulted in off-site doses that warranted further study. The team performed a historical review of air and water release data, including health physics and industrial hygiene reports, stack monitoring data, accident and investigation reports, logbooks, and procedures for the period 1944 through 1988.

The Task 6 team concluded that estimates of uranium releases were underestimated by the Atomic Energy Commission (AEC), DOE, and ORR site contractors. One major reason for the discrepancies at ORGDP involves releases from the S-50 Liquid Thermal Diffusion Facility. As an experimental predecessor to gaseous diffusion technology, this facility is considered one of the major undocumented (or partially documented) sources of historic uranium releases from the ORR. These losses were not included in prior DOE/AEC/ORGDP release estimates because, during its short 12-month operation in 1944-1945, S-50 was not considered part of ORGDP operations. The K-1131 feed plant and the K-1420 decontamination facility together represent the source of approximately 50% of the total material unaccounted for at ORGDP. Uncertainties and insufficient data for cascade releases, stack sampling, and water pathways such as storm sewer drains and settling ponds all were found to have the potential to add additional quantities of uranium to the Task 6 release estimates.

The evaluation of uranium airborne releases from the K-25 Complex (i.e., ORGDP and S-50) was based on analysis of uranium accountability records and incident reports, calculation of purge cascade releases from monitoring data, and results of periodic monitoring in three buildings at ORGDP. Estimates of airborne uranium releases over time were generated from the data gathered. The total mass (kg) of uranium released to the atmosphere from the K-25 Complex for the period 1944 through 1995 was estimated to be 16,000 kgU. Figure 2.5-3 shows the release estimates plotted over time.

The screening evaluation of potential off-site exposure to waterborne uranium was based on environmental measurements of uranium in local surface waters. Reported annual average uranium concentrations in the Clinch River were used for the Task 6 screening evaluation. These values were based on water samples collected at the confluence of Poplar Creek and the Clinch River for all the years of operation, up to 1995. Effluent monitoring data were also evaluated for quality and consistency with previous DOE historical uranium release reports. The average annual concentration of uranium in the Clinch River for the period 1944–1995 was estimated to be 0.015 mgL⁻¹.

⁸ *Reports of the Oak Ridge Dose Reconstruction, Vol.5, The Report of Project Task 6: "Uranium Releases from the Oak Ridge Reservation—a Review of the Quality of Historical Effluent Monitoring Data and a Screening Evaluation of Potential Off-Site Exposures,"* July 1999.

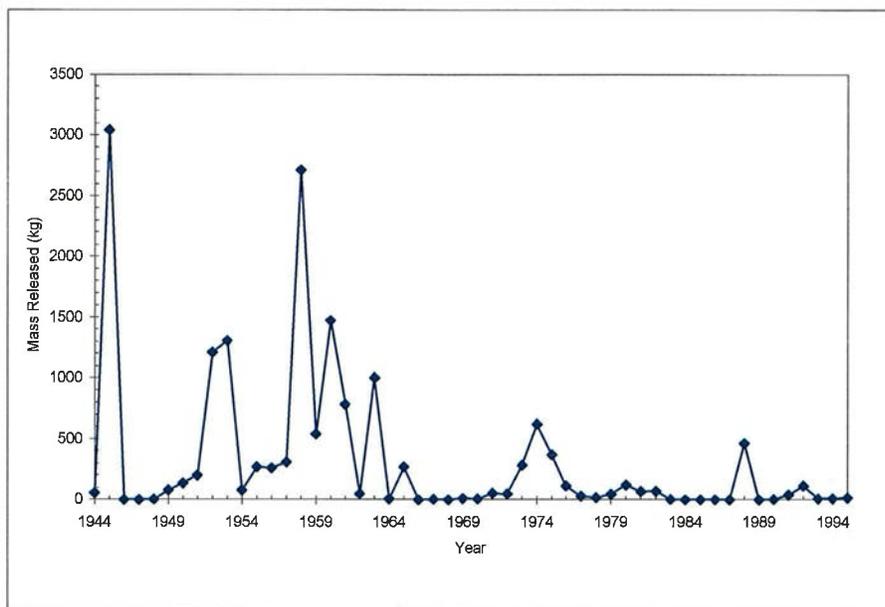


Fig. 2-5-3. Estimates of Annual Airborne Uranium Releases from the K-25/S-50 Complex.

Based on the decision guidelines from the ORHASP, the Task 6 team concluded that the uranium releases from the K-25 Complex are candidates for further study, but that they are not high priority candidates. Instead, further characterization of the extent of uranium contamination in soils should be evaluated for potential exposures to nearby residents.

The Task 7 component of the Oak Ridge Dose Reconstruction effort involved the screening of additional potential materials of concern, including Np and ⁹⁹Tc. This portion of the effort was documented in the July 1999 Task 7 report entitled *Screening-Level Evaluation of Additional Potential Materials of Concern*.⁹

2.5.4 Neptunium

The Task 7 team identified no historical stack monitoring or ambient air monitoring data for Np. Therefore, Np sources for ORGDP were estimated based on RU material sent to each plant. In the 1988 DOE Report *Historical Radionuclide Releases from Current DOE Oak Ridge Operations Office*, DOE reported releases of Np in liquid wastes from 1979 through 1983.¹⁰ However, DOE did not provide estimates for air releases of Np. The Task 7 team therefore estimated the total annual Np activity released from ORGDP by using a three-step process: calculate the mass of RU received annually at ORGDP; calculate the Np activity based on the mass of RU received annually and the specific activity of Np; and calculate the Np activity released to the air per year based on the uranium release fraction and the assumption that the Np fraction was equivalent to the uranium release fraction. Np concentrations were calculated based on the uranium upper alpha activity of 200,000dpm g⁻¹ (Egli et al., 1985). It was recognized that

⁹ *Reports of the Oak Ridge Dose Reconstruction, Vol.5, The Report of Project Task 7: "Screening-Level Evaluation of Additional Potential Materials of Concern,"* July 1999.

¹⁰ U.S. Department of Energy. *Historical Radionuclide Releases from Current DOE Oak Ridge Operations Office*, ORO-890, U.S. DOE Oak Ridge Operations, 1988.

the calculated estimate would be conservatively high because the alpha activity in uranium is a result of uranium, Pu, and Th, as well as Np. Table 2.5-6 provides the estimated airborne releases of Np per year from ORGDP for the period 1953 to 1995.

Table 2.5-6. K-25 Np-237 Release Estimates

Year	Air Release (mCi)	Water Release (mCi)
1953	110.0	2.2
1954	48.0	2.2
1955	50.0	2.2
1956	24.0	2.2
1957	24.0	2.2
1958	140.0	2.2
1959	39.0	2.2
1960	72.0	2.2
1961	54.0	2.2
1962	13.0	2.2
1963	49.0	2.2
1964	2.3	2.2
1965	13.0	2.2
1966	1.7	2.2
1967	1.6	2.2
1968	2.2	2.2
1969	2.9	2.2
1970	2.3	2.2
1971	3.4	2.2
1972	3.9	2.2
1973	6.5	4.5
1974	14.0	1.1
1975	0.81	1.1
1976	2.4	0.56
1977	1.5	1.7
1978	1.5	1.7
1979	1.5	1.5
1980	1.5	1.5
1981	1.5	2.1
1982	1.5	1.5
1983	1.5	0.4
1984	1.5	2.2
1985	1.5	2.2
1986	1.5	2.2
1987	1.5	2.2
1988	1.5	2.2
1989	1.5	2.2
1990	1.5	2.2
1991	1.5	2.2
1992	1.5	2.2
1993	1.5	2.2
1994	1.5	2.2
1995	1.5	2.2
TOTAL (mCi)	710.0	88.0

Estimates of waterborne Np releases at ORGDP from 1979 to 1983 were also provided in the DOE *Historical Radionuclide Releases from Current DOE Oak Ridge Operations Office*. The annual environmental monitoring reports provide waterborne release estimates for transuranics from the ORR for the period 1973 to 1986. Estimates for Np releases for these years were calculated as a fraction of the total transuranics released. For the years that no data were available, annual Np releases to water were assumed to be equal to the 95% of the upper confidence limit (UCL) of measured and estimated Np from 1973 to 1983 (0.0022 Ci)—a representative period of active equipment decontamination and barrier replacement. Table 2.5-6 presents ORGDP Np annual waterborne release estimates in mCi for the period 1953 to 1995.

2.5.5 Technetium

⁹⁹Tc is present in the environment as a result of global fallout from nuclear weapons testing and of nuclear fuel reprocessing worldwide. This man-made background source would become a part of ongoing measurements performed on or around the ORR. The estimated average concentration of ⁹⁹Tc in soil worldwide due to global fallout from nuclear weapons tests is 2.2 pCi kg⁻¹.¹¹

Historical measurements of ⁹⁹Tc in the environment near the ORR are extremely limited. The Task 7 team did not locate any information regarding airborne releases of ⁹⁹Tc prior to 1974. However, the 1978 *Draft Mass Balance, ORGDP* provides an estimate of the amount of ⁹⁹Tc received at ORGDP from 1953-1977,¹² and the team used these ⁹⁹Tc quantities to estimate the total ⁹⁹Tc releases. To calculate releases of ⁹⁹Tc to the air, the material balance report assumed that there were two release points to the atmosphere: the K-1131 feed plant stack and the purge cascade vent. K-1131 was shut down in the early 1960s and would not have contributed to releases beyond that time period. The material balance report assumed that the ORGDP feed plant functioned similarly to the PGDP facility, where an estimated 5% of the ⁹⁹Tc in the UO₃ was vented to the atmosphere during fluorination. A 5% release fraction applied to the 8.6 kg of ⁹⁹Tc received each year yields a calculated annual release of 0.43 kg (7.3Ci) of ⁹⁹Tc from the K-1131 stack from 1953 to 1962. For the second source of airborne ⁹⁹Tc releases from ORGDP (the purge cascade), the material balance report estimates airborne releases from 1953 to 1973 by averaging the purge cascade monitoring data for 1974 to 1976. The average release of 2.5 Ci per year from the purge cascade over this three-year period was applied to earlier time periods (1953 to 1973). In 1977, a scrubber was installed on the purge cascade vent, which resulted in a considerable decline in ⁹⁹Tc airborne releases. From 1978 through 1995, the screening analysis used release estimates reported in the annual environmental monitoring reports.

No measurements of ⁹⁹Tc concentrations in liquid effluent from ORGDP prior to the late 1980s were identified by the project team. Beginning in 1987, concentrations of ⁹⁹Tc were measured monthly in Poplar Creek. Concentrations from 1987 to 1995 ranged from less than the limit of detection to 1,860 pCi/L⁻¹. During this same time period, concentrations downstream in the Clinch River ranged from less than the limit of detection to 1,640 pCi/L⁻¹.

Based on the qualitative and quantitative screening performed by the Task 7 team, Np material used at ORGDP was judged not to warrant further study. ⁹⁹Tc was identified as one of the potential candidates for further study, but was not identified as a high priority.

¹¹ F. O. Hoffman, *Environmental Behavior of Technetium in Soil and Vegetation: Implications for Radiological Impact Assessment*, ORNL-5856, Oak Ridge National Laboratory, 1982.

¹² *Draft Mass Balance, ORGDP*, Oak Ridge Gaseous Diffusion Plant, 1978 (from Box 8-3-5, K-25 Site Records Center).

3.0 RECYCLED URANIUM MASS FLOW

3.1 URANIUM RECYCLE DESCRIPTION

For purposes of this project, RU has been defined as any uranium that has been irradiated in a reactor and as a result contains TRU (e.g., Pu and Np) and fission products (e.g., ^{99}Tc). The methodology applied in this project for identifying ORGDP's involvement with the flow of RU materials involves: (1) the source site and (2) the ^{235}U assay of the material. Sites identified as RU candidate source sites are the U.S. government facilities at Hanford and Savannah River that operated production reactors and used chemical separation processes to extract uranium from irradiated fuel, Harshaw Chemical Company, and foreign customers for U.S enrichment services. Secondary sites providing RU to ORGDP included PGDP, PORTS, and ORNL.

Data for ORGDP transactions with these RU candidate source sites was extracted from Material Balance Reports (MBR) issued by the site Nuclear Material Control and Accountability (NMC&A) organization. These reports provide official accountability data for all site uranium and for other accountable nuclear materials, including the name or symbol-code of the accountability station with which the receipt from or shipment to has occurred, material type, amount of uranium, ^{235}U , and the ^{235}U assay. The earlier MBRs listed the name and location of the accountability station (e.g., General Electric Company, Richland, Washington) rather than the accountability station symbol-code (e.g., HGE). The accountability station symbol-code, now referred to as the Reporting Identification Symbol (RIS), began appearing on the ORGDP MBRs in FY 1964.

The second level for identification of RU involves the ^{235}U assay of the uranium. Based on process knowledge relative to assay ranges, the annual average assay of RU receipts from the source sites provides a basis for tracking RU in inventories, feed to the gaseous diffusion process, and shipments.

Under the NMC&A program, uranium is an accountable nuclear material. However, RU is not separately accountable. It should be recognized that the methodology utilized in this project for identifying and tracking RU is imperfect, and some level of RU accountability is unavoidably lost. Physical losses of RU occurred which could not be identified and quantified. Loss of accountability likely occurred as a result of assay blending of RU with non-RU with the result that the RU could no longer be tracked. Other losses of accountability may have occurred as a result of data unavailability or the misinterpretation of data. Losses are discussed further in Section 3.4.

3.2 URANIUM RECEIPTS

ORGDP first received RU from Hanford in FY 1952 when 99,970 kg of UO_3 was recorded. Receipts from Hanford continued from FY 1952 through FY 1962. During the period 1952 through 1958, the annual average ^{235}U assay range for Hanford RU receipts was 0.646% to 0.666%. Beginning in FY 1959, the assay changed from depleted to slightly enriched in the range of 0.848% to 0.864%. In total, 4,276,111 kgU of RU was received from Hanford. Annual receipts are summarized in Table 3.2-1.

Table 3.2-1. RU Received at ORGDP from Primary Source Sites

Fiscal Year	Hanford		Harshaw		Savannah River		Foreign		Total kgU
	kgU	Assay	kgU	Assay	kgU	Assay	kgU	Assay	
1952	99,970	0.646							99,970
1953	578,249	0.666	1,402,761	0.666					1,981,010
1954	1,115,345	0.666	299,574	0.671					1,414,919
1955	526,475	0.657			271,949	0.682			798,424
1956	323,882	0.665			2,538,844	0.670			2,862,726
1957	98,218	0.652			2,635,163	0.667			2,733,381
1958	7,201	0.649			1,077,065	0.648			1,084,266
1959	261,253	0.848			828,250	0.625			1,089,503
1960	609,775	0.856			1,677,456	0.603			2,287,231
1961	611,020	0.853			1,121,645	0.598			1,732,665
1962	44,722	0.864			139,308	0.590			184,030
1963	1	0.650							1
1964 - 1968									
1969							2,033	1.332	2,033
1970							20,532	1.724	20,532
1971							4,734	1.698	4,734
1972							24	2.151	24
1973							61,531	1.638	61,531
1974							115,373	0.989	115,373
1975							73,892	0.888	73,892
1976+TQ							86,145	0.746	86,145
1977							55,965	1.090	55,965
1978							28,355	1.193	28,355
1979							46,454	1.037	46,454
1980							88,047	1.262	88,047
1981							67,078	1.011	67,078
1982									
1983							257,687	1.525	257,687
1984							173,916	1.257	173,916
1985									
1986							211,140	0.947	211,140
1987							1	3.207	1
1988							1,451	1.118	1,451
1989 - 1999									
TOTALS*	4,276,111		1,702,335		10,289,680		1,294,359		17,562,485

* Numbers may not sum because of rounding.

During FY 1953 and FY 1954, 1,702,335 kgU of RU was delivered to ORGDP from Harshaw Chemical Company. This material had previously been delivered to Harshaw from Hanford. Documentation found in *AEC Accountability Survey Reports, Reports for Period October 1947 Through May 27, 1953 (U)*¹ states that:

The feed manufacture plant began processing depleted uranium from the Hanford recovery process in June 1952. Difficulties, attributed to impurities in the recovered oxide, were experienced in processing this material. Consequently, during September the feed manufacture plant resumed operations in normal uranium trioxide from Harshaw and uranium tetrafluoride from Mallinckrodt. Present plans are to remove the objectionable impurities and render the Hanford recovered material chemically more reactive at Harshaw prior to processing it in the feed plant at Carbide K-25.

Receipts of RU from Savannah River were first recorded in FY 1955 and continued through FY 1962. During this time, 10,289,680 kgU was received. The ²³⁵U annual average assay range for receipts of Savannah River RU was 0.590% to 0.682%. Based on process

¹ *AEC Accountability Survey Reports, Reports for Period October 1947 Through May 27, 1953 (U)*

knowledge relative to assay for reactor fuels used at Hanford and Savannah River and on receipts from both, assay ranges for tracking Hanford and Savannah River RU at ORGDP were established as 0.59% to 0.69% for depleted and 0.84% to 0.87% for enriched. Inventories and transactions on the outer boundaries of these assay ranges were considered on a case-by-case basis.

Beginning in FY 1969, RU was received at ORGDP from foreign sources primarily in the form of UF₆. All foreign receipts, excluding normal assay assumed to be non-RU, were analyzed. Non-normal receipts from foreign entities continued through FY 1988, with the exception of FY 1982 and FY 1985 when no foreign receipts were recorded. All receipts ranged in assay from 0.746% ²³⁵U to 3.2% ²³⁵U.

Data collected from ORGDP MBRs indicates that from FY 1969 through FY 1988, a total of 1,294 MTU of non-normal material was received from foreign sources. Table 3.2-2 provides a summary of receipts by country.

Table 3-2.2. Foreign Reactor RU Returns to ORGDP

Country	MTU
France	843
United Kingdom	296
Germany	132
Netherlands	10
International Account*	10
Belgium	2
Japan, Namibia, India, and Sweden	1
Total	1,294

*From material distributed by the Division of International Affairs.

Receipts of 843 MTU from France at assays of less than 2% are believed to be RU. It is known that the French had the reprocessing capability. The United Kingdom returned 296 MTU. The United Kingdom material is believed to be RU, and 231 MTU of this material was fed to the cascade in FY 1975, FY 1976, the FY 1976 transition quarter, and FY 1978. It appears that 12 MTU of French material was fed in FY 1978. Quantities and assay range of foreign receipts are shown in Table 3-2.3.

Table 3-2.3. Quantities of Assay Range of Foreign Reactor Returns

Assay Range % ²³⁵ U	Quantity (MTU)	Average Assay % ²³⁵ U	Percent of Total
≤ 0.69	243	0.643	18.8
0.715 - 1.5	810	0.979	62.6
1.51 - 2.5	151	2.048	11.7
≥ 2.51	90	2.956	6.9
TOTAL	1,294		

In FY 1986, a year after ORGDP was placed in standby, 486 MTU of foreign uranium at average assays of about 1% was shipped to PGDP. PGDP recorded this as receipts of RU. One cylinder of approximately 1 MTU was returned to France in FY 1988. This material plus the 243 MTU depleted that is known to have been fed to the cascade leaves about 565 MTU to be accounted for. Of the amount of RU shipped to PGDP, 2,810 kgU was categorized by ORGDP as UF₆ heels. It is assumed that the full content of these cylinders, that now contain only heels, was fed to the ORGDP cascade and thus accounts for the 565 MTU. The 2,810 kgU heels represents about 367 30B cylinders, assuming a maximum heel of 11.34 kg UF₆ (7.666 kgU). The maximum full shipping weight limit per cylinder is 2,277 kg UF₆ (1,539 kgU). Therefore, the 367 cylinders can account for the 565 MTU as likely being fed to the ORGDP cascade.

In addition to receipts from source sites, ORGDP received material identified as RU from PGDP, PORTS, and ORNL. These receipts were identified from the MBRs based primarily on defined assay ranges and are presented on Table 3.2-4. The PGDP and PORTS RU was primarily in the form of UF₆. Receipts from ORNL were in the form of UO₃ and UF₄.

Table 3.2-4. RU Received at ORGDP from Secondary Sites

Fiscal Year	PGDP		PORTS		ORNL		TOTAL kgU
	kgU	Assay	kgU	Assay	kgU	Assay	
1952					12	0.656	12
1953	153,111	0.637					153,111
1954	21,396	0.669			694	0.653	22,090
1955	33,426	0.655			1,134	0.661	34,560
1956	27,341	0.669	3,048	0.673	830	0.655	31,219
1957	34,906	0.661			2,586	0.653	37,492
1958	29,020	0.670			4	0.670	29,024
1959	70,151	0.652			1	0.593	70,152
1960	2,091	0.642					2,091
1961	244	0.634			12	0.671	256
1962	10,511	0.634					10,511
1963	35,489	0.640					35,489
1964	9,052	0.641					9,052
1965	464	0.640					464
1966 - 1968							0
1969	236,325	0.643					236,325
1970	420,388	0.656			1	0.630	420,389
1971 - 1999							
TOTALS*	1,083,914		3,048		5,274		1,092,236

* Numbers may not sum because of rounding.

3.3 URANIUM SHIPMENTS

Shipments of RU from the ORGDP site were identified from the MBRs based on the assay ranges for RU receipts as discussed in Section 3.2. ORGDP shipments are summarized in Table 3.3-1.

Shipments to PGDP are presented by fiscal year in Table 3.3-2. Shipments to PGDP within the assay ranges defined as RU as shown in the MBRs were 13,994,541 kgU. This amount has been reduced by 1,946,116 kgU withdrawn from the ORGDP cascade and 419,096 kgU received from the Y-12 Plant within the defined assay range for RU, both of which were determined to be non-RU. Based on timing of these receipts of non-RU and shipments to PGDP,

it was determined that the most likely disposition of the non-RU was to PGDP. However, it is recognized that some part of this non-RU could have been fed to ORGDP.

Table 3.3-1. ORGDP Shipments of RU

Receiving Site	kgU
PGDP	11,629,329
PORTS	301,077
Y-12 Plant	189,146
ORNL	7,589
Savannah River	11,057
Fernald	1,909
Foreign	1,451
TOTALS	12,141,558

Table 3.3-2. ORGDP RU Shipments to PGDP

Fiscal Year	MBR Total Assay Range Shipments (kgU)	Adjustments		Net Shipments (kgU)
		Cascade Withdrawals (kgU)	Receipts from Y-12 (kgU)	
1952	7		1,310	0
1953	2,738,891	976,490	2,601	1,758,490
1954	1,768,711	120,163	139,919	1,508,629
1955	1,403,643	452,068	29,153	922,422
1956	2,669,834		112,659	2,557,175
1957	3,181,798		31,700	3,150,098
1958	29,096		29,033	63
1959	514,635		43,551	471,084
1960	580,679		28,468	552,211
1961	81,039		702	80,337
1962	46,825			46,825
1963	64,711			64,711
1964	17,498			17,498
1965 - 1969				
1970	14,126			14,126
1971				
1972	397,395	397,395		0
1973				
1974	(3)			(3)
1975 - 1985				
1986	485,656			485,656
1987 - 1999				
TOTALS*	13,994,541	1,946,116	419,096	11,629,322

* Numbers may not sum because of rounding.

In addition to off-site shipments, 5,914,681 kgU of RU, including 807,172 kgU of foreign receipts, were fed to the ORGDP cascade. Feed to the ORGDP cascade is presented in Table 3.3-3.

Table 3.3-3. Summary of Feed to ORGDP Based on Cumulative Cascade MBRs

Year	Reactor Returns (MTU)	Normal (MTU)	PGDP Product (MTU)	Other (Inc. Refeed) (MTU)	Total Feed (MTU)
CY 1947		592		111	703
CY 1948		674		101	775
CY 1949		674		511	1,185
CY 1950		822		462	1,284
JAN - JUN 1951		456		669	1,125
FY 1952		1,299		5,761	7,060
FY 1953	153	1,100	1,664	5,307	8,224
FY 1954		1	3,591	20	3,612
FY 1955	3	5	3,703	110	3,821
FY 1956		264	4,149	39	4,452
FY 1957			4,604	32	4,636
FY 1958		116	3,380	1,482	4,978
FY 1959	660	1,398	3,292	9	5,359
FY 1960	1,949	876	2,930	20	5,775
FY 1961	1,259	1,947	2,933	3	6,142
FY 1962	424	2,408	2,851	23	5,706
FY 1963	5	2,109	2,871	47	5,032
FY 1964	4	2,654	2,184	483	5,325
FY 1965			2,126	5,053	7,179
FY 1966	4	2	2,112	5,669	7,787
FY 1967			1,931	5,497	7,428
FY 1968			1,730	5,062	6,792
FY 1969	2	1,521	2,713	402	4,638
FY 1970	377	1,811	2,637	43	4,868
FY 1971	5	2,918	2,832	577	6,332
FY 1972		1,542	2,782	367	4,691
FY 1973	62	3,557	1,875	147	5,641
FY 1974	287	3,723	2,060	0	6,070
FY 1975	91	4,454	1,891	0	6,436
FY 1976	70	4,000	2,050	15	6,135
JUL - SEP 1976	74	956	412	1	1,443
FY 1977	60	4,264	1,954	0	6,278
FY 1978	66	4,929	1,131	151	6,277
FY 1979	32	4,847	1,218	394	6,491
FY 1980	31	4,156	2,099	367	6,653
FY 1981	67	7,271	4,945	1,260	13,543
FY 1982		3,444	3,457	123	7,024
FY 1983	150	3,368	2,689	310	6,517
FY 1984	79	1,493	1,294	154	3,020
FY 1985		2,361	2,295	602	5,258
TOTALS*	5,915	78,012	86,385	41,384	211,695

* Numbers may not sum because of rounding.

Reactor returns listed on Table 3.3-3 are based on assays received and fed in the ranges of 0.59% - 0.69% and 0.848% - 0.864%. For purposes of this table, normal uranium includes all feed to the cascade in the assay range of 0.70% - 0.72%. PGDP product includes all enriched

feeds which can be identified with receipts from PGDP. Some judgement was required for identifying the PGDP product since annual feed quantities include a blending of assays. Other feed recorded on Table 3.3-3 includes refeed of uranium previously withdrawn as tails and other miscellaneous feeds. Data for FY 1982 and FY 1985 were collected from NMMSS Reports versus MBRs.

3.4 RECYCLED URANIUM WASTE

Accountability data for uranium as reported in the MBRs does not identify losses at a level that can be associated specifically with RU. Cumulative losses and RU material unaccounted for (MUF) are calculated and presented in the ORGDP RU Mass Balance Summary, Table 3.4-1, as 598,192 kgU, or approximately 3% of total RU receipts. The project team was informed by individuals who were familiar with commercial uranium operations similar to the ORGDP feed plant—but who were using more recent technologies—that standards for normal operating losses are approximately 0.5%.

Table 3.4-1. ORGDP RU Mass Balance by Fiscal Year

Fiscal Year	Total Receipts (kgU)	Shipments						Fed to GDP (kgU)	Cumulative Losses and MUF (kgU)	Ending Inventory (kgU)
		PGDP (kgU)	PORTS (kgU)	Y-12 Plant (kgU)	ORNL (kgU)	Savannah River (kgU)	Fernald (kgU)			
1952	99,982	0		1,381	20				98,581	
1953	2,134,121	1,758,497		2,370	121		153,000		318,714	
1954	1,437,009	1,508,629		143,192	2,447				100,026	
1955	832,984	922,422		14,563	3,635		3,000		(10,618)	
1956	2,893,945	2,557,175	296,327	22,883	293				6,647	
1957	2,770,873	3,150,098	3,322	2,655	1,062	4,752			(384,369)	
1958	1,113,290	63			1	1,519			727,338	
1959	1,159,655	471,084		11	2	1,403	660,000		754,493	
1960	2,289,322	552,211		2,091	8	2,026	1,949,000		538,479	
1961	1,732,921	80,337	1,427			1,347	1,259,000		929,081	
1962	194,541	46,825					424,000		652,525	
1963	35,490	64,711	1				5,000		618,303	
1964	9,052	17,498					4,000		605,857	
1965	464								606,321	
1966							4,000		602,321	
1967 - 1968									602,321	
1969	238,358						2,033		838,646	
1970	440,921	14,126					376,532		888,909	
1971	4,734						4,734		888,909	
1972	24						24		888,909	
1973	61,531						61,531		888,909	
1974	115,373	(3)					287,000		717,285	
1975	73,892						91,039		700,138	
1976	86,145						144,297		641,986	
1977	55,965						60,362		637,589	
1978	28,355						66,355		599,589	
1979	46,454						31,785		614,258	
1980	88,047						31,081		671,224	
1981	67,078						67,078		671,224	
1982							150,595		520,629	
1983	257,687						79,235		699,081	
1984	173,918								872,997	
1985									872,997	
1986	211,140	485,656							598,481	
1987	1								598,482	
1988	1,451						1,451		598,482	
1989									598,482	
1990 - 1999									598,482	
TOTALS*	18,654,721	11,629,329	301,077	189,146	7,589	11,057	1,909	1,451	5,914,681	598,482

* Numbers may not sum because of rounding.

NOTE: Negative RU inventories in 1955 and 1957 result from the inability to accurately match by year gross shipments to PGDP with credits for cascade withdrawals (non-RU) within the same assay range as RU. Shipments to PGDP overall have been reconciled with PGDP receipt data.

The ORGDP feed plant, which began processing RU in 1952, represented a new technology and might be expected to have experienced greater process losses than more recent technologies. The feed plant process equipment was decontaminated and maintenance performed in Building K-1410. RU fluorination tower ash contained appreciable uranium as

well as TRU and various fission products. Some of this uranium was recovered while the rest was shipped to Paducah. The feed plant experienced many operating problems resulting in unmeasured releases of UF_6 to the atmosphere, loss of uranium as UO_3 and UF_4 to the environment, and the discard of wash solutions from K-1410 to Poplar Creek. Residual uranium "heels" amounting to several hundred pounds were left in the UF_6 feed cylinders. Interviews with former ORGDP personnel revealed that feed cylinders were not always exclusively reused as feed cylinders. There is some potential that feed cylinders, heels included, could have been used for tails withdrawal, hence the possibility that depleted uranium tails cylinders, now in storage at ORGDP, PGDP and PORTS may still contain these heels. There is little indication in the historical records that this material was recovered. Some of it was likely buried in the K-33 burial ground as low level waste. The balance was probably shipped to Paducah. Cascade compressors, converters, and other enrichment components containing RU deposits were decontaminated in Buildings K-1303 and K-1420. The wastewater generated in K-1303 was generally discharged to the K-1407B holding pond with little pre-treatment. The wastewater from K-1420, on the other hand, was processed for uranium recovery and then discharged to the K-1407B pond. Uranium recovery from these various maintenance facilities was not quantitative until after K-1420 was placed into operation, and even then recovered RU has lost its identity in the historical records. Significant uranium losses also occurred through the various purge cascade process vents associated with the enrichment plant. A process loss of 1 to 2% may be more realistic for the ORGDP feed plant. The additional 1 to 2% shown here likely results in part from the loss of accountability previously described.

3.5 RECYCLED URANIUM SCRAP

RU scrap can be identified primarily in two areas. Ash generated in the feed plant fluorination tower was pulverized and recycled through the top of the tower. When it was no longer practical to recover uranium through the ORGDP process, the remaining ash was shipped off-site (primarily to PGDP) for further processing and disposal. In addition, uranium holdup in process equipment, filters, and containers was processed, and the uranium recovered. Accountability for the uranium as RU was lost when the RU went through the recovery process.

3.6 INVENTORY AS OF MARCH 31, 1999

All RU received at the ORGDP site had been either shipped off-site or fed to the cascade as of March 31, 1999. Table 3.4-1 summarizes RU activity at ORGDP.

4.0 CONSTITUENTS IN RECYCLED URANIUM

4.1 INFORMATION SEARCH AND DATA SOURCES

The project team searched a variety of data collections and libraries at ETTP and other ORR locations to identify and retrieve analytical data. Much of the data found was located in the K-1034 retired records vault, the Environmental Restoration (ER) Information Center at ETTP, or the Information Resource Center. This information was supplemented by data gathered from Bechtel Jacobs organizations at ETTP (e.g., Radcon and Analytical Laboratories). Major data sources consulted and analyzed included:

- ORGDP historical site reports, including quarterly plant reports and engineering progress reports
- ORGDP historical technical and experimental research reports
- ORGDP reports describing operations and production processes
- Plant records, including employment, health physics, and environmental monitoring and materials release records
- ORGDP production records
- ORGDP analytical laboratory records
- Correspondence between shippers and receivers
- Historical DOE and contractor reports addressing RU
- More recent (i.e., post-1990) health physics reports and databases
- More recent environmental survey and safety basis reports (e.g., Basis for Interim Operation documentation, characterization reports, and hazard screenings)
- Environmental reports submitted to state and federal agencies

In addition to consulting the ORGDP analytical laboratory records, the team found it necessary to glean analytical data from a wide variety of sources, including the ORGDP historical quarterly reports, technical reports, environmental reports, and health physics reports. Correspondence between shippers and receivers also provided a record of comparisons of sets of analytical data (the first set developed by the site shipping RU and the second by the site receiving the material). In addition, analytical data has been compared and shared with other appropriate DOE sites.

For some areas that presented gaps in data that could not at present be filled by research, the project team developed estimates for quantities of RU and/or constituents. These estimates are based on extrapolations from actual data and represent (1) application of known data from similar material and/or circumstances or (2) application of known data from a specific time period over a longer or a shorter period of time. All such estimates and their bases are specifically identified in this report.

The approach used in searching for and collecting data useful to the project team's purpose was suitably comprehensive in terms of targeting the broad range of likely sources and locations of data. However, because of time and resource limitations, the

Site Team could not absolutely verify that all relevant and useable analytical data and records were identified and reviewed.

As a result of the brief but intensive search, the project team determined that a significant amount of information exists to address the scope and objectives established for this phase of the RU project. Further, results of this current effort have extended previous evaluations and have, in some instances, served to confirm earlier work. With respect to constituent analysis, a reasonable quantity of data was found and evaluated.

4.1.1 K-25 Analytical Laboratory Information System

Beginning in 1985, K-25 Site analytical laboratory information was captured in the K-25 Analytical Information Laboratory System (KANLIS). Analytical records prior to 1985 did not fall under the 75-year rule and were shipped to Atlanta for long-term storage. Whether the records were retained beyond five years was not confirmed. Previous experience indicates that the probability of retrieving records from the Atlanta repository is remote. Therefore, the Site Team focused its efforts on data available from ORGDP. Hard copy records of analytical data since 1985 (in KANLIS) are stored either in the K-1034 Retired Records Vault or at the Y-12 Plant. A database maintained by the analytical laboratory uses sample number and QA number to determine the physical location of the hard copy record. The team determined that it was feasible to use KANLIS as a potential source of quantitative TRU data.¹

The current KANLIS was queried to identify all records with laboratory analyses for Pu, Np and ⁹⁹Tc. This query identified approximately 700,000 records, which were scanned for building numbers and descriptions of interest to narrow the data set to approximately 70,000 records. Another scan identified 150 records that appeared to be the most relevant for the project. Table 4.1-1 presents a sample of these 150 records.

Table 4.1-1. Example of Records of Potential Interest Identified from KANLIS

Sample Number and Date Completed	Constituent	Result	Units	Description
850502-079	Tc	<0.005	µg/gU	ORGDP Tails
May 1985	Pu	<1	dpm/gU	ORGDP Tails
	Np	5	dpm/gU	ORGDP Tails
850723-118	Tc	3.65 E2	µg/gSample	Inc Ash 1420
August 1985	Pu	2	dpm/gSample	Inc Ash 1420
	Np	10	dpm/gSample	Inc Ash 1420
850723-119	Tc	5.16 E1	µg/gSample	Inc Ash 1420
August 1985	Pu	11	dpm/gSample	Inc Ash 1420
	Np	7	dpm/gSample	Inc Ash 1420
850723-120	Tc	2.62 E1	µg/gSample	Inc Ash 1420
August 1985	Pu	23	dpm/gSample	Inc Ash 1420
	Np	43	dpm/gSample	Inc Ash 1420
850924-056	Tc	0.040	µg/ml	Cylinder Wash
October 1985	Pu	11.75	dpm/g	Cylinder Wash
	Np	14.46	dpm/g	Cylinder Wash

¹ KANLIS Analytical Laboratory Data, March 1985 to current (received April 2000).

Unfortunately, these samples identified contained no QA number, and the location of the hard copy record could therefore not be determined through the database.

4.2 ANALYTICAL LABORATORIES

The ORGDP Analytical Laboratories are located in Buildings 1004-A, -B, -C, and -D. The laboratories have been in operation at the site since 1944.² In the earliest years of the plant, the physical and organizational sections of the Laboratory Division were the Conditioning Section, the Sampling Section, the Special Analysis Section, the Spectrometer Section, and the Uranium Analysis Section. Analyses performed and procedures for the activities within the Laboratory Division sections are described in a 772-page *K-25 Works Laboratory Manual* dated December 1952.³ Some specific examples of information in the manual of interest to this report included:

- The Industrial Hygiene Group within the Special Analysis Section performed urinalysis using a procedure that involved evaporation, dilution, and electroplating uranium, with the results of the analysis reported in alpha counts/min/100 ml of urine.
- A measurement control program was maintained for the Mass Spectrometer Section (within the Special Analysis Section) to closely track current measures of the precision of all types of routine analyses to enable adequate steps to be taken to keep the precision of all analyses within the desired control limits.
- The Uranium Analysis Section maintained a measurement control program and issued a monthly *Quality Control Report* based on data obtained by measuring control batch materials.
- The Counting Group (within the Uranium Analysis Section) followed detailed procedures for alpha counting in urine, alpha activity in air and water, and beta-gamma activity in water, residues, and recovered UO₃.

At the time this manual was issued, no analysis methods were listed for ⁹⁹Tc. It is noted that alpha counting instrumentation prior to the early 1960s did not discriminate the energy level of the alpha particle counted and thus did not discriminate the isotopic source of the alpha activity detected. The source of alpha activity so detected could have been from uranium, Pu, Np, or any other isotope decaying via alpha particle emission.

Prior to the development of instrumentation (alpha spectroscopy) for discriminating among the energy levels of alpha particles, some urinalysis was performed specifically for Pu and Np. The urinalysis was accomplished by separation of the elements by chemical means before the sample was alpha counted. The limited amount of data available from these analyses may suggest that urinalysis was performed only for specific cases in which transuranic exposure was suspected.

² W. B. Humes, K-25 Plant Superintendent, to C.D.W. Thornton, U.S. AEC, correspondence, January 21, 1949.

³ *K-25 Works Laboratory Manual*, K-990, Carbide and Carbon Chemicals Company, January 2, 1953.

More recent documentation shows that detailed practices and procedures continued to be used and refined for Analytical Laboratory activities.⁴ During this period (circa 1973), the laboratory functions included such services as sampling, sub-sampling, determination of chemical purity and specific impurities, and radiochemical and isotopic analyses. Laboratory functions of particular included:

- Uranium samples representing shipments to and from other AEC installations, uranium processors, and licensees were sub-sampled and distributed for various specification analyses.
- Purge cells and/or other off-stream equipment were sampled and analyzed for uranium. Samples were also removed for mass spectral analyses.
- The abundance of the various uranium isotopes was determined for UF₆ samples. These samples came from specified points in the cascade; from cylinders received, stored, or shipped; or from other uranium compounds which were fluorinated to UF₆.
- Radiochemical analyses were performed to quantitatively determine concentrations of various radioisotopes. Appropriate extraction procedures and detection instruments were selected for specific samples. Quantitative alpha, beta, and gamma radioactivity measurements on a variety of samples including air, water, soil, vegetation, and special materials were performed.
- The Special Analysis Section determined uranium content in samples of urine and other biological materials in support of the Industrial Hygiene program for personnel protection. This section also performed analyses of plant effluents, vegetation, and mud samples for purposes of pollution monitoring.

A number of historical reports and documents containing information on analytical and sampling practices were found and reviewed. *AEC Accountability Survey Reports*⁵ evidence a practice of on-going, contemporaneous review and evaluation of analytical and sampling practices during the period when RU was received and processed at ORGDP. Examples include:

- “The program whereby station HGE (Hanford) samples each lot of depleted uranium trioxide and sends the sample under separate cover to K-25 for analysis as representative of the lot of material has proven satisfactory. Carbide K-25 has compared their own analysis of Hanford-supplied samples with the K-25 analysis of samples taken from the lots of material on a random basis at K-25. These analyses agree with the expected limits of error of the x-ray photometric method of analysis so that the Hanford-supplied sample is considered as representative of trioxide received by Carbide K-25. The random sampling of lots by Carbide K-25 was continued as a control program.”
- “Sampling Methods. The sample exchange program between the K-25 Plant and Hanford and Harshaw are apparently under satisfactory control. An independent

⁴ *Nuclear Materials Management Manual*, K-P-4086, Rev. 4, Union Carbide Nuclear Company, Oak Ridge Gaseous Diffusion Plant, 1973.

⁵ *AEC Accountability Survey Reports, Reports for the Period October 1947 through May 27, 1953 (U)*, KZ-7801-31.

sample is taken of every fifth lot at K-25 to ascertain that the sample supplied by the shipper is adequate. There is no significant difference between the analyses made at K-25 and those made at Hanford or Harshaw.”

- “Uranium trioxide from Harshaw is shipped in 16 drum lots (grossing about 800 pounds per drum) with two lots comprising a shipment of about 12 tons of oxide. A sample taken as the drums are filled is supplied for each lot. These two lot samples are composited at the K-25 Plant and one analysis is made for uranium content and for isotopic ratio. Similar material is received from Hanford in shipments of 12 lots of 8 drums per lot, about 40 tons of material per shipment. Analysis is made on a lot basis in this case also, with the sample being supplied by Hanford. Spot samples are taken at K-25 from every fifth lot.”

4.3 HISTORIC STANDARDS/SPECIFICATIONS REGARDING MAXIMUM ALLOWABLE TRANSURANIC AND FISSION PRODUCT CONTENT IN RECYCLED URANIUM

A mutually agreeable and technically sound transuranic and fission product element specification between shipper and receiver for all recycle material shipped to and from all DOE sites handling recycle material was recommended in the Egli Report in 1985.⁶ The report stated that such a specification had probably never existed either within or between sites. Although most sites had their own “working” specification, there simply was no understanding and agreement on specifications for recycle material shipped to or from the DOE sites. Having said that, the task force further found that there were *informal* standards or specifications that were used within and between sites. Table 4.3.1 summarizes the various specifications that were (or might have been) used by ORGDP or by organizations supplying or receiving material to or from ORGDP.

Table 4.3-1. Summary of RU Specifications

Specification	Source
Maximum Alpha Activity from all Transuranic Elements: 15,000 dpm	AEC
Hanford UO ₃ Product: Pu <10 ppb	Hanford
Maximum Alpha Activity from all Transuranic Elements: 1,500 dpm	DOE – Savannah River
Maximum Alpha Activity from all Transuranic Elements: 3,000 dpm	DOE – Oak Ridge
Pu-239 < 10 ppb	DOE – Oak Ridge and FMPC
Alpha: $\frac{\text{(Activity per gram of Pu + Np +Th)} \times 700}{\text{(Nominal Activity of Enriched Uranium)}} \leq 1.0$	Y-12
Beta: $\frac{\text{(Activity of Sample)}}{\text{(Activity of Unmediated Uranium Standard)}} \leq 1.25$	
Gamma: Total Fission Product < 0.20 • Ci/g Uranium	
Transuranic Alpha <5,000 dpm/g U	ICPP

⁶ D. Egli, et al., *The Report on the Joint Task Force on Uranium Recycle Materials Processing*, DOE/OR-859, U.S. DOE Oak Ridge Operations, September 1985.

The American Society for Testing and Materials (ASTM) has two specifications for UF₆: one for UF₆ that is intended for feeding an enrichment plant and the other for enriched UF₆ product (up to 5% ²³⁵U). These specifications are:

- C787-96 “Standard Specification for Uranium Hexafluoride for Enrichment”
- C996-96 “Standard Specification for Uranium Hexafluoride Enriched to Less Than 5 Percent ²³⁵U”

It should be noted that these specifications apply to uranium used as fuel in commercial power reactors exposed to very high levels of burnup compared to production reactors. However, the cooling time for discharged fuel from production reactors was very much less. The fuel “slugs” were sent for reprocessing after cooling for 50 days to allow fission products (¹³¹I) to decay. The ASTM specifications for power reactor fuel are based on a cooling period of ten years to accommodate the burnup level of 50,000 megawatt-days per MTU.

Prior to 1966, the permissible concentration of transuranic elements in UF₆ feed was 150 alpha dpm/gU.⁷ In December 1966, (31FR16584) the AEC announced a tenfold relaxation of that level. This adjustment was made in anticipation that reactor returns would not average more than three tons per day in the period 1967 through 1975 and that the additional transuranic elements fed to the diffusion plants during that time could be tolerated without significant additional health risks.

The first specifications for UF₆ delivered to or by the AEC were published in *Federal Register*, 23 F.R. 4813, dated June 28, 1958. Federal Register Notice, Volume 32, Number 230, Wednesday, November 29, 1967, which is the genesis of the current UF₆ specifications, consolidated, revised, and superseded all previous notices. The product specifications were minimal—calling for UF₆ content of at least 99.5 wt % UF₆ and containing 0.01 mol % of hydrocarbons, partially substituted halo-hydrocarbons, or chlorocarbons. The feed specifications had limits for gamma and beta activity from fission products and alpha activity from all transuranics. The gamma activity was 20% of the gamma activity of aged natural uranium, and the beta activity was 10%. The alpha activity was 1500 disintegrations per minute (dpm) of total uranium. Current ASTM specifications are based on the same gamma and alpha activities. The beta activity has been replaced with a specification on ⁹⁹Tc.

In October 1988, DOE put into effect a feed specification based on ASTM 787. Finally, in June 1994, ASTM 787 and ASTM 996 were adopted as the specifications for UF₆ feed and product for DOE enrichment plants. Both of the current ASTM specifications provide for feed and product derived from RU. The following appears in both ASTM 787 and ASTM 996:

1. Reprocessed UF₆—any UF₆ made from uranium that has been exposed in a neutron irradiation facility and subsequently chemically separated from the fission products and transuranic isotopes so generated.
2. Discussion—The requirements for Reprocessed UF₆ given in this specification are intended to be typical of reprocessed spent fuel that has achieved burnup

⁷ R.W. Levin, *UF₆ Specifications for Feed for Gaseous Diffusion Plants*, K/TL-1092 Rev. 1, October 1, 1981.

levels of up to 50,000 MW days per tonne of uranium in light water reactors and has been cooled for ten years after discharge. It is recognized that different limits would be necessary to accommodate different fuel histories.

ASTM 787 has the following requirements for reprocessed uranium:

1. For Reprocessed UF₆, the gamma radiation from fission products shall not exceed 1.1×10^5 MeV Bq/kg U (1.1×10^5 MeV/sec kg U).
2. For Reprocessed UF₆, the alpha activity from neptunium (Np) and plutonium (Pu) isotopes may be specified in either of two ways as agreed upon between the parties concerned:
 - a) The total alpha activity from Np and Pu in the cylinder shall be limited to 25,000 Bq/kgU (1.5×10^6 disintegrations per minute per kilogram of uranium), or
 - b) The volatile alpha activity from Np and Pu in the liquid sample from the shipping container shall be limited to 3,300 Bq/kgU (0.2×10^6 disintegrations per minute per kilogram of uranium).
3. For Reprocessed UF₆ the concentration of ⁹⁹Tc shall be measured and reported. It shall not exceed 0.500 micrograms per gram of total uranium (μg/gU).
4. Minor isotopes in reprocessed UF₆ shall not exceed the limits given as micrograms per gram total uranium (• g/gU):

²³² U	0.005
²³⁴ U	480.0
²³⁶ U	8400.0

ASTM 996 has the following requirements for gamma and alpha activity:

1. For Enriched Reprocessed UF₆, the gamma radiation from fission products shall not exceed 4.4×10^5 MeV/sec kgU.
2. For Enriched Reprocessed UF₆, the alpha activity from neptunium and plutonium shall be less than 3,300 Bq/kgU (200,000 dpm/kgU).
3. The specification for minor isotopes represent limits obtainable from the enrichment of reprocessed UF₆ feed materials at the corresponding limits of Specification C 787:

²³² U	0.050 μg/gU
²³⁴ U	2000 μg/gU
⁹⁹ Tc	5 μg/gU

Note: Depending upon the demands placed on fuel fabricators and reactor operators, it may be necessary to agree on lower limits.

4.4 ANALYTICAL RESULTS FOR TRU AND FISSION PRODUCTS IN RECYCLED URANIUM MATERIALS RECEIVED AT ORGDP

On an activity basis, the principal radionuclides expected to pass through chemical processing of reactor returns and remain in the RU received are the TRU radionuclides produced in highest abundance and with moderate half-lives: ^{237}Np , ^{238}Pu , ^{239}Pu , ^{240}Pu , and ^{241}Am . In addition, certain fission and activation products may form volatile compounds in the fluorination process (^{99}Tc , ^{106}Ru , ^{125}Sb , ^{134}Cs , and ^{137}Cs). Some operational data from the 1950s and 1960s indicates the presence of detectable quantities of $^{95}\text{Zr-Nb}$, ^{106}Ru , and ^{137}Cs in ORGDP materials. However, because $^{95}\text{Zr-Nb}$, ^{106}Ru , and ^{134}Cs have short half-lives (65 days, 368 days, and 2.1 years, respectively) and RU was last introduced in 1984, they are unlikely to be present in significant quantities today.⁸

From the beginning, the presence of non-uranium constituents in RU receipts and the introduction of these contaminants into the ORGDP facilities and equipment as a result of processing those receipts were recognized. Evidence indicates that RU that was to be shipped to or was received at ORGDP was systematically sampled, with checks performed for TRU and fission products. Records of analytical data for ORGDP RU receipts were found to exist in the Building K-1034 Retired Records Vault. These records consisted of correspondence from the ORGDP Laboratory Division Superintendent reporting results obtained from analysis of material lot samples submitted to ORGDP by Hanford, Harshaw, and Savannah River during the 1952 through 1957 time period. Dates for this set of analytical data were found to correspond to the years that RU was received from Hanford, Harshaw, and Savannah River as determined from MBRs.⁹ These analytical results are thus considered as representative of the material received at ORGDP during the same time periods.

The analytical results, as reported in the correspondence found, were compiled and reviewed. Typically, the reported results included weight % ^{235}U , Pu in ppb, total beta activity and total gamma activity, and fission product beta and gamma activity. Beta and gamma activities were reported as a percentage relative to the beta or gamma activity of an equal weight of natural uranium in equilibrium with its daughters.

Analysis for Pu was not always performed. Contemporaneous correspondence indicated that from time to time an understanding existed between shipper and receiver that Pu was not expected to vary from earlier shipments because reprocessing process parameters remained unchanged. One example, which referred to UO_3 from Hanford, stated: "...and the ratio of plutonium produced versus UO_3 shipped has been fairly constant over the past few years and is not expected to change significantly in the near future."¹⁰ In another example, the good agreement between results obtained from separate analyses performed by ORGDP and by Savannah River on the same material is cited as a sufficient basis to discontinue the practice of duplicate ORGDP analysis on

⁸ *Assessment of Accessible Contamination at the K-25 Site Phase 3 Report: Cumulative Analytical Results*, K/HS-570, Oak Ridge K-25 Site, May 1994.

⁹ For the mass balance study, receipts were identified as RU based on the site from which the material was received and the assay range of the material, as determined from information contained in Material Balance Reports (MBRs). Historical Forms 741 for the shipments of interest, which could provide actual shipment dates or transfer numbers to directly link the material balance data to the analytical data, were not found.

¹⁰ W.L. Richardson to R.L. Dagley, "Shipment of UO_3 ," Union Carbide Internal Correspondence, June 22, 1962.

each lot of UO₃ from Savannah River.¹¹ In the case of material from Harshaw, it appears that a practice of sampling for Pu at a 1 in 4 frequency was adopted for the latter shipments. Similarly, beta and gamma was not always measured; rather, the data suggests that these were measured until it was judged that the material was sufficiently characterized.

Table 4.4-1 provides a summary of the Pu results for receipts of RU from domestic sources.¹² A weighted average was calculated for each source, based on annual averages and annual amounts of material received from each source. Pu data for receipts of RU from Harshaw, Hanford and Savannah River are presented in Fig. 4.4-1, 4.4-2, and 4.4-3, respectively. As can be seen in Figure 4.4-2 for material received from Hanford, Pu analytical results dated between January and April 1953 are significantly higher than for any other period.

Table 4.4-1. Summary of Data on Plutonium in Early ORGDP RU Receipts

Fiscal Year	No. of Lots	No. of Results	Max Pu (ppb)	Min Pu (ppb)	Avg Pu (ppb)	Total U (kgs)
Hanford						
1952	81	78	12	1	2.1	99,970
1953	109	92	40	1	13.7	578,249
1954	26	26	4	1	1.4	1,115,345
1955	10	5	2	1	1.2	526,475
Total	226	201			4.5	2,320,039
Harshaw						
1953	148	67	11	1	3.2	1,402,761
1954	7	2	9	1	5.0	299,574
Total	155	69			3.5	1,702,335
Savannah River						
1955	47	47	9	1	3.8	271,949
1956	256	19	8	2	4.6	2,538,844
Total	303	66			4.5	2,810,793

¹¹ J. C. Barton, Works Laboratory Superintendent, Union Carbide Nuclear Company, to W.H. Emslie, E.I. duPont deNemours and Company, "Analysis of SRO and K-25 samples from Lots 101 through 111," October 11, 1955.

¹² Where Pu results were reported as less than a given limit value, a value equal to 50% of the limit was used (i.e., for a reported result of <2, the average of the range 0 to 2 was used, or 50% of 2=1).

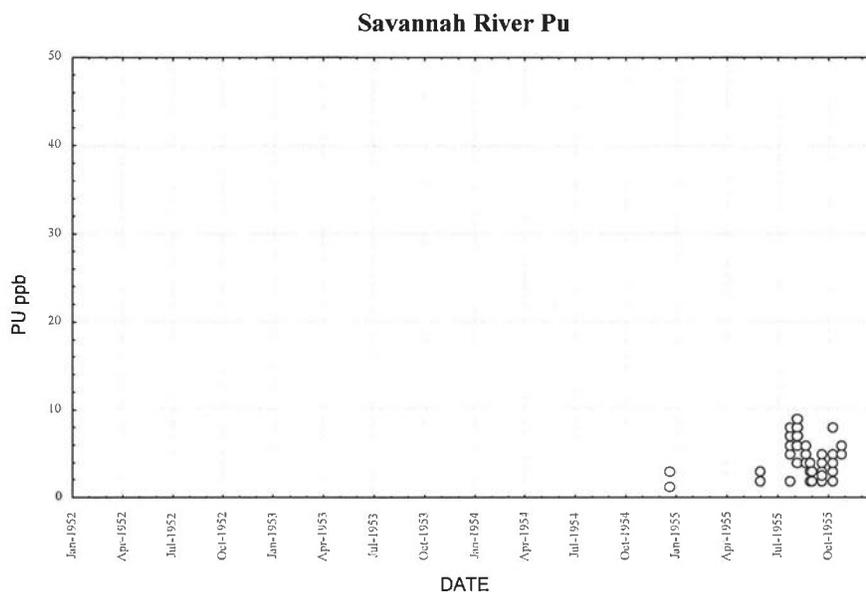


Fig. 4.4-3. Plutonium in ORGDP RU Receipts from Savannah River.

Total gamma activity results are presented in Fig. 4.4-4, 4.4-5, and 4.4-6. Total beta activity results are presented in Fig. 4.4-7, 4.4-8, and 4.4-9. Fission product beta activity results for material from Hanford and Savannah River are presented in Fig. 4.4-10 and 4.4-11 and fission product gamma activity results are shown in Fig. 4.4-12 and 4.4-13. There was no fission product activity data reported in this record set for material from Harshaw.

In addition to domestic sources of RU, ORGDP also received RU from foreign sources. From 1969 to 1988, ORGDP received 1,294 MTU of foreign RU reactor returns. Information was found in a series of reports of natural and reactor return feed analyses.^{13, 14, 15, 16} The reports summarized results of sampling and analysis performed at ORGDP for defining adherence to feed specifications. All cylinders of reactor return UF₆ were sampled and analyzed for full specifications. It was reported that during the period of 1969 through 1982, eight cylinders of reactor returns from COGEMA (French) failed to meet specifications (six for transuranic alpha and one each for fission product beta and gamma). No cylinders of foreign reactor returns were reported as exceeding the specifications for TRU and fission products for the period of 1983 through 1986.

¹³ W. D. Hedge, *Toll Enrichment Uranium Hexafluoride: Natural and Reactor Return Feed Analyses at ORGDP for CY 1982, Including Summaries for CYS 1969-1982*, K/TL/AT-58, Rev. 1 Addendum 2, Union Carbide Corporation Nuclear Division, April 1983.

¹⁴ W. D. Hedge, *Analyses of ORGDP Toll Enrichment Uranium Hexafluoride for CY 1983*, K/PS-5034, Union Carbide Corporation, March 1984.

¹⁵ W. D. Hedge, *Analyses of ORGDP Toll Enrichment Uranium Hexafluoride for CY 1984*, K/PS-5034, Addendum 1, Union Carbide Corporation, May 1985.

¹⁶ W. D. Hedge, *Analyses of ORGDP Toll Enrichment Uranium Hexafluoride for CY 1985 Through September 1986*, K/PS-5034, Addendum 2, Union Carbide Corporation, January 1987.

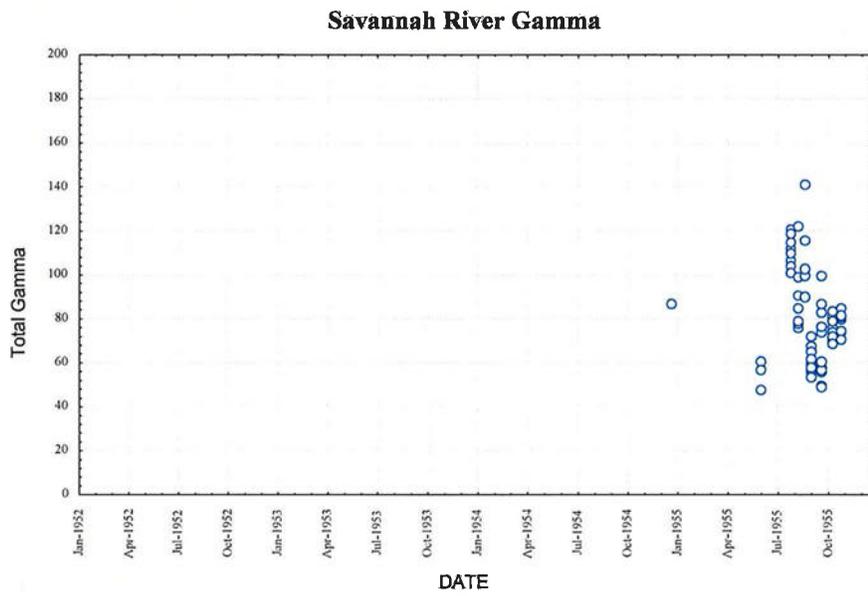


Fig. 4.4-6. Total Gamma Activity for ORGDP RU Receipts from Savannah River.

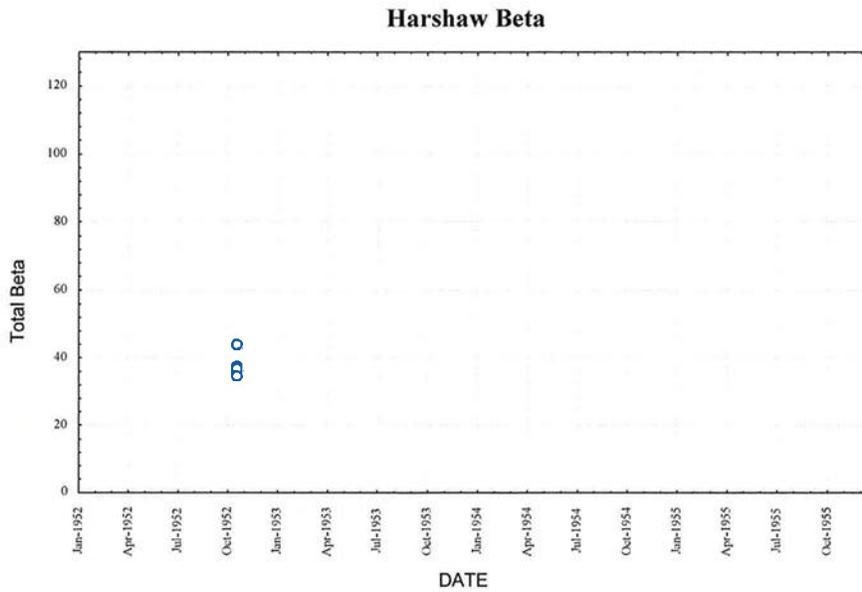


Fig. 4.4-7. Total Beta Activity for ORGDP RU Receipts from Harshaw (% relative to normal uranium standard).

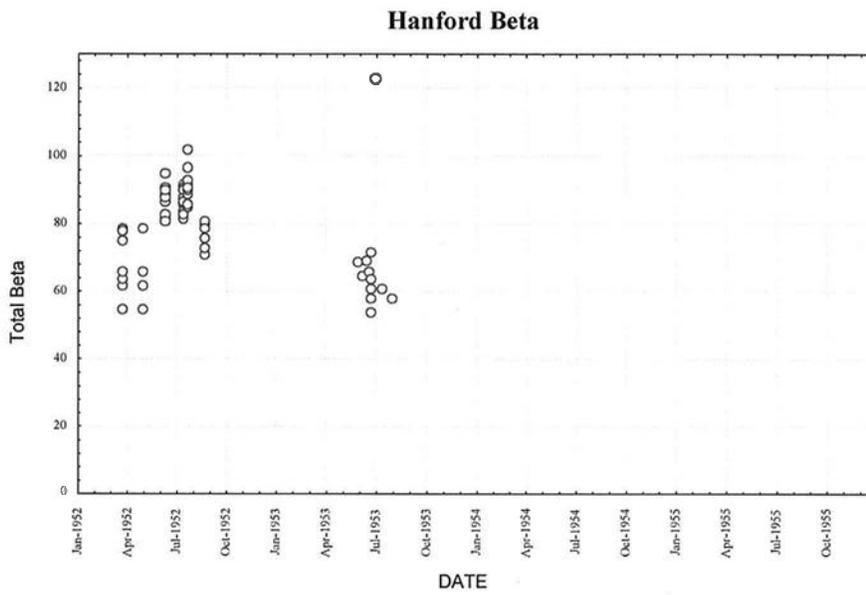


Fig. 4.4-8. Total Beta Activity for ORGDP RU Receipts from Hanford (% relative to normal uranium standard).

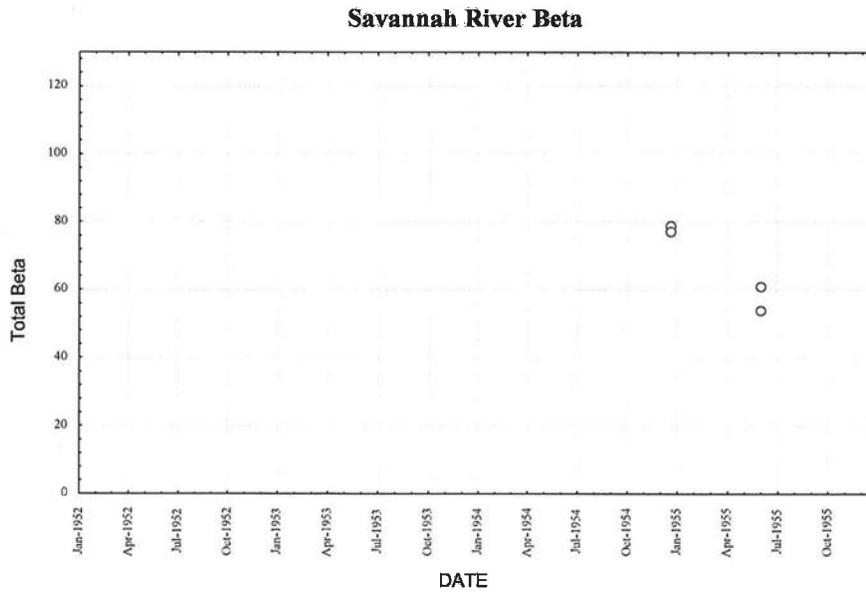


Fig. 4.4-9. Total Beta Activity for ORGDP RU Receipts from Savannah River (% relative to normal uranium standard).

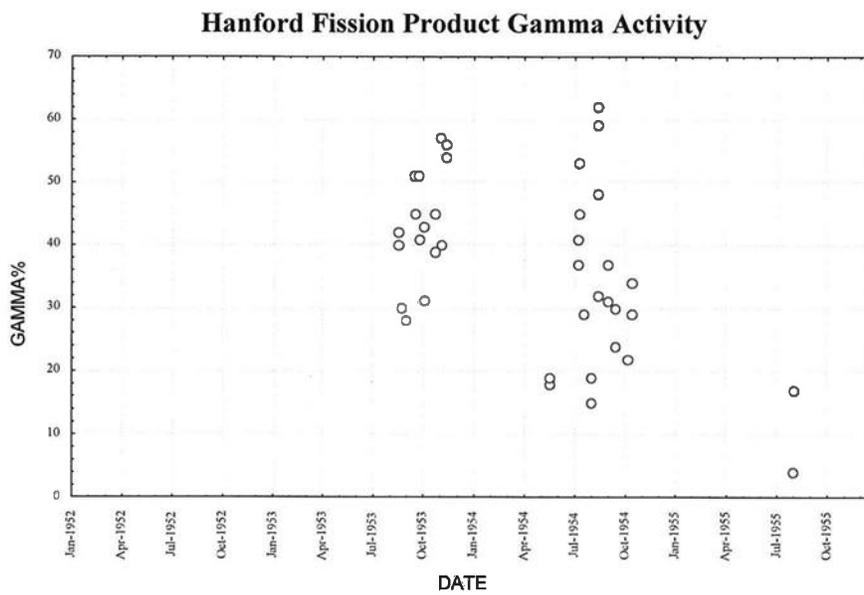


Fig. 4.4-12. Fission Product Gamma Activity for ORGDP RU Receipts from Hanford.

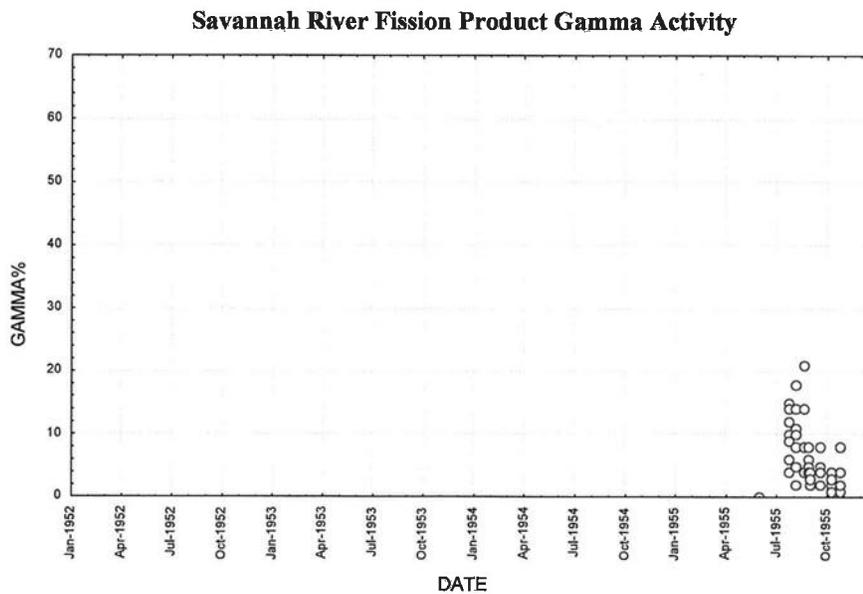


Fig. 4.4-13. Fission Product Gamma Activity for ORGDP RU Receipts from Savannah River.

Table 4.4-2 summarizes, by year, results of analysis for TRU and fission products in material from foreign fuel reprocessors. Transuranic alpha was observed in most reactor return samples.

Table 4.4-2. Analyses of TRU and Fission Products in ORGDP RU Receipts from Foreign Sources

CY	Property	U-235 (wt%)	U-236 (wt%)	Fission Product Gamma (% Aged Natural U)	Fission Product Beta (% Aged Natural U)	TRU Alpha (dpm/gU)	Tc (ppm U)
1969	French (Cogema)	1.62300	0.0390	100.0	13.00	<150.0	
1970	Belgian (Euro-Chem)	0.95830	0.1850	<5.0	<2.00	134.0	
1970	British (BNFL)	1.80500	0.0500	<5.0	<2.00	186.0	
1970	French (Cogema)	1.76700	0.2320	6.2	<2.00	1,323.0	
1972	British (BNFL)	1.91700	0.0710	<5.0	<2.00	386.0	
1972	French (Cogema)	1.51800	0.1580	<5.0	<2.00	180.0	
1973	British (BNFL)	1.37500	0.0450	<5.0	<2.00	140.0	
1973	French (Cogema)	1.97700	0.2420	<5.0	<3.00	748.0	
1974	British (BNFL)	0.64230	0.0110	<5.0	<2.00	170.0	
1974	French (Cogema)	1.50700	0.1760	<5.0	<3.00	250.0	
1975	British (BNFL)	0.83900	0.0120	<5.0	<2.00	42.0	
1976	French (Cogema)	2.01700	0.0110	<5.0	<2.00	<25.0	
1976	British (BNFL)	0.64200	0.0220	<5.0	<2.00	<10.0	
1977	Belgian (Euro-Chem)	1.05270	0.0290	<5.0	<2.00	44.0	
1977	British (BNFL)	2.06400	0.0570	<5.0	<2.00	<25.0	
1978	British (BNFL)	1.06200	0.0510	<5.0	<2.00	5.0	
1978	French (Cogema)	1.04600	0.1520	<5.0	<2.00	30.0	
1979	French (Cogema)	1.02900	0.0240	<5.0	<0.30	18.0	
1979	German	2.01500	0.0280	<5.0	<0.30	<5.0	
1980	French (Cogema)	1.07000	0.2540	6.4	<3.00	42.0	
1980	Russian	2.67800	0.0160	<5.0	<0.30	<5.0	
1981	French (Cogema)	1.01300	0.2390	6.7	0.44	6.3	
1982	French (Cogema)	1.31100	0.2400	<5.0	0.73	6.1	0.041
1983	French (Cogema)	1.03462	0.2835	<0.1	0.20	5.2	0.022
1983	Netherlands (Urenco)	1.96135	0.3180	9.0	0.20	<5.0	0.008
1983	Russian	2.67762	0.0172	<0.1	<5.00	<5.0	<0.000
1984	French (Cogema)	1.18864	0.2918	9.7	2.30	5.7	0.006
1984	Germany	3.09910	0.0023				
1985	French (Cogema)	1.21652	0.3257	6.1	3.00	3.5	0.013

4.5 ANALYTICAL RESULTS FOR TRU AND FISSION PRODUCTS IN RECYCLED URANIUM PROCESS STREAMS AND WASTE STREAMS AT ORGDP

4.5.1 Feed Plant Ash

In a 1957 ORNL paper¹⁷, Lantz and Parker note that a moderate amount of Np was discovered in uranium oxide at ORGDP. Lantz and Parker state that sampling and analysis of various material streams from the PGDP metal recovery plant, which

¹⁷ P. M. Lantz and G. W. Parker, "Investigation of Paducah Ash and Metal Recovery Waste as a Large-Scale Source of Neptunium-237," Oak Ridge National Laboratory, July 1957.

processed all of the waste from the diffusion plant, including ash from the feed plant, was subsequently undertaken. Results indicated that most of the Np was deposited in the nonvolatile ash collected in the feed plant. No neptunium was found in the product uranium or tails, and no samples were available from intermediate stages.

Records from Fernald indicate that two shipments of feed plant ash from PGDP were received at Fernald in 1978 and 1980. Analytical results for samples of the 1980 shipment exist and were provided by Fernald.¹⁸ While the data provided are for ash shipped to Fernald from PGDP, it is reasonable to assume that the constituent nature of the PGDP ash is similar to that produced by ORGDP. ORGDP shipped much of its feed plant ash to PGDP, and some ORGDP ash was directly included in PGDP ash. The ORGDP feed plant also operated in a nearly identical manner as the PGDP feed plant.

Analytical data was provided for 16 samples taken from 16 hoppers containing a total net weight of 40,651 kg of material. The net weight contained by individual hoppers ranged from 1,394 kg to 4,147 kg. Analytical data provided included wt % U, wt % ²³⁵U, Np in disintegrations per minute per gram (dpm/g) sample, total Pu in dpm/g sample, and ⁹⁹Tc in dpm/g sample. The mass fractions of Np, Pu, and ⁹⁹Tc in parts per billion parts U (ppb U) were calculated using the analytical results and specific activities for the given radionuclides. For Pu, the conversion was performed assuming the Pu was 100% ²³⁹Pu. Table 4.5.1-1 summarizes the mass fraction data for Np, Pu, and ⁹⁹Tc.

Table 4.5.1-1. Summary of Data for Paducah Feed Plant Ash Shipped to Fernald in 1980

	⁹⁹ Tc (ppb U)	Np (ppb U)	Pu (ppb U)
Sample Population	16	16	16
Mean	3,091	6,724	1,262
Median	1,652	4,434	385
Minimum	354	1,173	67
Maximum	11,977	25,287	7,747

Mass fraction data for Np, Pu and ⁹⁹Tc plotted against wt% ²³⁵U are shown in Fig. 4.5-1, 4.5-2 and 4.5-3, respectively. With such a small sample population, meaningful extension of the result using statistical methods is unlikely. However, the data appear to support the inference that a large fraction of the Np in the RU feed partitions to and becomes concentrated in the feed plant ash. Given the average of 1,262 for Pu in ash, and considering an average Pu concentration of 4 ppb in feed to the feed plant, the data in Fig. 4.5-2 supports the conclusion that Pu partitions to and becomes concentrated in the feed plant ash waste stream.

¹⁸ C. W. Lowery, Fernald, facsimile transmittal of "Paducah Feed Plant Ash Received in Hoppers, 1980," April 6, 2000.

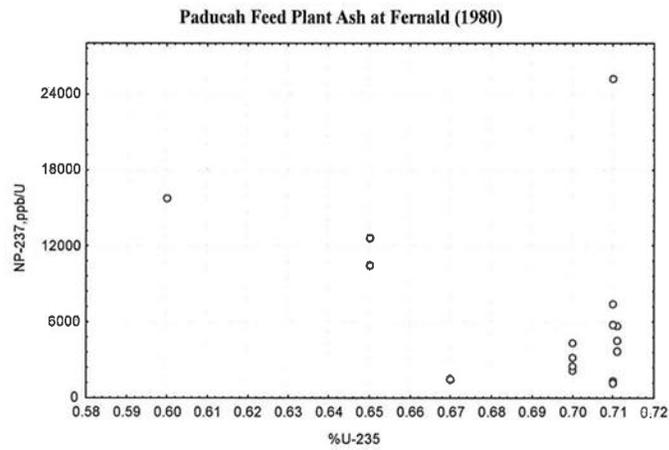


Fig. 4.5-1. Neptunium in PGDP Feed Plant Ash Shipped to Fernald in 1980.

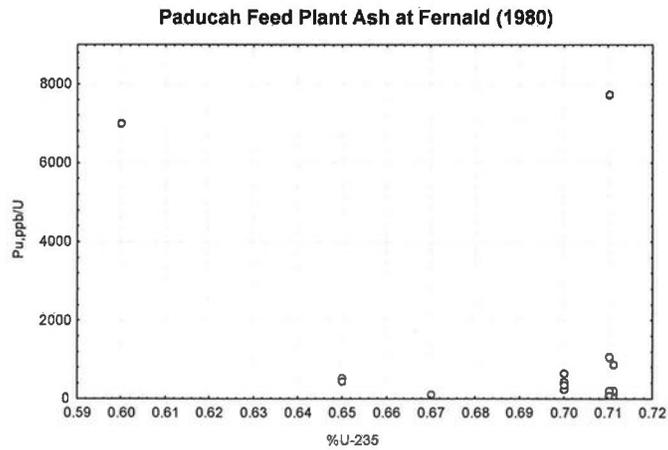


Fig. 4.5-2. Plutonium in PGDP Feed Plant Ash Shipped to Fernald in 1980.

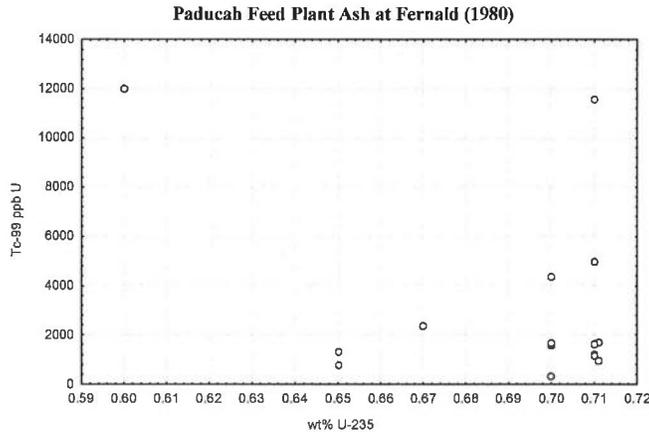


Fig. 4.5-3. Technetium in PGDP Feed Plant Ash Shipped to Fernald in 1980.

Additional data dealing specifically with Pu content was found in a 1953, K-1131 feed plant sampling report.¹⁹ Between 15 and 41 samples were taken of four ash streams and analyzed for Pu (reported in ppb U). The data is summarized in Table 4.5.1-2.

Table 4.5.1-2. Pu in K-1131 Feed Plant

Pu (ppb U)	Mean	Min	Max
Flange 1	1,455	13	8,100
Flange 2	905	50	3,900
Flange 3	169	5	1,100
Barrier Filter Powder	769	0	14,800

The flange (1 through 3) samples are believed to be ash streams from the fluorination bed in the feed plant. The barrier filter powder is the ash stream from the vent at the end of the feed plant process. This data also supports the conclusion that Pu in RU processed through the feed plant partitioned to and became concentrated in the feed plant ash.

The data is shown graphically in Fig. 4.5-7. A period of higher Pu results is seen during April and May 1953, which generally corresponds with the period when high Pu results were seen in the Hanford material receipts (i.e., January through March 1953).

¹⁹ A. F. Becher to J. Dykstra, *Monthly Plutonium Report*, Union Carbide Nuclear Company, Internal correspondence, January 1953 through July 1961

K-1131 Feed Plant Samples

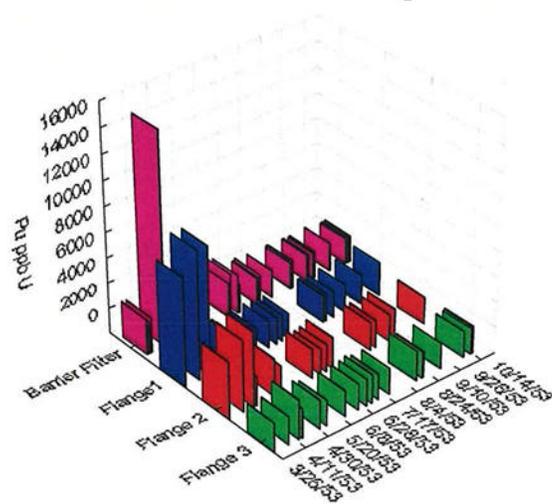


Fig. 4.5-7. Plutonium in K-1131 Feed Plant Samples.

4.5.2 Neptunium in the K-33 Building

Information was found in the *ORGDP Quarterly Report*²⁰ for the fourth quarter of 1962 regarding a sampling program conducted in the K-33 portion of the cascade. The sampling program was designed to detect the presence of radioactive contaminants other than uranium and its daughter products and to follow the movement of these contaminants through the cascade. Samples of barrier and converter deposits were obtained from converters in the K-33 Building. The report notes that since Np is ten times more harmful than uranium on an alpha basis, more stringent safety precautions are required when the Np concentration is found in excess of the "acceptable limit of 10 $\mu\text{gNp/gU}$."

The report states that the highest Np to uranium ratio in any deposit obtained from cascade equipment occurred in a gray powder that was observed on or near the converter B-outlet tube sheet. Reported results are shown and summarized in Table 4.5-2.

The origin of the powder and the mechanism by which Np was retained in the cascade were documented as "not known at the present time." The gray powder was relatively inaccessible in the converter and would only be encountered when the equipment was entered for inspection or when the converter was being disassembled. Many other samples were documented as having been examined from cascade equipment, including converters, compressors, and piping, but only the gray powder showed the presence of Np in concentrations in excess of the limit of 10 $\mu\text{gNp/gU}$. As of the writing of the fourth quarter report, samples with Np to uranium ratios in excess of this value were confined to K-33; however, Np may have been present in K-602-2.6.

Table 4.5-2. Results for K-33 Cascade Equipment Deposits

Location	Sample Date	U (g/g)	Np ($\mu\text{g/g}$)	Np:U ($\mu\text{g/g}$)
K-902-1.9-6	09/08/61	0.100	3.80	38
K-902-1.8-6	08/30/61	0.084	3.10	37
K-902-2.7-2	12/10/61	0.066	3.10	47
K-902-2.7-3	02/24/61	0.066	3.70	56
K-902-3.3-1	11/14/61	0.150	12.00	80
K-902-3.5-3	08/08/61	0.070	0.80	11
K-902-3.5-6	07/25/61	0.130	1.30	10
K-902-3.9-5	10/25/61	0.076	2.10	28
K-902-3.10-3	10/13/61	0.092	1.60	17
K-902-4.5-4	12/08/61	0.066	4.90	75
K-902-4.5-5	09/22/61	0.059	5.30	90
K-902-4.5-6	09/24/61	0.069	4.70	68
K-902-5.1-1	09/24/61	0.075	15.00	200
K-902-5.8-1	03/07/61	0.150	0.02	0.1
K-902-5.8-4	01/23/62	0.046	9.60	210
K-902-7.7-5	12/29/61	0.030	0.80	27
K-902-7.2-3	10/19/61	0.037	0.30	8
Sample Population		17	17	17
Mean		0.08	4.242	58.9471
Median		0.07	3.1	38
Range		0.12	14.98	209.9
Minimum		0.03	0.02	0.1
Maximum		0.15	15	210

4.5.3 Technetium Removal Plant Test

Information was found in the *ORGDP Quarterly Report*²¹ for the fourth quarter of 1962 concerning a plant test using MgF_2 traps to remove ^{99}Tc from the cascade in Building K-33. Removal of ^{99}Tc from PGDP product UF_6 by sorption on MgF_2 was investigated using traps installed at the K-33 feed point. The report states that ^{99}Tc in the ORGDP cascade feed streams was of concern because it can cause a 1 to 2% loss in barrier permeability. At that time, the value of ^{99}Tc was believed to be approximately

²⁰*ORGDP Quarterly Report*, April 1, 1962 through June 30, 1962 (Q4)

²¹*ORGDP Quarterly Report*, April 1, 1962 through June 30, 1962 (Q4)

\$90/gm, thus making recovery of the material more desirable. Analytical results from the test showed that most of the ⁹⁹Tc had been sorbed in the first and second bed sections, with almost none sorbed at the discharge end of the trap.

Table 4.5-3. Impurities Scavenged from PGDP UF₆ by MgF₂

Spectrographic analyses of impurity concentration, ppm			
Bed 1	Bed 2	Bed 3	Bed 4
8000	3000	<20	<20

Total grams sorbed: 12.0 grams
 Equivalent reduction in impurity concentration: 1.0 ppm

The amount of ⁹⁹Tc trapped represents a reduction of 1.0 to 1.4 ppm in the UF₆ processed through the trap. This reduction was consistent with the observation of negligible concentration of ⁹⁹Tc in the trap outlet and an estimated average value of 1.6 ppm ⁹⁹Tc in the PGDP product flow. Np concentration on the sorbent suggests its presence in the PGDP product at approximately 0.35 ppb, which was well below the 20 ppb limit of detection at that time.

4.6 ANALYTICAL RESULTS FOR TRU AND FISSION PRODUCTS IN FACILITIES AND EQUIPMENT IN WHICH RECYCLED URANIUM WAS PROCESSED AT ORGDP

Early in ORGDP's operating history, the presence of non-uranium constituents in ORGDP RU receipts and the introduction of non-uranium contaminants into the facilities and equipment as a result of processing RU at ORGDP was recognized. A number of related studies and historical reports have been found to contain information and data useful for this project.

4.6.1 Monthly Plutonium Reports

A series of "Monthly Plutonium Reports" covering the period 1953 through 1961 were found in retired records located in Building K-1034.²² Labeling of the file indicates that these specific reports were discontinued in 1961. The reports contain results of health physics air monitoring and surface wipe samples and evidence a routine monitoring program for uranium and Pu. Sample descriptions identify the building, location, and operation sampled and include information about the source of the material being processed at the time of the sample (e.g., Savannah River oxide and Hanford oxide). Data contained in the reports were compiled into a data set. The data set contains results of Pu and uranium analysis for 298 samples taken in buildings K-1131, K-1231, K-132, K-1413 and K-1004-J. No Pu was detected in 165 of the 298 samples, and Pu ranged from 3 ppb-U to 18,833 ppb-U for the remaining 135 samples. Table 4.6.1-1 shows the 20 samples with the highest Pu results.

²² A. F. Becher to J. Dykstra, "Monthly Plutonium Report," Union Carbide Internal Correspondence, January 1953 through July 14, 1961.

Table 4.6.1-1. Health Physics Monitoring Results - 20 Highest Pu Results

Year	Bldg	Desc. of Operation	Location	U (mg)	U (c/m/ft ³)	Pu (mg)	Pu (c/m/ft ³)	Pu (ppb U)
1957	K-1131	Routine Operations	Cold Trap Area, Center of UF6 Pumps	0.0060	0.0090	1.13E-07	0.0200	18,833
1956	K-1131	Routine Operations	Cold Trap Area Near Barrier Filters	0.0200	0.0290	1.80E-07	0.0290	9,000
1953	K-1131	Hydrofluorination and fluorination of Uranium compounds to furnish process material and removal	VH #1	0.0790	0.2000	5.00E-07	0.1150	6,329
1959	K-1131	Routine UF6 manufacture	"B" Line, East End of Reactor	0.0200	0.0300	6.45E-08	0.0100	3,224
1954	K-1131	Towers not operating; UF6 header open on tower platform	35' Tray Area	0.0063	0.2100	1.60E-08	0.0036	2,540
1954	K-1131	Ash Receiver Change and Dismantling of UF6 Lines and Towers	West End 35' Tray	0.1030	0.2470	2.15E-07	0.0480	2,087
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	21.8800		3.64E-05		1,664
1953	K-1131	Hydrofluorination and fluorination of Uranium compounds to furnish process material and removal	Tower #1	0.2060	0.5020	3.20E-07	0.0736	1,553
1955	K-1131	Routine Operations	Barrier Traps	0.0300	0.0640	4.50E-08	0.0090	1,500
1955	K-1131	Routine Operations	Near Barrier Filters	0.0900	0.1570	1.29E-07	0.0210	1,433
1954	K-1131	Routine Tower and Tray Operation	Tower Platform	1.0900	2.7000	1.37E-06	0.3100	1,257
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	17.3700		1.96E-05		1,128
1959	K-1131	Routine UF6 manufacture	"B" Line, East End of Trays	0.0600	0.1300	6.09E-08	0.0120	1,015
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	33.8700		2.96E-05		874
1955	K-1131	Routine Operations	Tray Area	0.0200	0.0500	1.70E-08	0.0050	850
1957	K-1131	Routine Operations	South Wall of Screener Area	0.1400	0.2300	1.08E-07	0.0200	771
1957	K-1231	No Operations in Progress	Center of Pulverizing Area	0.0300	0.0400	2.10E-08	0.0020	700
1955	K-1231	Samples were taken during pulverizing operation.	Near Blender Booth	1.5600	11.0000	1.08E-06	0.6670	692
1957	K-1231	No Operations in Progress	Between Booths	0.0300	0.0300	2.00E-08	0.0020	667
1955	K-1131	Routine Operations	Cold Trap Area Near Barrier Trap	0.0400	0.0600	2.50E-08	0.0030	625

Table 4.6.1-2 shows the results of samples taken of the area in Building K-1004-J where laboratory analysis for Pu was performed. The data shown includes results of air samples as well as surface wipe samples from the work area. No Pu was detected in the samples.

Table 4.6.1-2. Health Physics Monitoring Results - Pu Sample Analysis Area

Year	Bldg	Desc. of Operation	Location	U (mg)	U (c/m/ft ³)	Pu (mg)	Pu (c/m/ft ³)	Pu (ppb U)
1956	K-1004-J	Routine plutonium analysis of uranium feed material and ash	2' from Hood	0.40	0.04	0.00	0.00	0.00
1956	K-1004-J	Routine plutonium analysis of uranium feed material and ash	2' from Hood "F"	0.50	0.03	0.00	0.00	0.00
1956	K-1004-J	Routine plutonium analysis of uranium feed material and ash	2' from Hood "G"	0.30	0.03	0.00	0.00	0.00
1956	K-1004-J	Routine plutonium analysis of uranium feed material and ash	Floor at Hood "G"	0.00	0.00	0.00	0.00	0.00
1956	K-1004-J	Routine plutonium analysis of uranium feed material and ash	Inside Hood "E"	0.00	0.00	0.00	0.00	0.00
1956	K-1004-J	Routine plutonium analysis of uranium feed material and ash	Inside Hood "F"	0.00	0.00	0.00	0.00	0.00
1956	K-1004-J	Routine plutonium analysis of uranium feed material and ash	Inside Hood "G"	0.00	0.00	0.00	0.00	0.00
1956	K-1004-J	Routine plutonium analysis of uranium feed material and ash	On Top of Sink	0.00	0.00	0.00	0.00	0.00
1956	K-1004-J	Routine plutonium analysis of uranium feed material and ash	Table in Center of Room	0.00	0.00	0.00	0.00	0.00
1956	K-1004-J	Routine plutonium analysis of uranium feed material and ash	Top of Funnel Rack	0.00	0.00	0.00	0.00	0.00

Table 4.6.1-3 shows the results of samples taken in Building K-132 during operations to unplug the UF₆ evacuation line used to "de-smoke" ash receivers. Table 4.6.1-4 shows results associated with changing barrier filters in Building K-1131. Table 4.6.1-5 shows results of air samples associated with the pulverizing operations in K-1231. Table 4.6.1-6 shows results of smear samples in and around the K-1231 ash pulverizing equipment.

**Table 4.6.1-3. Health Physics Monitoring Results
K-132 Unplugging Operation**

Year	Bldg	Desc. of Operation	Location	U (mg)	U (c/m/ft ³)	Pu (mg)	Pu (c/m/ft ³)	Pu (ppb U)
1954	K-132	Samples were taken during an unplugging operation of the UF ₆ evacuation line used to "de-smoke" ash receivers.	Northeast Corner	2.01	11.28	0	0	0
1954	K-132	Samples were taken during an unplugging operation of the UF ₆ evacuation line used to "de-smoke" ash receivers.	Platform, East Side	3.76	21.06	1.3E-07	0.067	35
1954	K-132	Samples were taken during an unplugging operation of the UF ₆ evacuation line used to "de-smoke" ash receivers.	Platform, South Side	5.19	26.17	0	0	0

**Table 4.6.1-4. Health Physics Monitoring Results
K-1131 Changing Barrier Filters**

Year	Bldg	Desc. of Operation	Location	U (mg)	U (c/m/ft ³)	Pu (mg)	Pu (c/m/ft ³)	Pu (ppb U)
1953	K-1131	Changing Barrier Filters	North & South Barrier	1.33	32.00	5.8E-07	1.01	436
1953	K-1131	Changing Barrier Filters	North & South Barrier		14.60	1.1E-06	0.39	307
1953	K-1131	Changing Barrier Filters	North & South Barrier	21.62	72.60	1.4E-06	0.43	65
1953	K-1131	Changing Barrier Filters	North & South Barrier		19.46	5E-08	0.02	13
1953	K-1131	Changing Barrier Filters Wipe 413A		87.30		1.3E-05		152
1953	K-1131	Changing Barrier Filters Wipe 414A		45.00		9.2E-06		205
1953	K-1131	Changing Barrier Filters Wipe 415A		313.00		3.1E-05		97

**Table 4.6.1-5. Health Physics Monitoring Air Sample Results
K-1231 Pulverizing Operation**

Year	Bldg	Desc. of Operation	Location	U (mg)	U (c/m/ft ³)	Pu (mg)	Pu (c/m/ft ²)	Pu (ppb U)
1955	K-1231	Samples were taken during pulverizing operation.	Near Blender Booth	1.56	11.00	1.1E-06	0.667	692
1955	K-1231	Samples were taken during pulverizing operation.	Near Pulverizer Booth	1.54	10.00	1.5E-07	0.093	98
1955	K-1231	Samples were taken during pulverizing operation.	Top of Pulverizer Booth	5.72	41.00	6.5E-07	0.429	113
1955	K-1231	Samples taken during the sampling and sealing of drums.	Near Blender Booth	0.15	0.49	0	0.000	0
1955	K-1231	Samples taken during pulverizing operations.	Inside Pulverizer Booth	85.62	205.00	8.7E-07	0.190	10
1955	K-1231	Samples taken during pulverizing operations.	Near Pulverizer Door	3.58	7.10	0	0.000	0
1955	K-1231	Samples taken during pulverizing operations.	Top of Pulverizer Platform	1.50	3.90	0	0.000	0
1956	K-1231	Pulverizing Operations	Center of Pulverizing Booth	4.61	10.32	4.4E-07	0.089	95
1956	K-1231	Pulverizing Operations	In Pulverizer Booth	136.00	381.00	4.1E-06	1.040	30
1956	K-1231	Pulverizing Operations	Platform Near Pulverizer	6.71	12.53	2.4E-06	0.407	356
1956	K-1231	Pulverizing Operations	Platform Near Pulverizer	2.80	5.90	1.1E-07	0.020	40
1954	K-1231	Pulverizing of ash - unit in operation during time of air sampling	10' North of Pulverizer Door	1.92	7.40	4.3E-07	0.154	224
1954	K-1231	Pulverizing of ash - unit in operation during time of air sampling	Pulverizer Platform	3.47	12.50	3.7E-07	0.121	105
1957	K-1231	No pulverizing operations in progress; grease seal on pulverizer being replaced by maintenance.	Center of North End	0.04	0.05	0	0.000	0
1957	K-1231	No pulverizing operations in progress; grease seal on pulverizer being replaced by maintenance.	Pulverizing Booth	0.04	0.05	0	0.000	0
1957	K-1231	No pulverizing operations in progress. Only normal or depleted uranium processed during the past 3 months.	Inside Blender Booth	0.11	0.15	0	0.000	0
1957	K-1231	No pulverizing operations in progress. Only normal or depleted uranium processed during the past 3 months.	Inside Pulverizing Booth	0.14	0.16	0	0.000	0
1957	K-1231	No Operations in Progress	Between Booths	0.03	0.03	2E-08	0.002	667
1957	K-1231	No Operations in Progress	Center of Pulverizing Area	0.03	0.04	2.1E-08	0.002	700
1954	K-1231		Between Pulverizer and Blender	0.43	1.27	8.5E-08	0.024	198

**Table 4.6.1-6. Health Physics Monitoring Smear Sample Results
K-1231 Pulverizing Operation**

Year	Bldg	Desc. of Operation	Location	U (mg)	Pu (mg)	Pu (ppb U)
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	21.88	3.6E-05	1,664
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	17.37	2E-05	1,128
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	33.87	3E-05	874
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	35.48	1.5E-05	428
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	23.79	8.7E-06	365
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	28.51	9.3E-06	325
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	25.88	3.9E-06	150
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	31.89	4.4E-06	138
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	42.88	4.5E-06	105
1954	K-1231	Wipe samples were taken on top of the pulverizing unit and inside the material entry port. Unit was not in operation.	K-1231, Top of Pulverizing Unit	55.06	1E-06	19
1955	K-1231	Unit not in operation. Samples reported are surface smear samples.	Floor of Booth	1.86	6.8E-08	37
1955	K-1231	Unit not in operation. Samples reported are surface smear samples.	Floor of Main Room	0.53	3.9E-08	73
1955	K-1231	Unit not in operation. Samples reported are surface smear samples.	Floor of Platform	22.00	1.5E-07	7
1955	K-1231	Unit not in operation. Samples reported are surface smear samples.	Mouth of Hopper	24.50	3.4E-06	138

4.6.2 Fluorination of Special Nuclear Materials in K-1420

Information about the November 1960 processing of two shipments of HEU uranium oxide received from Hanford and Savannah River was found in retired records located in Building K-1034. The information consisted of correspondence, in the form of a letter report, from the Safety and Health Physics Organization to Operations.²³ The report stated that the material was processed through the K-1420 fluorination tower in two runs made November 3-9 and 9-14, 1960. The letter states that processing of the Savannah River Operations (SRO) shipment was of special interest because of the

²³ A. F. Becher to J. Dykstra, "Fluorination of Special Nuclear Materials—K-1420, November 3-14, 1960," Union Carbide Internal Correspondence, January 26, 1961

possible concentration of fission products in the system. Processing of the Hanford shipment was notable because the system had not been used previously to fluorinate uranium at “these high enrichments.” Examination of the two sets of material yielded the following information:

- Beta-gamma survey of 15 process system locations (for Savannah River material).
- Spot-air samples of 15 locations at or near the process area (for the Hanford material) to delineate the area affected by the operation. The results are shown in Table 4.6.2-1.
- Continuous air monitor (CAM) results from two CAMs: one located adjacent to the west end of cold trap F-20-B in “E” area, and one located adjacent to the system charging point in “H” area. Data reported are shift averages and peaks and are shown for the two material runs in Table 4.6.2-2.
- Special bioassay of affected Maintenance and Operations personnel (20 workers).
- Additional gamma and alpha checks on samples from routine, off-site environmental air surveys that had shown higher than normal results for the period coincident with the two runs.
- Sampling of K-1420 roof surfaces and measurements and analysis for alpha counts, uranium, and ^{235}U .

Table 4.6.2-1. Spot-Air Sample Results from K-1420 Fluorination Tower Process November 1960

Spot-Air Sample Results - Hanford Material		
Location	Start of Operations Alpha Activity (c/m/ft ³)	During Operation Alpha Activity (c/m/ft ³)
H Area - 6' North of Tower	8.0	993.000
H Area - 2' from Open Can		52.000
E Area - B Cold Trap	2.0	0.400
E Area - Tower Room	25.0	10.000
B Area - 16' from West Wall		0.840
C Area - Column D-6		1.000
Outside E Area West Wall		0.210
E Area - Elevator Door		0.300
C Area - Column G-6		1.180
Outside E Area East Wall		0.240
E Area - Stairwell		2.520
C Area - Column G-10		0.320
Outside E Area North Wall Near Exhaust Fan		0.330
C Area - Column G-2		0.400
Roof - Near E Area Vent		0.100
Roof - Near H Area Vent		0.200
E Area Tower Room		13.800
F Area Center		1.500

**Table 4.6.2-2. Shift Averages from Continuous Air Monitors
During Processing of Savannah River and Hanford Material**

Date	12-8 Shift Activity (c/m/ft ³)		8-4 Shift Activity (c/m/ft ³)		4-12 Shift Activity (c/m/ft ³)	
	Average	Peak	Average	Peak	Average	Peak
Savannah River Material						
"H" Area						
11/09/60			977.90	11,397.12	125.44	1,296.64
11/10/60	26.88	87.00	32.00	97.28	812.80	7,984.64
11/11/60	550.40	4.76	972.80	6,475.52	2,257.92	5,459.20
11/12/60	1401.60	4,066.56	1,491.20	7,240.96	32.12	299.52
11/13/60	666.88	6,560.00	64.0	803.84	440.32	4,616.96
11/14/60	19.20	140.80	116.48	1,126.40	64.00	787.20
11/15/60	12.80	1,437.44	75.52	186.88	592.64	6,856.96
11/16/60	131.84	42.24	125.44	893.44	44.80	241.92
11/17/60	24.32	51.20	17.92	58.88	21.76	186.88
11/18/60	7.68	15.36	15.36	46.08	35.84	240.64
11/19/60	26.88	112.64	14.08	53.76	6.40	47.36
11/20/60	7.68	17.92	398.08	4,268.80	72.96	487.28
11/21/60	16.64	42.24	47.36	3,146.88	20.48	103.68
11/22/60	3.84	5.12	6.40	39.68	69.12	262.40
11/23/60	8.96	88.40				
"E" Area						
11/09/60			8.55	49.14	1.61	4.67
11/10/60	2.77	10.79	4.60	44.67	5.91	21.13
11/11/60	2.48	16.55	15.01	50.63	6.80	19.54
11/12/60	14.40	46.57	19.62	29.29	11.39	44.47
11/13/60	13.16	46.14	2.76	25.89	9.75	41.34
11/14/60	0.79	1.83	4.17	39.61	6.51	36.69
11/15/60	0.59	0.72	3.52	14.78	4.63	2.50
11/16/60						
11/17/60	2.60		0.67	2.29	0.67	1.44
11/18/60	2.73	7.05	0.45	0.86	0.71	3.45
11/19/60	11.09	41.40	4.56	39.28	0.36	0.61
11/20/60	0.50	0.61	3.77	39.82	13.60	43.13
11/21/60	7.00	39.68	0.77	2.48	5.72	27.51
11/22/60	7.13	43.34	6.58	21.31	1.44	4.14
11/23/60	4.33	45.53	6.58	21.31	1.44	4.14
Hanford Material						
"H" Area						
11/04/60	0.55		⁽¹⁾ 4427.50	6,515.20 ⁽²⁾	1624.30	11,032.30
11/05/60	638.70	5,899.50	16.60	38.40	147.20	590.00
11/06/60	17.90	88.30	1,358.00	10,695.70	472.30	3,576.30
11/07/60	12.80	29.40	106.20	331.50	165.00	769.30
11/08/60	47.40	327.70	271.40	1,272.00	650.20	5,017.60
11/09/60	1,857.30	14,720.00				
"E" Area						
11/04/60	6.40	37.50	9.41	43.89	2.42	8.69
11/05/60	8.07	42.20	11.11	9.96	0.77	2.62
11/06/60	1.35	2.90	8.27	25.67	11.51	45.49
11/07/60	0.43	0.87	8.31	22.46	10.61	37.71
11/08/60	2.85	27.77	8.56	37.17	10.65	46.84
11/09/60	8.22	47.06				

(1) Feed Screw Broken. Feed Hopper emptied pneumatically. Feed screw removed.
(2) Feed Hopper leaked. New gasket installed. Hopper charged.

The letter states that soon after start-up of the first run it became apparent that the air activity levels would be considerably in excess of the PAL²⁴, with average levels of 6.62 c/m/ft³ and 787.2 c/m/ft³ obtained for the "E" and "H" Areas respectively. The primary source of air-borne contamination was reported as being in "H" area, involving the pulverizer, hopper, and feed screw units. Peak periods were associated with operations of system opening, pneumatic transfer of material, and maintenance of equipment. The letter also notes that during the first four days of the operations, wearing of respirators by the personnel assigned was poor. Results of urinalysis for 11 of the 20 affected personnel showed uranium alpha counts in excess of the established control values, and those 11 were scheduled for recall visits. Excretion rates of all of the employees involved subsequently dropped below the follow-up level. Based on the information obtained by the evaluation, additional engineering controls (filtered containment enclosure) were recommended for the screw feed and hopper units.

4.6.3 Assessment of Accessible Contamination at the K-25 Site

In 1990, sampling conducted at PGDP suggested that levels of TRU contaminants at PGDP might be higher than previously estimated. A phased assessment program was undertaken at the GDPs, including the K-25 Site, to determine the magnitude of non-uranium radionuclides present in contamination in the process areas of the plants. The purpose of the assessment was to evaluate the potential impact of non-uranium radionuclides on the internal exposure control programs at the site. Results of that assessment are reported in *Assessment of Accessible Contamination at the K-25 Site Phase 3 Report: Cumulative Analytical Results*, May 1994.²⁵ Useful information provided by that report included the following:

- K-25 Pu urinalysis records (indicating negative results) exist from the early 1950's.
- In 1977, special air samples were analyzed for Np, Pu, and Am and controls were instituted based on the Np and ⁹⁹Tc results.
- For the assessment, samples were collected from a broad cross-section of the areas where contamination was exposed during the study. These samples are viewed as likely to be representative of the materials one would encounter during everyday activities within the site buildings where they were collected.
- The assessment was based on 96 samples taken in 19 buildings. Only one gamma-emitting fission or activation product, Cs-137, was reliably detected in contamination samples at the K-25 Site. It was found in only three samples.

Analysis methods included gamma ray spectroscopy for fission and activation products and separative chemistry followed by appropriate counting for ⁹⁹Tc, uranium isotopes, and transuranic radionuclides. Quality assurance aspects of the analysis are documented in the assessment report.

²⁴ The PAL acronym was seen defined alternatively as Plant Acceptance Limit, Plant Allowable Limit and Plant Action Limit. The correct definition and usage remains to be confirmed.

²⁵ *Assessment of Accessible Contamination at the K-25 Site Phase 3 Report: Cumulative Analytical Results*, K/HS-570, Oak Ridge K-25 Site, May 1994.

Fig. 4.6.3-1 presents results reported for the ratio of ^{99}Tc to U activity in samples collected from buildings where contamination was exposed. In Fig. 4.6-1, the ^{99}Tc to U ratio was plotted by building, and the buildings were ordered approximately in accordance with the order material was processed through the ORGDP. Fig. 4.6.3-2 shows a plot of TRU to U ratios and was constructed in the same manner as Fig. 4.6.3-1.

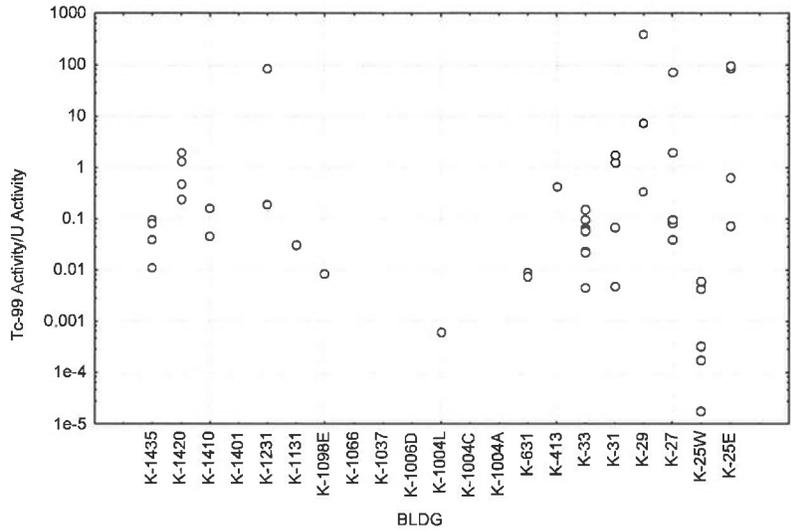


Fig. 4.6.3-1. Ratio of ^{99}Tc to U Activity in Accessible Contamination Samples.

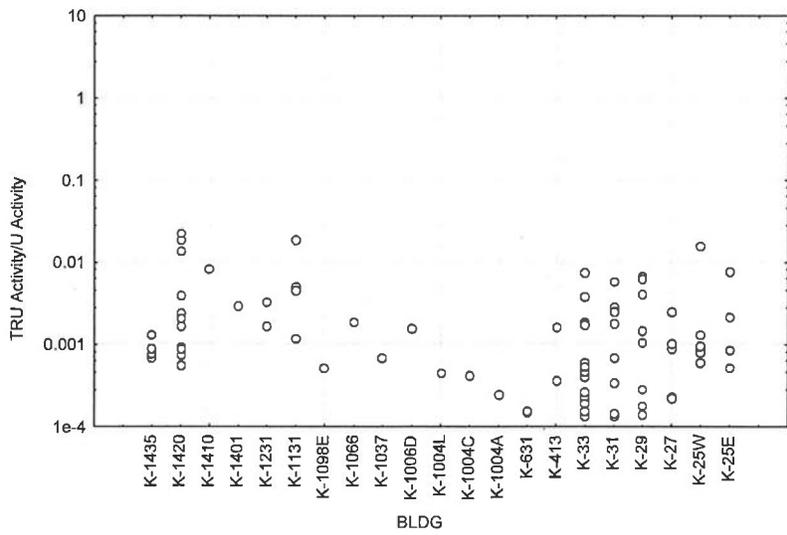


Fig. 4.6.3-2. Ratio of TRU to U Activity in Accessible Contamination Samples.

Recent safety authorization basis documentation^{26, 27} indicates that large areas of the LEU and HEU buildings have radioactive surface contamination. Selected areas of Buildings K-33, K-31, K-29, K-25, and K-27 are designated as High Contamination Areas because of ⁹⁹Tc contamination. These areas are the north side of the Building K-33 operating floor, the west end of the Building K-31 operating floor, the entire cell floor of Building K-29, the north and south ends of the east side of K-25 on the cell and operating floors, in K-27 on the east and west ends of the cell floor, and in many cell areas on the K-27 operating floor (covering approximately 50% of the floor area). High Contamination is defined as activity levels exceeding 10,000 dpm/100 cm² from removable contamination and 50,000 dpm/100 cm² from fixed and removable contamination. In general, the ⁹⁹Tc contamination is characterized as easily removable. The characterization of the Contamination Areas is based on the results of radiological work permit job specific surveys and the large area wipe survey completed in 1994.

4.7 ANALYTICAL RESULTS FOR TRU AND FISSION PRODUCTS IN MATERIAL RELEASES ASSOCIATED WITH RU AT ORGDP

The *Oak Ridge Gaseous Diffusion Plant Historical Uranium and Radionuclide Release Report*²⁸ serves as the most comprehensive source found for information regarding material releases. This report compiled available historical data on the quantities of uranium and various radionuclides (including Pu, Np and ⁹⁹Tc) released from ORGDP from 1946 through 1984. The historical release data are organized into three major categories: airborne releases, liquid effluent releases, and on-site solid waste burial. The report contained no data indicating burial of material containing Pu, Np, or ⁹⁹Tc.

Because of the historical uranium accounting requirements at ORGDP, uranium release data are fairly extensive. However, the data for the other radionuclides are limited. Intermittent data were used, as appropriate, to tabulate quantities of radionuclides released. No attempt was made to extrapolate data for those years in which data were not available. Radiation levels are expressed in curies to depict release totals. Because the same quantity of each radionuclide generates a different level of radioactivity, the curie was used to standardize measurements of radioactivity released and to allow comparisons to be made.

4.7.1 Airborne Emissions

The *Oak Ridge Gaseous Diffusion Plant Historical Uranium and Radionuclide Release Report* indicates that the primary source of uranium and ⁹⁹Tc emissions have

²⁶ Basis for Interim Operation of the Low-enriched Uranium (LEU) Process Buildings at the East Tennessee Technology Park (ETTP), K/OPS-038, Rev.1, October 1997.

²⁷ Basis for Interim Operation of the High-Enriched Uranium (HEU) Process Buildings at the K-25 Site, K/OPS-050, Rev. 0, August 25, 1995.

²⁸ A. C. Lay and J. G. Rogers, *Oak Ridge Gaseous Diffusion Plant Historical Uranium and Radionuclide Release Report*, K/HS-95, ORGDP, February 28, 1986.

been the ORGDP purge cascade, the K-1131 feed plant, and several accidental releases. Airborne uranium emissions are presented in Table 4.7-1.

It is known that the feed plant was a major source of uranium air emissions during its operation, and ⁹⁹Tc was undoubtedly emitted. However, no data are available on the amount of ⁹⁹Tc emitted from the feed plant. The primary source of ⁹⁹Tc airborne emissions for ORGDP was the purge cascade. Beginning in 1974, the purge cascade vent was sampled continuously and analyzed on a daily and weekly basis. The data from those analyses were used to determine the ⁹⁹Tc emissions from ORGDP and are shown in Table 4.7-2. However, because the period of RU receipts from primary sources was 1952 to 1963, the greatest potential for ⁹⁹Tc emissions would have occurred during the period of 1953 to 1973 before this information was recorded.

Improved emission control equipment was installed on the purge cascade in 1977 in the form of solid chemical traps and a liquid potassium hydroxide scrubber. These improvements resulted in fewer emissions, as reflected in the data.

Uranium recovery processes were used in the K-1420 decontamination facility to avoid disposal of concentrated uranium solutions. However, residual concentrations of uranium, ⁹⁹Tc, Np, and Pu were released through liquid discharges. Liquid wastes discharged from the recovery operation were passed through K-1407-B and -C settling ponds where insoluble uranium compounds were removed and retained on-site. Soluble radionuclide compounds were discharged to Poplar Creek, which flows into the Clinch River.

Table 4.7-1. ORGDP Airborne Uranium Emissions 1946 - 1984

Year	Total Uranium Released (curies)	Total Uranium Released (kg)
1946	0.01	1
1947	<0.01	<1
1948	<0.01	5
1949	<0.01	45
1950	0.10	136
1951	0.02	146
1952	0.23	345
1953	1.60	*1,307
1954	0.26	68
1955	0.26	264
1956	0.81	225
1957	0.15	306
1958	1.80	*2,711
1959	1.10	531
1960	1.50	977
1961	3.10	773
1962	0.24	29
1963	3.10	*1,005
1964	0.01	7
1965	0.14	269
1966	<0.01	**1
1967	<0.01	2
1968	<0.01	<1
1969	<0.01	9
1970	<0.01	8
1971	0.02	21
1972	0.03	49
1973	0.13	144
1974	0.44	622
1975	0.27	371
1976	0.05	45
1977	0.03	17
1978	0.02	19
1979	0.04	25
1980	0.03	21
1981	0.01	5
1982	<0.01	2
1983	<0.01	2
1984	<0.01	1
Total	***15.61	***10,516

Note: The ratio between curies and mass differs from year to year due to varying isotopic enrichments.

* A major portion of the quantities reported in 1953, 1958, and 1963 resulted from accidental releases due to valve and trap failures in the K-402-1, K-1131, and K-1420 feed and processing facilities.

** Declining production levels was a factor, which reduced emissions in the 1966 to 1970 time period.

*** This total includes the actual stated value for any quantity which was reported as a less than (<) value.

Table 4.7-2. ORGDP Airborne ⁹⁹Tc Emissions 1974 - 1984

Year	⁹⁹ Tc Released (Curies)	* ⁹⁹ Tc Released (grams)
1974	0.27	16
1975	0.3	18
1976	** 6.79	405
1977	***0.00	0
1978	0.29	17
1979	1.34	80
1980	0.88	53
1981	0.04	2
1982	0.03	2
1983	0.02	1
1984	0.02	1
Total	9.98	595

* This is based a ⁹⁹Tc activity of 59.7 g/Ci.

** This elevated valued may be due to increased purging of the cascade associated with the beginning of a large equipment changeout program that began in 1976.

*** This year the purge cascade location was changed from the K-25 Building to the K-29 Building. Data for both locations were added; however, the total amount was 2x10⁻⁶ curies/yr.

4.7.2 Liquid Emissions

The major radionuclides present in the liquid effluent were uranium and ⁹⁹Tc. Traces of Np and Pu were also present. ⁹⁹Tc liquid effluent releases are shown in Table 4.7-3. Np releases are shown in Table 4.7-4. This table shows that Np was found only in small quantities. Sampling of surface waters for Pu near the effluent of the uranium recovery operation revealed the presence of Pu only twice. On both occasions, the concentration was just above the detection limit of 0.1x10⁻¹⁴ ci/ml.

Table 4.7-3. Tc-99 in ORGDP Liquid Effluent

Year	⁹⁹ Tc Released (curies)	⁹⁹ Tc Released (grams)
1974	3.5	208
1975	9.0	539
1976	*24.1	1,437
1977	5.8	344
1978	4.0	239
1979	7.3	436
1980	5.1	307
1981	3.5	211
1982	1.7	100
1983	**17.0	1,018
1984	**10.1	604
Total	91.1	5,443

* This evaluated value may be due to increased decontamination efforts associated with the beginning of a large equipment change out program.

** In 1983 and 1984, there was a great amount of decontamination work performed on equipment from an area of the cascade highly contaminated with Tc-99. Also in 1983, there occurred a larger than normal technetium-99 release from the decontamination facility. The cause of this release was never determined.

Table 4.7-4. Np in ORGDP Liquid Effluent

Year	Np Released (curies)	Np Released (grams)
1979	0.0015	0.2
1980	0.0014	0.2
1981	0.0021	0.3
1982	0.0019	0.3
1983	0.0004	0.0
Total	0.0073	1.0

4.8 ANALYTICAL RESULTS FOR TRU AND FISSION PRODUCTS IN URANIUM MATERIALS SHIPPED FROM ORGDP

Results of TRU and fission product analyses performed on samples of ORGDP enriched product for the period 1983 through 1985 were found in a series of reports of natural and reactor return feed analyses.^{29, 30, 31, 32} The reports summarized results of sampling and analysis performed at ORGDP for defining adherence to feed specifications. Summarized results for ORGDP product were included for comparison purposes. Product results were reported for shipments to both domestic and foreign fuel fabricators or enrichment customers. The number of analyses performed for ORGDP product was not as extensive as that performed for the foreign reactor returns feed to ORGDP. However, some analysis for TRU and fission products in ORGDP product was performed. The summarized results are shown in Table 4.8. None of the product samples analyzed exceeded specifications.

²⁹ W. D. Hedge, *Toll Enrichment Uranium Hexafluoride: Natural and Reactor Return Feed Analyses at ORGDP for CY 1982, Including Summaries for CYS 1969-1982*, K/TL/AT-58, Rev. 1 Addendum 2, Union Carbide Corporation Nuclear Division, April 1983.

³⁰ W. D. Hedge, *Analyses of ORGDP Toll Enrichment Uranium Hexafluoride for CY 1983*, K/PS-5034, Union Carbide Corporation, March 1984.

³¹ W. D. Hedge, *Analyses of ORGDP Toll Enrichment Uranium Hexafluoride for CY 1984*, K/PS-5034, Addendum 1, Union Carbide Corporation, May 1985.

³² W. D. Hedge, *Analyses of ORGDP Toll Enrichment Uranium Hexafluoride for CY 1985 Through September 1986*, K/PS-5034, Addendum 2, Union Carbide Corporation, January 1987.

Table 4.8. Summarized Results for TRU and Fission Products in ORGDP Enriched Uranium Product

CY	Property	U-235 (wt%)	U-236 (wt%)	Fission Product Gamma (% Aged Natural U)	Fission Product Beta (% Aged Natural U)	TRU Alpha (dpm/gU)	Tc (ppm/U)
1982	ORGDP Product	2.96900	0.0079	8.2	0.9	9.7	0.036
1983	ORGDP Stockpile	3.10144	0.0175	<0.1	<5.0	<5	0.026
1983	French (Cogema)	2.88520	0.0050	<0.1	<5.0	<5	0.026
1984	British (BNFL)	2.56632	0.0176	<0.1	1.1	<5	0.279
1984	Japan	3.11195	0.0175	<0.1	0.8	<5	0.026
1984	Westinghouse Electric	3.26739	0.0137	<0.1	<5.0	<5	0.056
1984	ORGDP Stockpile	3.06811	0.0207	<0.1	1.2	<5	0.026
1985	ORGDP Stockpile	2.58587	0.0479	<0.1	1.5	3.5	0.014
1985	Japan	2.95407	0.0115	<5.0	<0.1	<5	0.028
1985	Westinghouse Electric	3.14285	0.0138	<0.1	<0.1	<5	0.046

5.0 MASS BALANCE ACTIVITIES

5.1 ESTIMATED OVERALL MASS BALANCE OF RECYCLED U (INCLUDING Pu, Np, AND ⁹⁹Tc) BASED ON PREVIOUS ANALYSIS

Previous analysis by Egli, Smith¹, Bailey², and Parks³ provide a good deal of perspective and insight regarding the flow and disposition of RU and the key constituents of interest (Pu, Np, ⁹⁹Tc) throughout the GDPs. Section 5.1 presents an analysis of the flow and disposition of these constituents at ORGDP based primarily on data and analysis presented in these referenced documents. This is provided for comparison with our current analysis presented in Section 5.2.

5.1.1 Uranium

Fig. 5.1-1 presents a summary of RU flow to and through ORGDP. Data are based on the Parks report issued as a preliminary draft in December 1999. The overall RU receipts at ORGDP was established to be 16,800 MTU. Approximately two-thirds of the UF₆ produced in the ORGDP feed plant was shipped to PGDP (including a small amount to PORTS), and only 5,350 MT of the RU converted to UF₆ in the ORGDP feed plant were fed to the ORGDP cascade.

Over its operating lifetime, 86,385 MTU of PGDP product were fed to the ORGDP cascade, along with 78,013 MTU of natural UF₆ feed, 41,947 MTU of other UF₆ (including re-feed), and the previously identified 5,350 MTU of RU. A portion of the 78,013 MTU of natural uranium feed was also processed in the ORGDP feed plant. This flow of natural uranium through the feed plant is not illustrated in Fig. 5-1, which is intended to highlight RU.

5.1.2 Plutonium

Fig. 5.1-2 presents the overall mass balance for Pu at ORGDP. A very high percentage of Pu is removed from RU in the feed plant and in the feed plant cylinder heels. In particular, the conversion from UF₄ to UF₆ results in the formation of nonvolatile compounds that result in the removal of most of the Pu, some of the Np, and a modest fraction of ⁹⁹Tc in the feed plant ash and in cylinder heels. Bailey estimates that 99.85% of the Pu is removed from RU in the feed plant at both PGDP and ORGDP. Smith and Parks estimate approximately 99.97% of the Pu is removed in the PGDP feed plant and/or retained in the UF₆ feed cylinders based on sampling of residue or "dust" in the PGDP cascade near feed points and analysis for Np and Pu. For

¹ R. F. Smith, *Historical Impact of Reactor Tails on the Paducah Cascade*, KY/L-1239, Martin Marietta Energy Systems, Inc., Paducah Gaseous Diffusion Plant, March 1984.

² J. C. Bailey, "Radionuclides in the Equipment of the Oak Ridge Gaseous Diffusion Plant," Presentation to DOE Oak Ridge Operations and DOE Headquarters at the ORGDP, March 10, 1988.

³ J. W. Parks, et al., *Recycled Uranium Processed at the Department of Energy's Oak Ridge, Paducah, and Portsmouth Gaseous Diffusion Plants: Preliminary Report*, U.S. DOE Oak Ridge Operations, December 1999.

perspective, the PORTS mass balance draft report⁴ assumes 99.9% of the Pu is removed in the feed plant.

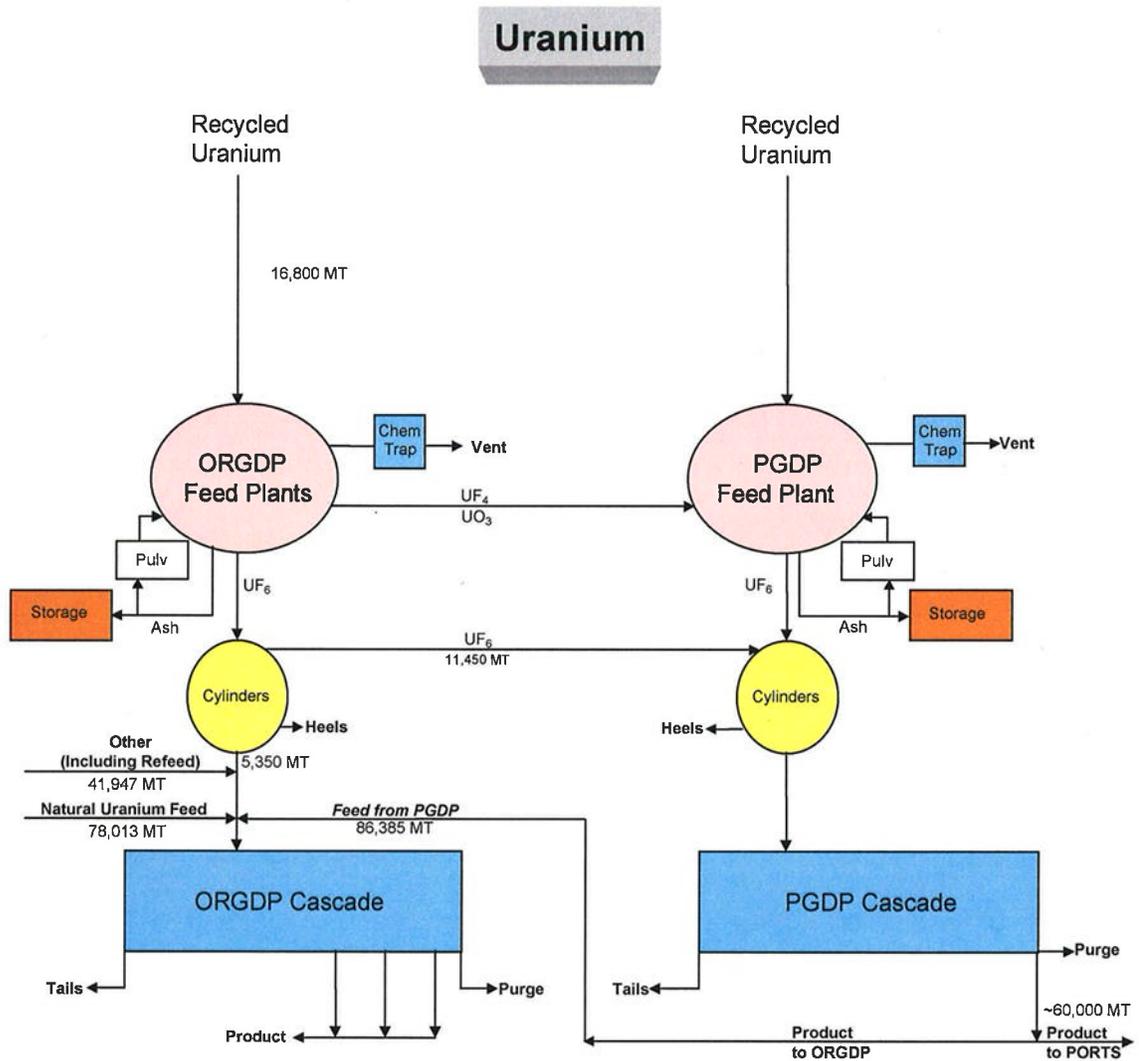
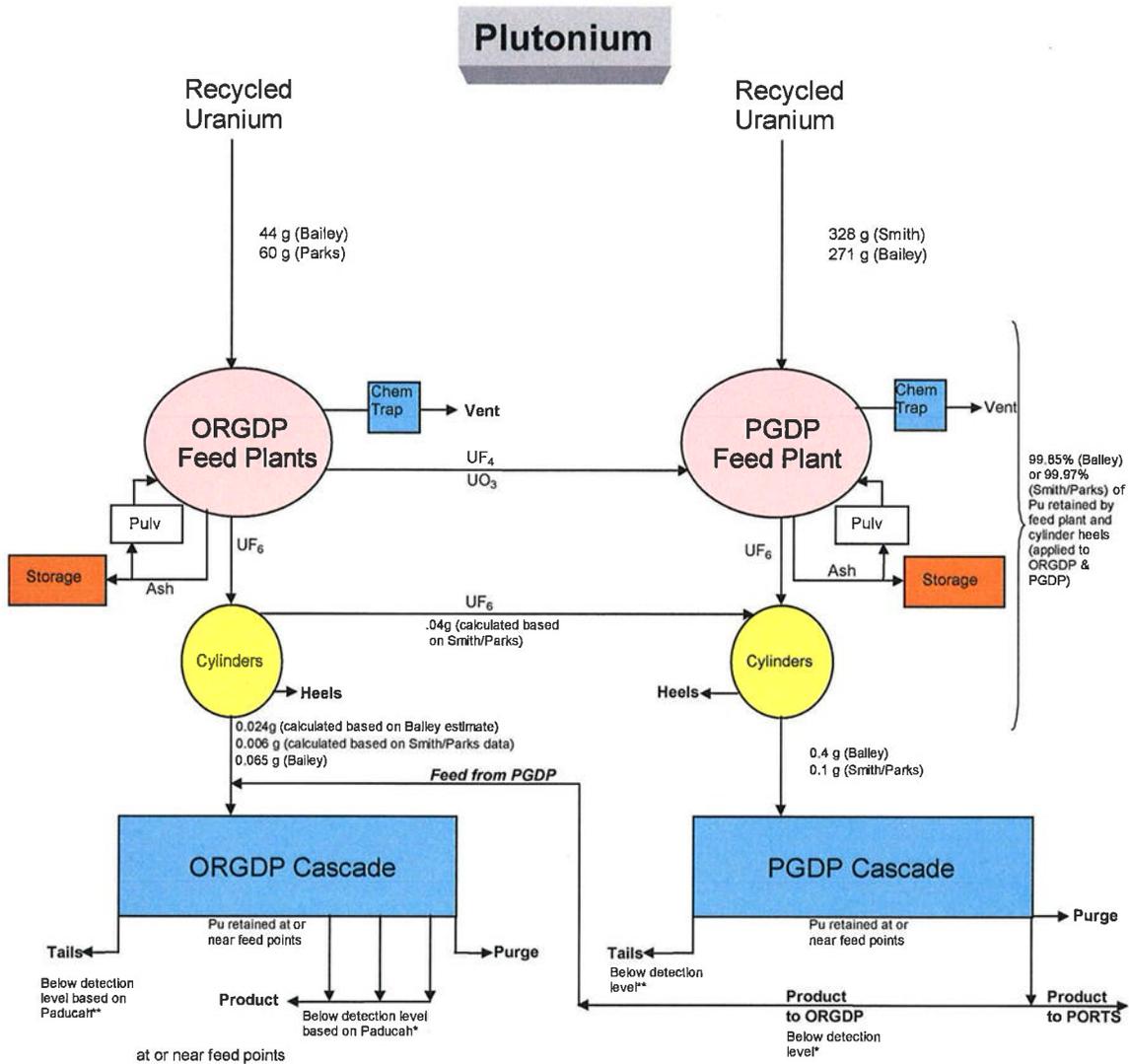


Fig. 5.1-1. Summary of Baseline RU Flow (Based on Parks Report).

⁴ Draft of Recycled Uranium Mass Balance Project Portsmouth, Ohio, Site Report, BJC/PORTS-139, Bechtel Jacobs Company, LLC, Portsmouth Gaseous Diffusion Plant, March 2000



**Three product cylinders measured in 1973. Sixty product cylinders measured between 1975 - 1982; all were below detection level of 0.05 ppb initially and 0.01 ppb after 1980 except two cylinders, one showing 0.06 ppb and one showing 0.02 ppb (Smith).*

***Two tails cylinders measured in 1973 <0.01 ppb Pu. Routine measurements since 1975 show <0.01 ppb Pu detection level (Smith).*

Fig. 5.1-2. ORGDP Baseline Mass Balance for Plutonium.

Extrapolating the Smith and Parks's analysis to ORGDP yields a projection of 0.006 g of Pu fed to the ORGDP cascade, versus the Bailey estimate of 0.065 g of Pu. Note that Bailey's estimate does not appear to take into account the fact that only about one-third of the RU received at ORGDP as oxide and converted to UF₆ was fed to the ORGDP cascade. Based on Bailey's estimate of 99.85% retained in the feed plant and 44 g received, we calculate 0.024 g fed to the ORGDP cascade.

All evidence indicates that essentially all Pu fed to the ORGDP and PGDP cascades was retained at or near the feed points. Based on analysis at PGDP, both product and tails samples indicate Pu concentrations are below detection levels. If trace quantities of Pu entered the cylinders it would tend to react and become fixed to the cylinder wall. Depending on the method of sampling, Pu on the cylinder wall might not be detected by sampling the contents.

5.1.3 Neptunium

Fig. 5.1-3 presents the overall mass balance for Np at ORGDP. The Bailey estimates for Np received at PGDP and ORGDP are somewhat lower than the Smith and Parks estimates. Bailey believed that documented information regarding the disposition of ⁹⁹Tc among the plants was probably the most reliable index for evaluating distribution of Pu and Np. Bailey used the ⁹⁹Tc values to calculate proportional amounts of Pu and Np. Smith estimated the Np concentrations in the RU based on limited available composite samples. These estimates appear to provide a reasonable bound on the range of Np receipts.

Both Bailey and Smith/Parks project that approximately 75% of the Np is retained in the feed plant and UF₆ feed cylinders and the remaining 25% is fed to the cascade. For perspective, the PORTS mass balance draft report makes the same assumption. Np fed to the cascade tended to plate out near the feed points. This is borne out by actual sample data from cascade equipment and is illustrated in the estimated Np distribution in the PGDP cascade shown in Fig. 5.1-4 (which is from Bailey).

No detectable levels of Np were found in the tails stream at PGDP based on 40 tails cylinders analyzed (Smith). Very minimum but detectable levels of Np were found in a few of the 60 product cylinders sampled at PGDP. Based on these results, it is assumed that an average of 2.5 ppb Np is included in the product stream from PGDP to ORGDP. This assumption is based on using one-half of the larger 5-ppb detection level available before 1980. This assumption results in projection of an additional 0.17 kg of Np fed to ORGDP.

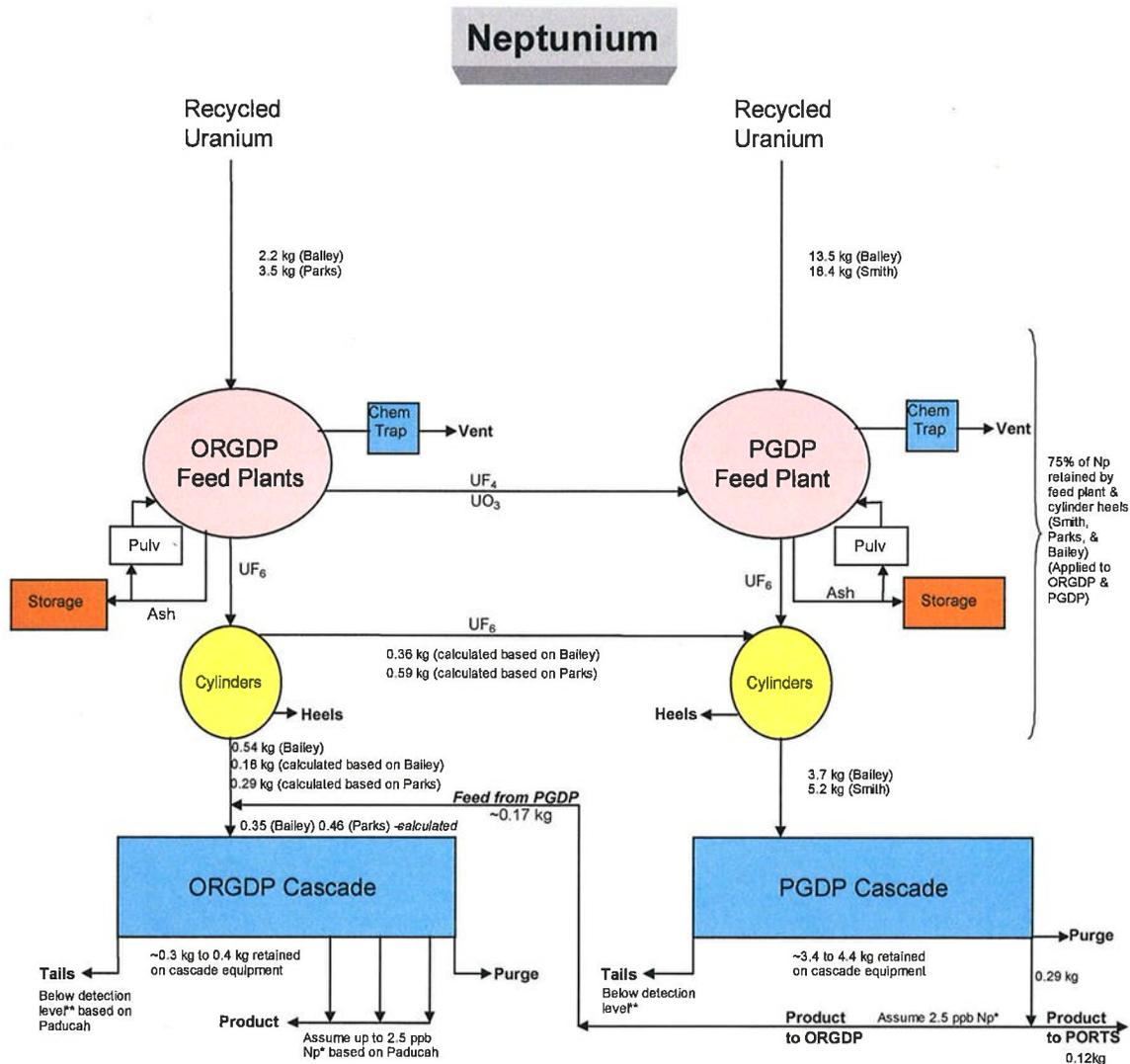
As illustrated in Fig. 5.1-4, Np fed to the ORGDP cascade is expected to have plated out quickly near the feed points. Based on an analysis of product cylinders at PGDP, it was estimated that less than 2.5 ppb Np might have progressed to the ORGDP product stream. Tails from the ORGDP cascade would be expected to be below the detection level for Np. If trace quantities of Np entered the cylinders, it would tend to react and become fixed to the cylinder wall. Depending on the method of sampling, Np on the cylinder wall might not be detected by sampling the contents.

5.1.4 Technetium

Fig. 5.1-5 presents the overall mass balance for ⁹⁹Tc at ORGDP. The projections of total ⁹⁹Tc in RU at PGDP are in good agreement at 670 kg (Bailey) and 661 kg (Smith and Parks). Approximately 15% of this is estimated by Smith to be retained in the feed plant and in cylinder

heels at PGDP. Bailey estimates similar retention of ^{99}Tc . For perspective, the PORTS mass balance draft report assumes that 10% of the ^{99}Tc is retained in the feed plant and cylinders.

For ORGDP, Bailey projects 86 kg of ^{99}Tc are received and fed to the cascade—which does not provide an allowance for retention in the feed plant and cylinder heels or for the portion of feed shipped to Paducah. However, after allowance for this retention and shipments to Paducah based on the Parks estimate, the estimated ^{99}Tc that was fed to the ORGDP cascade is 207 kg from Bailey and 152 kg estimated from Parks. Note that the total ^{99}Tc feed to the ORGDP cascade includes a significant contribution (121 kg) from ^{99}Tc contained in PGDP product shipped to ORGDP.



*60 product cylinders analyzed for Np at Paducah; a few exceeded 5 ppb detection level; highest measurement 27 ppb; most cylinders showed undetectable levels of Np; i.e., <1 and 5 ppb detection levels used (Smith). Assume average Np concentration was half of 5 ppb detection level.

**40 tails cylinders analyzed for Np at Paducah; all were below 1 & 5 ppb detection levels (Smith).

Fig. 5.1-3. ORGDP Baseline Mass Balance for Neptunium.

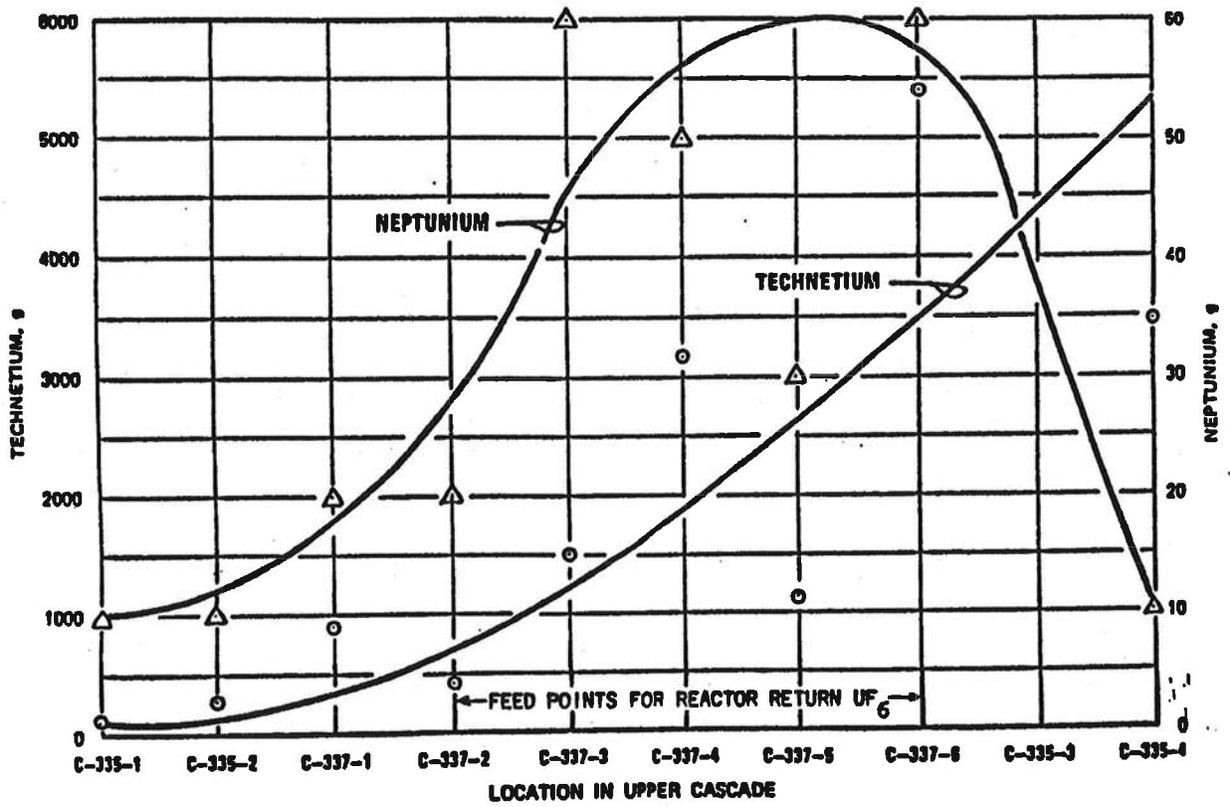


Fig. 5.1-4. Deposition of Neptunium and Technetium in the Upper Cascade of PGDP.

Technetium

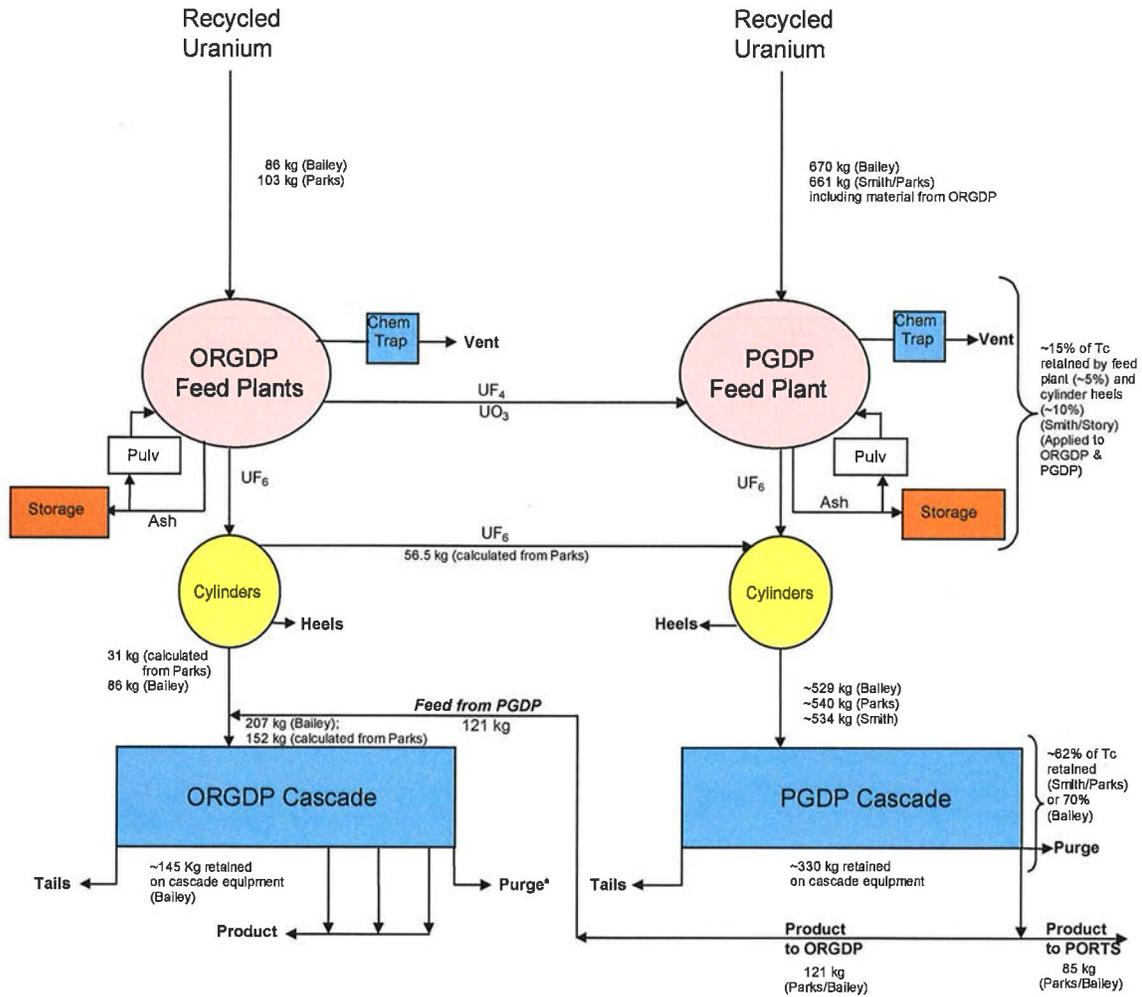


Fig. 5.1-5. ORGDP Baseline Mass Balance for Technetium.

Smith and Parks estimate that approximately 62% of the ^{99}Tc was retained on cascade equipment at PGDP, while Bailey estimates retention in the ORGDP cascade to be approximately 70% of the ^{99}Tc fed. The ^{99}Tc distribution in the cascade above the feed point at PGDP is also illustrated in Fig. 5.1-4.

The configuration of the ORGDP cascade is unique in that it includes an intermediate molecular weight gas purge system near the top of the cascade. Bailey projects that essentially all of the remaining 62 kg of ^{99}Tc at ORGDP accumulated in the purge cascade equipment or was trapped at the purge system.

5.2 ESTIMATED OVERALL MASS BALANCE OF RECYCLED URANIUM (INCLUDING Pu, Np, AND ^{99}Tc) BASED ON ANALYSIS OF BEST AVAILABLE DATA

Section 5.1 provided a baseline analysis developed from existing studies (primarily by Egli, Smith, Parks, and Bailey). The Section 5.2 analysis extends the evaluation by incorporating the best available data derived from a brief but intensive search of ORGDP records as previously described in Chapter 1.

This analysis presents a conservative estimate of the constituents contained in the RU considering both the previous analysis and new data that has been accumulated during this effort.

5.2.1 Uranium

As derived from the project team's investigation, the flow of RU to and through ORGDP is presented in Section 3.0 and summarized in Fig. 5.2-1. The total RU recognized to have been received at ORGDP has increased from the 16,800 MTU presented in the Parks report to 18,654 MTU. Most of the additional material was received in the form of UF_6 from foreign and other domestic sources.

The total RU fed to the ORGDP cascade is projected to be 5,915 MTU. It is important to note that approximately two-thirds of the RU received at ORGDP as oxide was shipped to PGDP as UF_6 after being processed in the ORGDP feed plant.

Table 5.2-1 presents the summary of RU received, shipped, and fed at ORGDP in tabular form.

Uranium

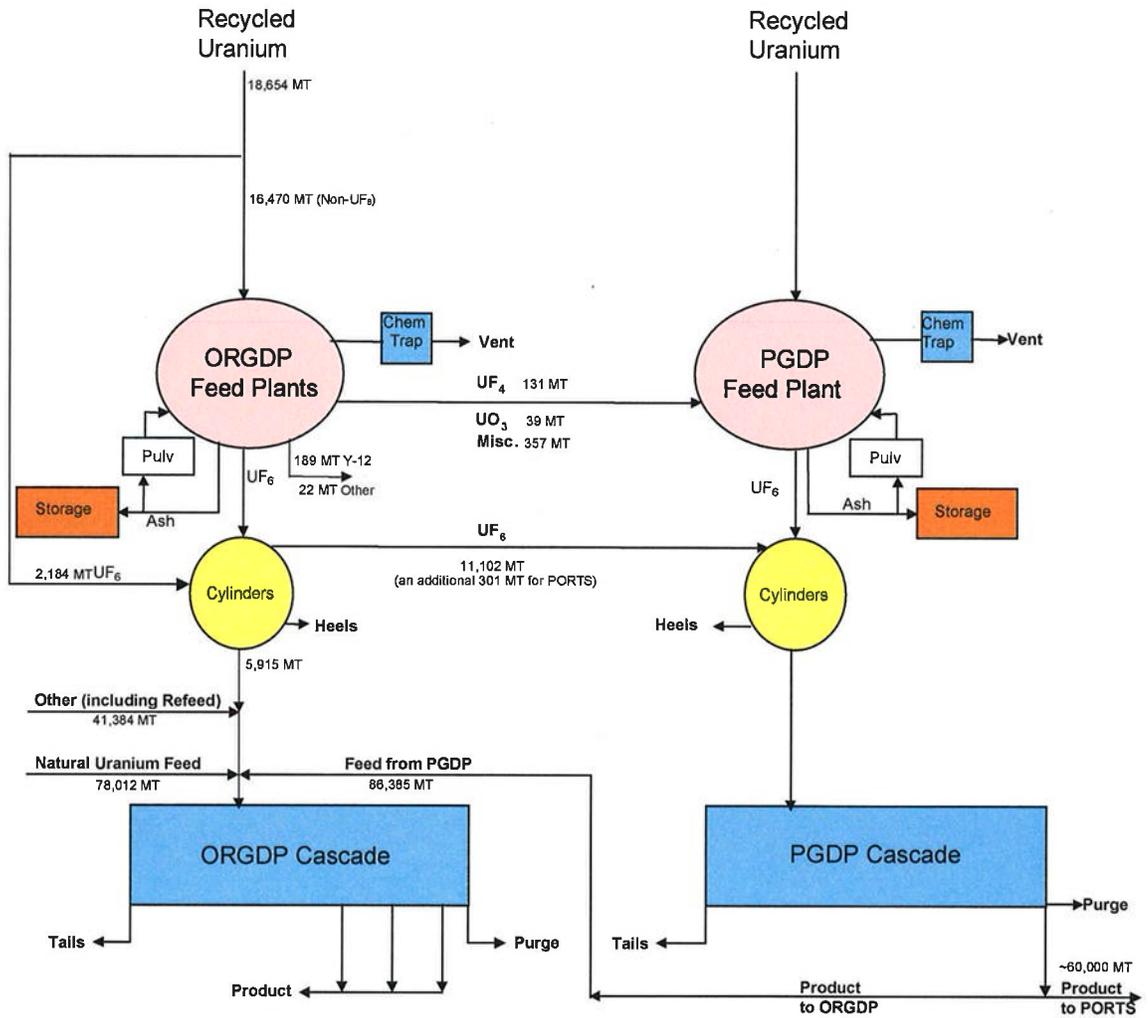


Fig. 5.2-1. Summary of Recycled Uranium Flow (Based on Section 3 and Table 5.2-1).

**Table 5.2-1. Summary of RU Received, Shipped, and Fed at ORGDP
Based on Analysis of Best Available Data**

Receipts - Source Sites	MTU
Hanford (1952 - 58)	2,749 UO3(.646% - .666%)
Hanford (1959 - 62)	1,527 UO3(.848% - .864%)
Savannah River (1955 - 62)	10,290 UO3(.590% - .682%)
Harshaw (1953 - 54)	1,702 UO3(.666% - .671%)
Foreign (1969 - 88)	243 UF6 (~.65%)
	1,051 UF6 (Power Reactor Returns)
Subtotal - Receipts Major Flows	17,562
Receipts - Secondary Sites:	
PGDP	98 UO3 (~.65%)
	88 UF4 (~.65%)
	887 UF6 (~.65%)
	11 Misc. (Includes Ash)
PORTS	3 UF6 (~.65%)
ORNL	3 UO3
	2 UF4
Subtotal - Receipts Other Flows	1,092
Total Available	18,654
Shipments To:	
PGDP	39 UO3 (~.65%)
	122 UF4 (~.65%)
	9 UF4 (~.85%)
	10,577 UF6 (~.65%)
	39 UF6 (~.85%)
	486 UF6 (foreign returns)
	357 Misc (~.65%)
PORTS	3 UO3 (~.65%)
	296 UF6 (~.65%)
	2 UF6 (~.85%)
Y-12	189 Misc.
Other	22 Misc.
Subtotal - Shipments	12,141
Feed to the Cascade	5,915
Total Available less Shipments and feed to Cascade	598
Inventory 3/31/1999	0
Cumulative losses and MUF	598

5.2.2 Plutonium

Specific information on Pu in ORGDP RU receipts from Harshaw (October 1952 to December 1953), Hanford (February 1952 to June 1956), and Savannah River (December 1954 to July 1957) was obtained from correspondence from the ORGDP Laboratory Superintendent to the shipping site representative for analysis of RU as received. Based on these data, the weighted mean value of Pu concentration is 4.4 ppb in RU oxide shipped from these primary sources as shown on Table 5.2-2.

Table 5.2-2. Weighted Mean Value of Pu Concentration

Source	Average Pu (ppb)	Total Receipts (kgs)	Total Pu Received (grams)
Hanford	4.5	4,276,111	19.24
Harshaw	3.5	1,702,335	5.96
Savannah River	4.5	10,289,680	46.31
<i>Weighted Average</i>	4.4		

We should note that there is a discrepancy between Oak Ridge data and Hanford data for Pu content in RU from Hanford during the period of January to April 1953. The Oak Ridge data shows Pu concentrations during this period well above 10 ppb (see Figure 4.4-2). Hanford reported less than 10 ppb Pu concentration during this period.⁵ If the Hanford data was used, the total projected Pu received at the ORGDP would have been closer to the Parks estimate of 60g.

The Oak Ridge data was used in this analysis. Other supporting evidence tends to confirm the higher estimate of Pu concentration from Hanford receipts during this period. For example, a January 6, 1953, memo discussing Pu buildup notes that "Pu content in RU from Hanford was less than 10 ppb except for approximately 30 tons which had 30 ppb."⁶

Other and foreign receipts were primarily in the form of UF₆ containing very low concentrations of Pu, Np, and fission products. The only specific data for these materials are identified by Smith, who reports the calendar year 1982 combined concentration of Np and Pu to average 6.1 ppb (<5 to 13) and states that for 1982 through 1983, the Pu ranged from <0.01 to 0.04 ppb and that Np ranged from <3 to 10 ppb. Based on this information, an average Pu concentration of 0.025 ppb and a Np concentration of 6.1 ppb have been projected for this material.

Table 5.2-3 presents the projected receipts of Pu per year. Based on this analysis, the total Pu receipts at ORGDP are projected to have been 71.5 g. (This estimate may be compared with the estimate of 44 g by Bailey and 60 g by Parks).

Essentially all of the Pu is believed to be retained in the feed plant and cylinder heels. The very low concentration of Pu in the foreign RU receipts (already converted to UF₆) provides support for this conclusion. The fraction of Pu retained in the feed plant and cylinder heels is estimated by Bailey at 99.85%; by the PORTS mass balance draft report at 99.9%; and by Parks at 99.97%. Based on these estimates, the Pu fed to the ORGDP cascade over the life of the plant is projected to be 0.01 to 0.04 g.

⁵ "Reconciliation of Pu Data Between K-25 and Hanford," personal communication from Walt Scarbrough (Oak Ridge) to David Dodd (Hanford), 6/1/00.

⁶ "Interim Report on Plutonium Buildup," memo from J.A. Marshall to A. P. Huber, January 6, 1953.

Table 5.2-3. Projected Annual Pu Received at ORGDP and Fed to the Cascade

Fiscal Year	Harshaw RU (kg)	Hanford RU (kg)	Savannah River RU (kg)	Other (PGDP, PORTS, ORNL, and Foreign) RU (kg)	Pu in Harshaw RU at 3.5 ppb (g)	Pu in Hanford RU at 4.5 ppb (g)	Pu in Savannah River RU at 4.5 ppb (g)	Pu in Other (PGDP, PORTS, ORNL, and Foreign) RU at 0.025 ppb (g)	Total Pu Received in RU at ORGDP (g)	Total Pu Fed to the ORGDP Cascade (g)
1952		99,970				0.45			0.45	
1953	1,402,761	570,249			4.91	2.60			7.51	
1954	299,574	1,115,345			1.05	5.02			6.07	
1955		526,475	271,949			2.37	1.22		3.59	
1956		323,882	2,538,844			1.46	11.42		12.88	
1957		98,218	2,635,163			0.44	11.86		12.30	
1958		7,201	1,077,065			0.03	4.85		4.88	
1959		261,253	828,250			1.18	3.73		4.91	
1960		609,775	1,677,456			2.74	7.55		10.29	
1961		611,020	1,121,645			2.75	5.05		7.80	
1962		44,722	139,308			0.20	0.63		0.83	
1963										
1964										
1965				Total Foreign 1969 - 1988						
1966				1,294,359				negligible	negligible	
1967				Total PGDP and PORTS 1953 - 1970						
1968				1,086,962				negligible	negligible	
1969										
1970										
TOTALS*	1,702,335	4,276,111	10,289,680	2,386,695	5.96	19.24	46.31		71.51	0.01 to 0.04

* Numbers may not sum because of rounding.

The estimates for Pu fed to the cascade are based on analysis of dust samples from Paducah cascade equipment confirming that plutonium alpha is approximately 1% of Np alpha.^{7,8} Further analysis based on this information indicates that Pu fed to the cascade was ~0.011% of Np fed to the cascade, which led to the estimate of Pu retained in the feed plant and cylinder heels by Bailey, Parks, and the Portsmouth Mass Balance Report. Smith indicated this analytical approach resulted in a conservative upper limit of Pu fed to the cascade.

Recently, information relevant to these assumptions was requested from Gus Cook of Paducah. Cook advised that a classified Paducah document⁹ was used to validate the (unclassified) Smith report data shown in Table 5.2-4.

Table 5.2-4. Validated Data From Smith Report

	Remaining in Feed Plant Ash	Remaining in Cylinder Heels	Fed to the Cascade
Pu	99.0%	0.9%	0.1%
Np	25.0%	50.0%	25.0%
Tc	5.0%	10.0%	85.0%

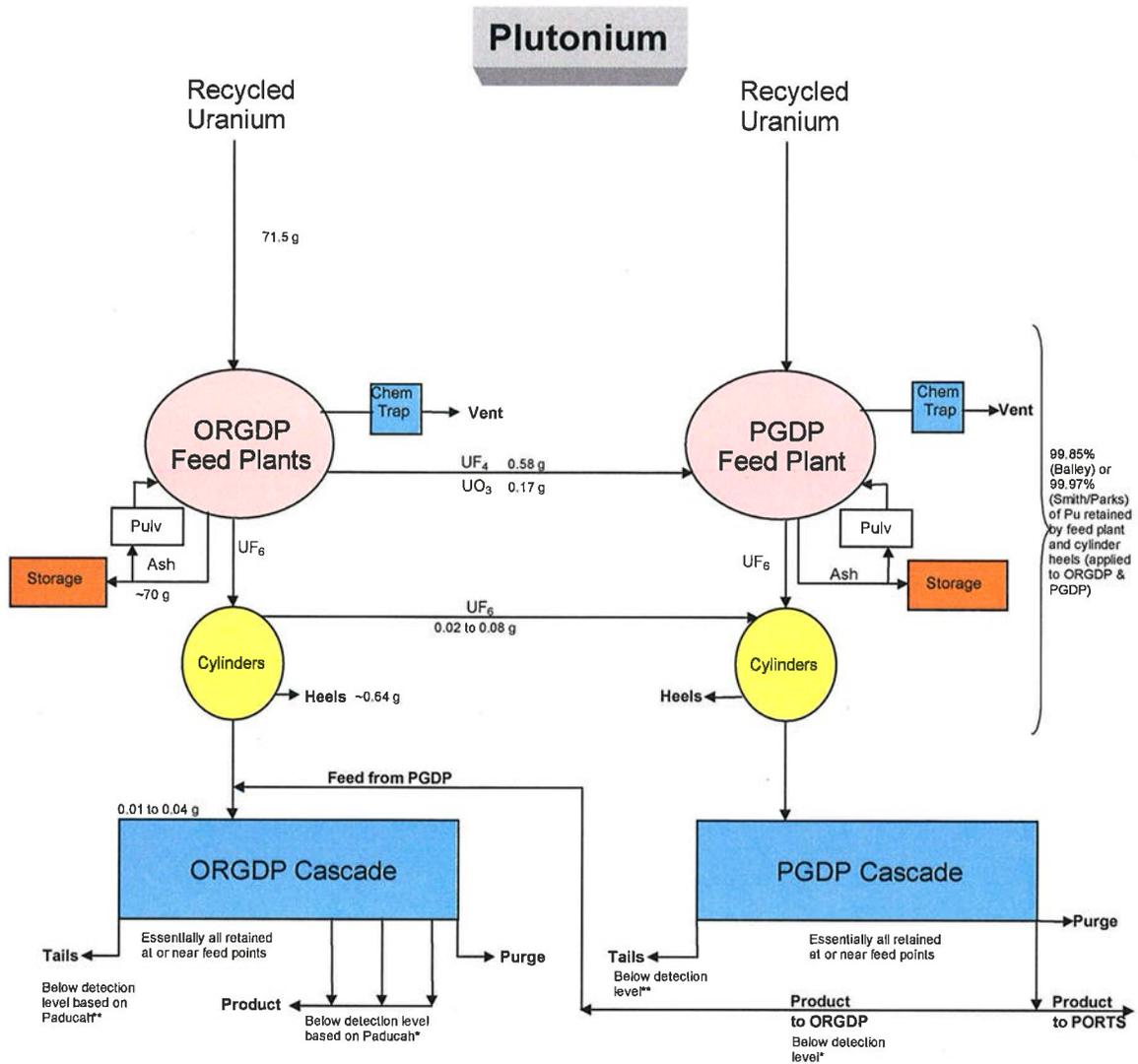
The presence of Pu in ORGDP product and tails is expected to be well below detectable levels. Pu fed to the cascade is expected to have plated out on metal surfaces near the feed points and to have been removed with cascade equipment during the cascade improvement and cascade upgrade programs. This conclusion is supported by limited sample analysis of product and tails.

Fig. 5.2-2 presents the overall projected flow of Pu to and through ORGDP.

⁷ Estimates of Transuranium Alpha Fed to the Paducah Cascade, memo from R. F. Smith to R. W. Levin, KY-L-411, April 19, 1966.

⁸ Neptunium and Plutonium Plant Material Balance, memo from A. J. Lemonds to R. W. Levin, KY-L-565, July 19, 1971.

⁹ Technetium and Plutonium Summary, KY-L-936 (classified), June 21, 1978.



**Three product cylinders measured in 1973. Sixty product cylinders measured between 1975 - 1982; all were below detection level of 0.05 ppb initially and 0.01 ppb after 1980 except two cylinders, one showing 0.06 ppb and one showing 0.02 ppb (Smith).*

***Two tails cylinders measured in 1973 < 0.01 ppb Pu. Routine measurements since 1975 show < 0.01 ppb Pu detection level (Smith).*

Fig. 5.2-2. ORGDP Mass Balance for Plutonium.

5.2.3 Neptunium

The Smith report contains an Appendix 10 that summarizes the results of Np concentration analysis in RU measured subsequent to 1957. This summary is presented as Table 5.2-5.

Table 5.2-5. Neptunium Received in Reactor Tails and Fed to PGDP Cascade

Stream	Quantity of Reactor Tails MTU	Average Concentration ppm Np, U Basis	Concentration Range, ppm Np, U Basis	Apparent Np Received (kg)
Hanford and Savannah River FY 1957 to FY 1967	74,898	0.24	0.01 to 0.60	16.3
Hanford after FY 1967	22,326	0.09	0.05 to 0.27	1.8
Savannah River after FY 1967	1,890	0.12	<0.01 to 0.22	0.2
Enriched RU	2,154	0.05	0.01 to 0.11	0.1

During the early 1950s, ORNL Chemistry Division was exploring Np recovery from RU and from Purex Process Pu wastes. An ORNL paper prepared in 1957 by Lantz and Parker¹⁰ provides information on four composite samples of Hanford UO₃ RU as shown in Table 5.2-6

Table 5.2-6. ORNL Analysis of Neptunium in Composite Hanford RU Samples

Sample Date	Sample Code	Description of Sample	Np ²³⁷ ppm*
03/16/57	Composite 16 UA	Hanford UO ₃	0.823
03/16/57	Composite 504	Hanford UO ₃	0.869
05/03/57	Serial # 192-D	UO ₃ Feed (Hanford)	1.098
06/18/57	UA-3615 21	UO ₃ Feed (Hanford)	0.514

* Np concentration is presented in gram per ton in these historical reports, which we interpret to be grams per metric ton or parts per million.

Lantz and Parker concluded that the theoretically calculated yield of Np in irradiated normal uranium is expected to be 2.5 to 3 gm of Np per kg of Pu. They assumed the level of Hanford metal to be 600 gm Pu per ton resulting in a Np yield of approximately 1.8 grams per ton; they concluded that almost one-half was being fed to the PGDP plant in RU.

Table 5.2-7 shows four additional data points on Np content from Savannah River calcined UO₃ (RU) at ORGDP from the ORNL Chemistry Division Semi Annual Progress Report for the period ending December 20, 1955, (ORNL-2046).

¹⁰ P. M. Lantz and G. W. Parker, "Investigation of Paducah Ash and Metal Recovery Waste as a Large-Scale Source of Neptunium-237," Oak Ridge National Laboratory, July 1957.

Table 5.2-7. ORNL Analysis of Neptunium Content of Savannah River Calcined UO₃

Sample Date	Sample Code	Np ²³⁷ ppm*
<u>Approximately 1955</u> No specific date given but samples taken over several months prior to analysis	K-25, Lot 168	
	- Composite No. 1	0.694
	- Composite No. 2	0.682
	K-25, Lot 1196	
	- Trailer Load No. 1	0.747
	- Trailer Load No. 2	0.769

* Np concentration is presented in gram per ton in these historical reports, which we interpret to be grams per metric ton or parts per million.

The report notes that the higher than expected Np concentration was not a transient condition as shown by the results from the composite samples, which were collected over several months.

Bailey asserts that documented information regarding the ⁹⁹Tc content in RU is probably the most reliable index for evaluating the distribution of Pu and Np. Bailey's analysis of Np received in RU oxide at ORGDP is 2.2 kg or approximately 0.13 ppm.

Finally, based on analysis of the French RU received at ORGDP in 1982 (Smith), Np received in foreign receipts in the form of UF₆ is projected to be approximately 6.1 ppb. Again, since this material is already converted to UF₆, it would be expected that most of the Pu and Np would have been removed from the UF₆ feed.

In summary, for the period when Hanford and Savannah River RU oxides were received at ORGDP, Smith projects a Np concentration of 0.24 ppm, Bailey calculated a Np concentration of 0.13 ppm, and the eight composite data points for Hanford and Savannah River RU in 1955-57 show an average Np concentration of 0.78 ppm. This is obviously a wide range of variation. The Smith estimates are based on monthly composite sample analysis for material received between 1957 and 1967. The much higher ORNL estimates are for eight composite samples performed in 1955 and March thru June 1957. The Bailey estimate does not appear to be supported by data.

This analysis is based on using the ORNL data as the representative Np concentration for 1952 through mid-1957 and the Smith data for mid-1957 through 1967. This approach is not meant to suggest that there was a dramatic reduction in Np concentration received in 1957, but rather that this is a conservative basis for estimating Np receipts based on data available.

Table 5.2-8 summarizes the projected receipts of Np at ORGDP on this basis. The total projected receipts based on this analysis are approximately 9 kg.

Table 5.2-8. Projected Np Received at ORGDP and Fed to the Cascade

Fiscal Year	Harshaw RU (kg)	Hanford RU (kg)	Savannah River RU (kg)	Other (PGDP, PORTS, ORNL, and Foreign) RU (kg)	Estimated Np Concentration (ppm)	Np Received at ORGDP (kg)	Np Fed to ORGDP Cascade (kg)
1952		99,970			0.78	0.08	
1953	1,402,761	578,249			0.78	1.55	0.14
1954	299,574	1,115,345			0.78	1.10	0.10
1955		526,475	271,949		0.78	0.62	0.06
1956		323,882	2,538,844		0.78	2.23	0.20
1957		98,218	2,635,163		0.78 half yr. 0.24 half yr.	1.39	0.13
1958		7,201	1,077,065		0.24	0.26	0.02
1959		261,253	828,250		0.24	0.26	0.02
1960		609,775	1,677,456		0.24	0.55	0.05
1961		611,020	1,121,645		0.24	0.42	0.04
1962		44,722	139,308		0.24	0.04	
1963		1			0.24		
1964							
1965				Total Foreign 1969 - 1988			
1966				1,294,359	0.006	0.01	
1967				Total PGDP and PORTS 1953 - 1970			
1968				1,086,962			
1969					0.006	0.48	0.04
1970							
TOTALS*	1,702,335	4,276,111	10,289,680	2,386,595		8.99	0.80

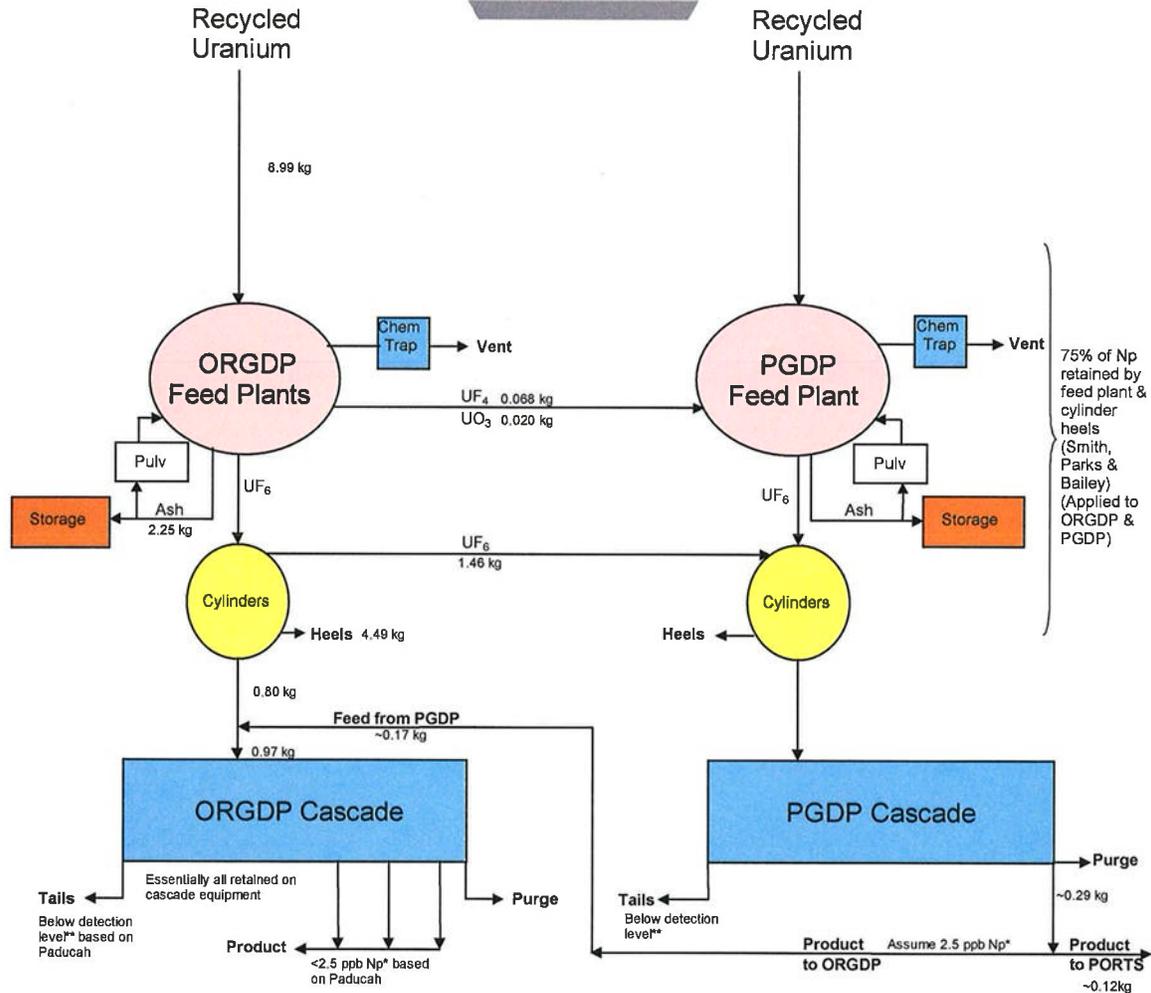
* Numbers may not sum because of rounding.

Bailey and Smith/Parks project that 75% of the Np is retained in the feed plant and cylinder heels and that 25% is fed to the cascade. This estimate was based on (1) the quantity of neptunium fed to a group of feed cylinders during a closed cycle in which the cylinders were repeatedly filled with reactor tails UF₆, (2) a material balance across the feed plant for the period during which neptunium containing feed was processed, and (3) dust samples from various cascade equipment and cascade barrier. Smith estimated the range of Np retained in the feed plant and cylinder heels to be 60% to 90% and used an average of 75% in his analysis.

Based on this assumption, 0.97 kg (0.80 kg and 0.17 kg) of Np are projected to have been fed to the ORGDP cascade from RU received at ORGDP and from PGDP product as shown in Fig. 5.2-3. [Note that only about 36% of the RU oxide processed in the ORGDP feed plant is fed to the ORGDP cascade.] Fig. 5.2-3 presents the overall mass balance for Np at ORGDP based on this analysis, which is somewhat higher than the projections of Np fed to the ORGDP by Bailey (~0.36 kg) and Parks (~0.46 kg) as shown on Fig. 5.1-3.

Np fed to the ORGDP cascade is expected to have plated out quickly near the feed points as illustrated in Fig. 5.1-4. Based on analysis of product cylinders at PGDP, it was estimated that less than 2.5 ppb Np might have progressed to the ORGDP product stream. Tails from the ORGDP cascade would be expected to be below the detection level for Np.

Neptunium



*60 product cylinders analyzed for Np at Paducah; a few exceeded 5 ppb detection level; highest measurement 27 ppb; most cylinders showed undetectable levels of Np; i.e., <1 and 5 ppb detection levels used (Smith). Assume average Np concentration at Paducah was half of 5 ppb detection level.

**40 tails cylinders analyzed for Np at Paducah; all were below 1 & 5 ppb detection levels (Smith).

Fig. 5.2-3. ORGDP Mass Balance for Neptunium.

5.2.4 Technetium

5.2.4.1 Technetium Contained in PGDP Product Fed to ORGDP Cascade

The Smith/Parks estimate of 121 kg ⁹⁹Tc in the 86,385 MTU of PGDP product shipped to ORGDP is based on an estimated overall average ⁹⁹Tc content of approximately 1.4 ppm.

There are no data for 1953 through 1961, 1964 through 1971, and 1982 through 1985. ORGDP made ⁹⁹Tc measurements of PGDP product for the 5 months preceding the installation in January 1963 of a MgF₂ trap at PGDP to reduce the ⁹⁹Tc concentration in PGDP product. The average ⁹⁹Tc concentration in the PGDP product for the five months preceding the trap installation was 3.2 ppm. After installation of the trap, ORGDP continued measurements for 4 months during which the average ⁹⁹Tc concentration dropped to 0.15 ppm ⁹⁹Tc.

During the first 10.5 months of operation with the trap, 11.4 kg of ⁹⁹Tc was recovered from the trap. This rate of recovery implies that the ⁹⁹Tc concentration would have been approximately 4.7 ppm for the year without the trap. Assuming 3.2 ppm for 1 month and 0.15 ppm for 11 months, the estimated annual concentration of ⁹⁹Tc for 1963 was estimated to be 0.4 ppm.

Smith indicates that at some point not specified, attention to emptying the MgF₂ trap beds became lax, saturation resulted, and ⁹⁹Tc again increased in the product. Smith further indicates there was no RU fed to the PGDP cascade from 1965 to 1968 and in 1971.

Based on this information, an estimate of annual ⁹⁹Tc transferred to ORGDP in PGDP product was generated as shown on Table 5.2-9. The 3.2 ppm ⁹⁹Tc data from 1962 were attributed to PGDP product from 1953 through 1962 and 1969 through 1970. The ⁹⁹Tc concentration of 0.4 ppm in 1963 was previously explained. A modest increase to 1 ppm was assumed for 1964 through 1968 and for 1971 because, according to Smith, no RU was fed during 1965 through 1968 and in 1971. This estimate assumes a modest concentration during these years from residue in the cascade. Average ⁹⁹Tc concentrations presented for 1972 through 1982 were based on routine ⁹⁹Tc measurements made at PGDP as reported by Smith. For 1982 through 1985, ⁹⁹Tc concentrations were extrapolated from the data and trend for previous years.

The overall result, as shown in Table 5.2-9, is an estimate of 165 kg ⁹⁹Tc fed to the ORGDP cascade in PGDP product, an overall average concentration of 1.9 ppm. It is acknowledged that the previous estimate by Smith of 121 kg ⁹⁹Tc (1.4 ppm) may have been based on operational information that was available at PGDP—allowing a more precise estimate of ⁹⁹Tc concentration for years when data was not available. Lacking that additional insight, the project team judged the estimate presented in Table 5.2-9 to be reasonable.

Table 5.2-9. Projected Annual Tc Content in PGDP Product Fed to the ORGDP Cascade

Fiscal Year	PGDP Product Fed to ORGDP Cascade (MTU)	Average Tc (ppm)	Range of Tc (ppm)	Tc fed to ORGDP Cascade (kg)
1953	1,664	3.2	Assumption based on '62 data	5.30
1954	3,591	3.2	Assumption based on '62 data	11.50
1955	3,703	3.2	Assumption based on '62 data	11.80
1956	4,149	3.2	Assumption based on '62 data	13.30
1957	4,604	3.2	Assumption based on '62 data	14.70
1958	3,380	3.2	Assumption based on '62 data	10.80
1959	3,292	3.2	Assumption based on '62 data	10.50
1960	2,930	3.2	Assumption based on '62 data	9.40
1961	2,933	3.2	Assumption based on '62 data	9.40
1962	2,851	3.2	Average for last 5 months of '62 (Smith)	9.10
1963	2,871	0.4	MgF2 trap installed; 11.4 kg Tc trapped in 10.5 months; later dumping MgF2 trap became lax, saturation resulted, and Tc again increased in product (Smith)	1.10
1964	2,184	1.0	MgF2 trap in operation. Assumed 1.0 ppm for '64 and years when no recycled uranium fed	2.20
1965	2,126	1.0	No tails Fed (Smith)	2.10
1966	2,112	1.0	No tails Fed (Smith)	2.10
1967	1,931	1.0	No tails Fed (Smith)	1.90
1968	1,730	1.0	No tails Fed (Smith)	1.70
1969	2,713	3.2	Assumption based on '62 data	8.70
1970	2,637	3.2	Assumption based on '62 data	8.40
1971	2,832	1.0	No Tails Fed (Smith)	2.80
1972	2,782	0.67	0.19 to 1.7 (Smith)	1.80
1973	1,875	4.5	<0.1 to 20 (Smith)	8.40
1974	2,060	6.1	<0.2 to 20 (Smith)	12.60
1975	1,891	1.0	<0.2 to 3 (Smith)	1.90
1976	2,462	0.98	<0.3 to 3.7 (Smith)	2.30
1977	1,954	0.71	0.02 to 0.97 (Smith)	0.40
1978	1,131	0.19	<0.01 to 0.40 (Smith)	0.20
1979	1,218	0.14	<0.01 to 0.38 (Smith)	0.20
1980	2,099	0.09	<0.01 to 0.18 (Smith)	0.20
1981	4,945	0.01	<0.01 to 0.02 (Smith)	0.00
1982	3,457	<0.01		0.00
1983	2,689	<0.01		0.00
1984	1,294	<0.01		0.00
1985	2,295	<0.01		0.00
TOTALS*	86,385	1.90		164.80

* Numbers may not sum because of rounding.

5.2.4.2 Technetium Received by ORGDP from Source Sites and Fed to ORGDP Cascade

The project team reviewed the Smith/Parks estimate of 103 kg ⁹⁹Tc in RU shipped to ORGDP based on revised projected receipts as shown on Table 5.2-10. Smith reports that hundreds of measurements were performed from 1959 to 1973 on ⁹⁹Tc content in depleted RU from Hanford and Savannah River and that essentially all of them clustered in a range of 4 to 10 ppm. Smith indicates the best ⁹⁹Tc concentration estimate for all depleted Hanford and Savannah River RU received through 1974 is 7 ppm ± 30%. Only five measurements were performed on enriched RU from Hanford with an average concentration of 16 ppm. These measurements provide the best estimate for that material.

Table 5.2-10. Projected Annual Tc Received by ORGDP Directly and Fed to the Cascade

Fiscal Year	Hanford, Savannah River, and Harshaw Depleted RU (kg)	Hanford Enriched RU (kg)	Other Receipts (PGDP, PORTS, ORNL, and Foreign) RU (kg)	Tc in Depleted RU at 7 ppm (kg)	Tc in Enriched RU at 16 ppm (kg)	Tc in Other Receipts of RU (kg)	Total Tc Received Directly at ORGDP (kg)	Tc from Receipts Fed to the ORGDP Cascade <i>15% of Tc received is projected to be retained in the Feed Plant & cylinder heels</i> (kg)
1952	99,970			0.7			0.7	0.2
1953	1,981,010		153,111	13.9			13.9	4.2
1954	1,414,919		21,396	9.9			9.9	3
1955	798,424		33,426	5.6			5.6	1.7
1956	2,862,726		30,389	20.0			20.0	6.1
1957	2,733,381		34,906	19.1			19.1	5.8
1958	1,084,266		29,020	7.6			7.6	2.3
1959	828,251	261,253	70,150	5.8	4.2		10.0	3.1
1960	1,677,456	609,775	2,091	11.7	9.8		21.5	6.6
1961	1,121,645	611,020	244	7.9	9.8		17.7	5.4
1962	139,308	44,722	10,511	1	0.7		1.7	0.5
1963	1		35,489					
1964			9,052					
1965			464					
1966								
1967								
1968								
1969 - 1988			1,951,071			6.7	6.7	5.7
TOTALS*	16,268,126		2,386,595	103.2	24.5	6.7	134.4	44.6

* Numbers may not sum because of rounding.

RU received from other and foreign sources was primarily in the form of UF₆. The largest source of this material was from French Reactor Tails. The French receipts contained 0.041 ppm ⁹⁹Tc. Receipts from PGDP and PORTS are estimated at 6.6 kg and foreign receipts at 0.1 kg.

Based on these projected receipts and ⁹⁹Tc concentrations, the total ⁹⁹Tc in RU received directly at ORGDP was ~134.4 kg. Of this total, approximately 44.6 kg ⁹⁹Tc are expected to have been fed to the ORGDP cascade. [Note that only about 36% of the RU processed in the ORGDP feed plant is fed to the ORGDP cascade.]

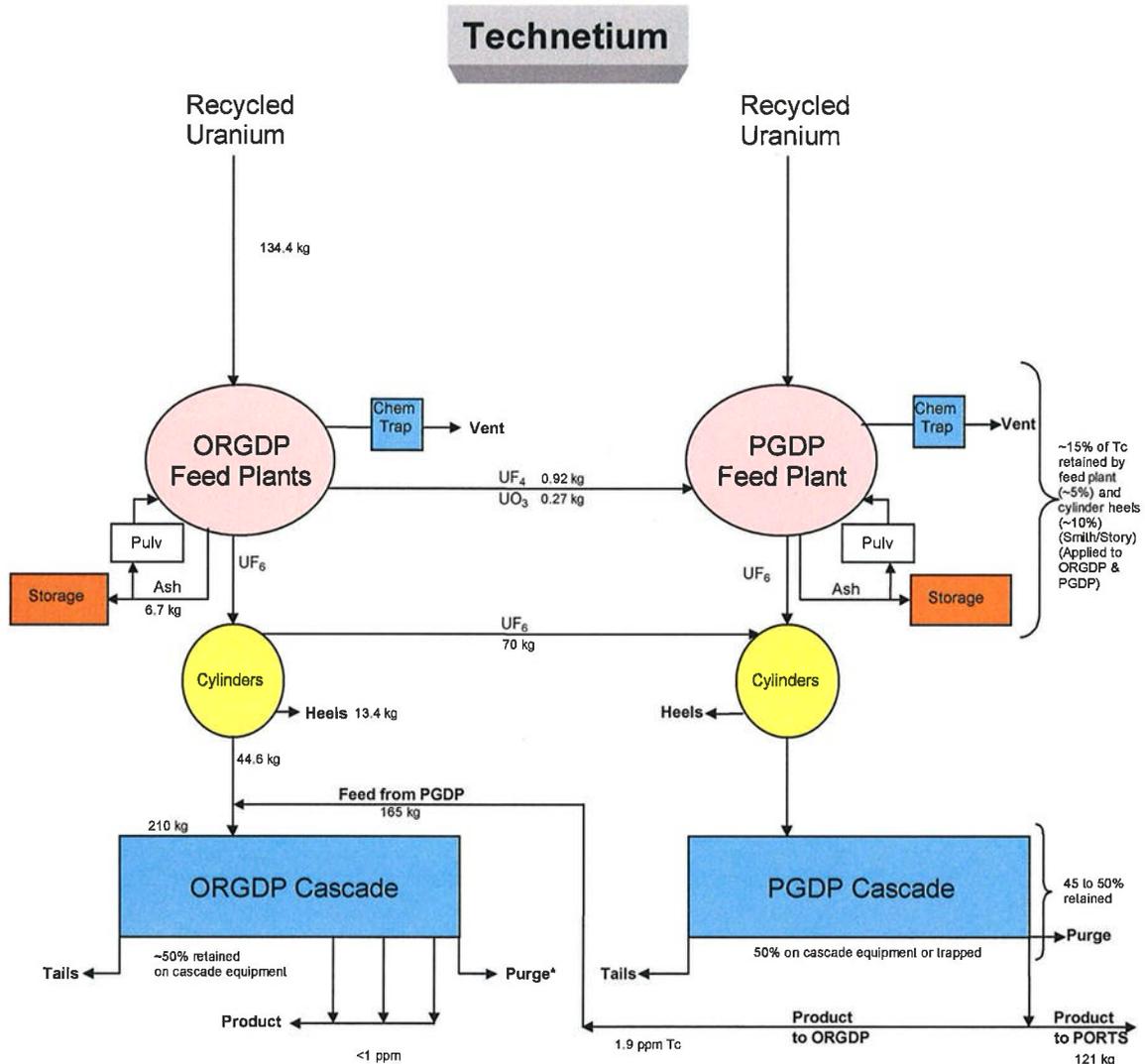
5.2.4.3 Overall Technetium Projection

Fig. 5.2-4 presents the overall projected flow of ⁹⁹Tc to and through ORGDP. It is projected that the overall flow of ⁹⁹Tc to ORGDP is approximately 134.4 kg in RU receipts of which 44.6 kg is estimated to have been fed to the ORGDP cascade, along with 165 kg received in PGDP product, for a total estimate of 210 kg of ⁹⁹Tc fed to the ORGDP cascade. An estimated 70 kg of ⁹⁹Tc were shipped to PGDP in 11,102 MT of UF₆. The total projected flow of ⁹⁹Tc to the ORGDP cascade of approximately 210 kg may be compared with the 207 kg projected by Bailey and 152 kg calculated from Parks data. [Note that Bailey in his analysis used the same estimate for ⁹⁹Tc received by ORGDP and that fed to the ORGDP cascade.]

It is important to note that the calculation of 165 kg of ⁹⁹Tc contained in PGDP product shipped to ORGDP, along with the equivalent estimate of 121 kg shipped to PORTS, results in a lower estimate of ⁹⁹Tc retained in the PGDP cascade (45 to 50%) than the projections of Smith/Parks (approximately 62%) or Bailey (approximately 70%), as shown in Fig. 5.1-5 in Section 5.1.

The most important concentration point for ^{99}Tc is in the ORGDP purge cascade equipment and the purge chemical trap. Other more modest projected concentration points include the feed plant, cylinder heels, and the ORGDP cascade equipment above the feed point.

Very little ^{99}Tc is expected to have been included in the product stream—certainly <1 ppm. In the tails stream, ^{99}Tc is expected to be below the detectable level.



**Most of the remaining Tc from the ORGDP cascade (up to ~110 kg) is projected to be in purge cascade equipment, i.e., the K-311-1, K-310-3 system and the K-402-8, K-402-9 system or in the trapped material. A significant quantity of Tc was removed from the purge system by trapping, but the specific quantity is not reported. Very little Tc is expected to have been included in the Product, certainly <1 ppm. Tc in the tails stream is expected to be below detectable levels.*

Fig. 5.2-4. ORGDP Mass Balance for Technetium.

5.3 POTENTIAL AREAS OF CONCENTRATION

Of the 18,654 MTU of RU received by ORGDP, the total estimated quantities of RU constituents of interest are:

- Pu: 71.5 g, based on data from RU receipts obtained from ORGDP Laboratory Superintendent Correspondence, of which only 0.01 to 0.04 g is estimated to have entered the cascade. The overwhelming majority of Pu was concentrated in the ash from the feed plant, and a small fraction was retained as cylinder heels. This estimate, based on ORGDP laboratory data, is modestly higher than the Parks estimate of 60 g.¹¹
- Np: 9 kg, based on ORNL composite sample analysis prior to 1957 and Paducah sample analysis for 1957 to 1967, of which approximately 0.80 kg is estimated to have entered the ORGDP cascade, along with up to 0.17 kg of Np in PGDP product fed to the ORGDP cascade. Approximately 75% of the Np received as UO₃ is estimated to have remained in the feed plant ash and cylinder heels. Almost 1.5 kg of Np was shipped to PGDP in 11,102 MT of UF₆. Analysis for Np performed by ORNL in 1955 and early 1957 on composite samples of Hanford and Savannah River RU show much higher concentrations of Np (0.78 ppm Np average) than subsequent analysis reported by Smith (0.24 ppm Np average) for the period from mid-1957 through 1967.¹² This estimate is based on using the ORNL analysis for estimated Np concentration during 1952 through mid-1957 and the Smith analysis for the period from mid-1957 through 1963, when shipments from Hanford and Savannah River ceased.
- ⁹⁹Tc: 135 kg, based on measurements performed from 1959 to 1973 on Tc content in RU from Hanford and Savannah River, of which approximately 45 kg is estimated to have entered the ORGDP cascade in the RU feed stream—along with up to 165 kg of ⁹⁹Tc contained in PGDP product feed based on Paducah data for 1972 to 1982 and ORGDP measurements of ⁹⁹Tc in Paducah product during 1962 and 1963. Approximately 70 kg of ⁹⁹Tc was transferred to PGDP in 11,102 MT of UF₆. In the ORGDP cascade, ⁹⁹Tc tended to accumulate at the top of the cascade or to migrate to the purge cascade points at the high end of the plant configuration, where it was vented and trapped.

Throughout this analysis of constituents, the ORGDP Site Team has attempted to be conservative; i.e., to err on the side of over estimating rather than under estimating the concentration level of the constituents (Pu, Np, ⁹⁹Tc).

In performing the analysis, results are sometimes presented at a level of precision, based on the mathematics, which implies a greater level of confidence than the underlying data would justify. The Site Team has attempted to identify the underlying data used throughout the analysis so that the reader will have a basis for evaluating our results.

¹¹ J. W. Parks, et al., *Recycled Uranium Processed at the Department of Energy's Oak Ridge, Paducah, and Portsmouth Gaseous Diffusion Plants: Preliminary Report*, U.S. DOE Oak Ridge Operations, December 1999.

¹² R. F. Smith, *Historical Impact of Reactor Tails on the Paducah Cascade*, KY/L-1239, Martin Marietta Energy Systems, Inc., Paducah Gaseous Diffusion Plant, March 1984.

Table 5.3-1 summarizes ORGDP receipts of RU, including constituents (i.e., Pu, Np, and ⁹⁹Tc) and Table 5.3-2 summarizes ORGDP shipments of RU, including constituents. Table 5.3-2 also summarizes the site accumulation, releases, and other unaccounted-for material.

Table 5.3-1 ORGDP Receipts of RU

Shipping Site	Material Form	Quantities Received (MTU)	Quantity of Pu (grams)	Quantity of Np (grams)	Quantity of Tc (grams)
Hanford	UO3	4,276	19.24	2,480	43,700
Savannah River	UO3	10,290	46.31	4,733	72,000
Harshaw	UO3	1,702	5.96	1,328	11,900
PGDP	UF6	887	trace	345	5300
	UO3	98	trace	51	700
	UF4	88	trace	46	600
	Misc	11	trace	6	100
PORTS	UF6	3	trace	1	trace
ORNL	UO3	3	trace	2	trace
	UF4	2	trace	1	trace
Foreign	UF6	1,294	trace	trace	50
TOTAL RECEIPTS		18,654	71.51	8,993	134,350

Table 5.3-2. ORGDP Shipments of RU

Receiving Site	Material Form	Quantities Shipped (MTU)	Quantity of Pu (grams)	Quantity of Np (grams)	Quantity of Tc (grams)
PGDP	UF6	11,102	0.05	1,460	70,000
	UF4	131	0.58	68	917
	UO3	39	0.17	20	273
	Ash	16	~70	2,250	6,380
	Misc	341	trace	trace	trace
PORTS	UF6	298	trace	trace	trace
	UO3	3	trace	trace	trace
Y-12	Misc	189	.48	102	840
ORNL	UO3	6	trace	trace	trace
	Misc	2	trace	trace	trace
Savannah River	UO3	11	trace	trace	trace
Fernald	UO3	2	trace	trace	trace
Foreign	UF6	1	trace	trace	trace
Feed To Cascade	UF6	5,915	0.03	800	44,600
TOTAL SHIPMENTS (and feed to the cascade)		18,056	~71.31	4,700	123,010
Site Accumulation, Releases, and other Unaccounted For		598	~0.20	4,293	11,340

NOTE: PGDP Product in the amount of 86,385 MTU produced in part from RU was fed to the ORGDP cascade for further enrichment. This feed to ORGDP, which is in addition to the amounts in the above table, contained an estimated 170 grams Np and 165,000 grams Tc.

ORGDP received a total of 18,654 MTU of RU. A total of 12,141 MTU has been identified as being shipped off-site. Included in the shipment total is 486 MTU in the form of UF₆ from foreign sources that remained at ORGDP until 1986, when the material was shipped to PGDP. A

total of 5,915 MTU has been identified as being fed to the plant cascade. Accountability records do not show any RU remaining in the ORGDP inventory. The remaining 598 MTU represents process losses and other unaccounted for RU. Process losses occurred that could have amounted to 1 to 2% of the RU processed. In addition, blending of RU with non-RU inventory (including both physical blending and the blending, or averaging, of assays of historical data in available documentation) resulted in a loss of the ability to identify RU inventories and transactions.

Based on historical data, it is estimated that nearly all of the incoming Pu (i.e., on the order of 99%) ended up in the fluorination tower ash while a small fraction was collected with the UF₆. Cumulative data also suggest that the bulk of Pu collected in the UF₆ feed cylinder remained in the UF₆ feed cylinder heel, allowing <0.1% of the incoming Pu to reach the ORGDP cascade. PuF₆ is easily reduced to non-volatile species. Consequently, any Pu entering the process with UF₆ was essentially immobilized at the feed points to the process. A total of 16 MTU of ash has been identified as being produced from RU. Historical records indicate that this ash was shipped off-site to Paducah, and most likely subsequently shipped to Fernald along with Paducah ash.

An interview with Mr. Joe Dykstra, who managed the feed plant during the period when RU was received and processed, revealed that the RU oxide was in general much less reactive than natural uranium oxide feed. As a result, the RU ash often contained a large fraction of unreacted UF₄. This ash was often pulverized and recycled to recover more of the uranium. One consequence of this poor reactivity would have been to reduce the concentration of ppb Pu/U in the ash.

Based on the projections previously noted by Smith¹ and Bailey², and confirmed by Cook⁹, we estimate that over 70.7 g (approximately 99%) of Pu were retained in the feed plant ash. If all this Pu were contained in the 16 MTU identified as being shipped to Paducah, the concentration would be 4,400 ppb Pu/U. Analysis obtained from Fernald on ~22.5 MTU of ash shipped from Paducah to Fernald has an average batch concentration of 1300 ppb Pu/U and a maximum batch concentration of 7650 ppb Pu/U, which seems to bound the expected range.

The bulk of the incoming Np was also distributed between the tower ash (25%) and the cylinder heels (50%). In this case, however, a significant fraction of the Np (25%) was fed to the enrichment cascade (ORGDP or PGDP). A small increment of Np was also received in the PGDP product. Since NpF₆ is also easy to reduce compared to UF₆, Np was also retained on the high surface area barrier and other process surfaces near cascade feed points. Cascade data indicate that very small quantities of the Np likely reached the top of the enrichment cascade and were discharged to the environment. Very little Np is expected to have ended up in the UF₆ product. The estimated 4,513 g of site accumulation, releases, and unaccounted-for material is expected to have primarily accumulated in cylinder heels. Washing of the cylinder heels would have resulted in release of this material in sludge. However, historical records do not indicate that the UF₆ feed cylinders were washed at ORGDP.

Approximately 85% of the ⁹⁹Tc received in the RU was fed to the cascade (ORGDP or PGDP). ⁹⁹Tc formed volatile and semi-volatile chemical compounds that tended to migrate to the top of the enrichment cascade with the enriched uranium. Consequently, a larger fraction of ⁹⁹Tc was discharged to the environment. Chemical traps installed at the top of the enrichment cascade in the 1960s retained up to 80% of the ⁹⁹Tc in the process vent gas. The estimate of 11,340 g of site accumulation, releases, and other unaccounted-for material would include losses in cylinder heels. Washing of the cylinder heels would have resulted in release of this material in sludge.

From the feed points, ⁹⁹Tc migrated primarily toward the top of the cascade. Overall, approximately 50% of the ⁹⁹Tc fed to the ORGDP cascade is expected to have been plated out throughout the upper cascade as shown in Fig. 5.3-2.

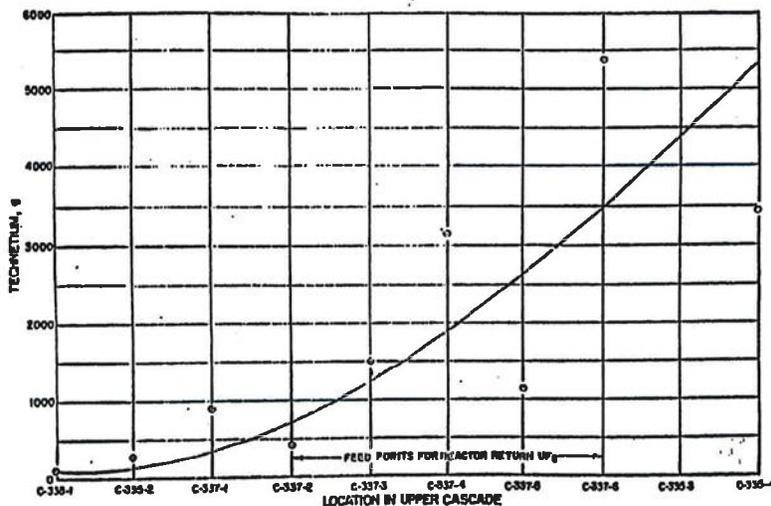


Fig. 5.3-2. Deposition of Tc in the Upper Cascade of PGDP.

Because of the unique configuration of the ORGDP cascade, the primary concentration of ^{99}Tc is expected to have occurred in the purge cascade equipment at the top of the enrichment plant. Specifically, the K-311-1 and K-310-3 systems and the K-402-8 and K-402-9 systems are likely concentration points. Portions of the ^{99}Tc were trapped at the purge cascade (approximately 100 pounds of ^{99}Tc and uranium

compounds were trapped, but the fraction of this material which is ^{99}Tc is not known).

No detectable levels of ^{99}Tc are expected to have been contained in the tails. It is reasonable to assume that some ^{99}Tc was present in the product because of evidence of ^{99}Tc deposited throughout the upper cascade. However, unlike PGDP, which produced product containing an average of 1.9 ppm ^{99}Tc , at ORGDP the purge system, rather than the product withdrawal point, was the primary ^{99}Tc concentration point. As a result, very little ^{99}Tc is expected to have been in the product stream at ORGDP—certainly <1 ppm.

5.4 POTENTIAL FOR WORKER EXPOSURE

5.4.1 Film Badge Exposure

To gain insight into the numbers of workers who could potentially have been exposed to RU constituents at ORGDP, the project team reviewed *ORGDP Quarterly Reports* from FY 1952 to FY 1963.¹³ The reports provided quarter-ending total ORGDP employment numbers, which are shown in Figure 5.4-1.

The *Quarterly Reports* also provided information generally documenting the number of personnel exposures above the Plant Allowable Limit (PAL) and/or providing exposure summaries relative to other points in time (i.e., an increase or decrease from a previous reporting period). Table 5.4-1 summarizes discussions on personnel exposures in the *Quarterly Reports*.

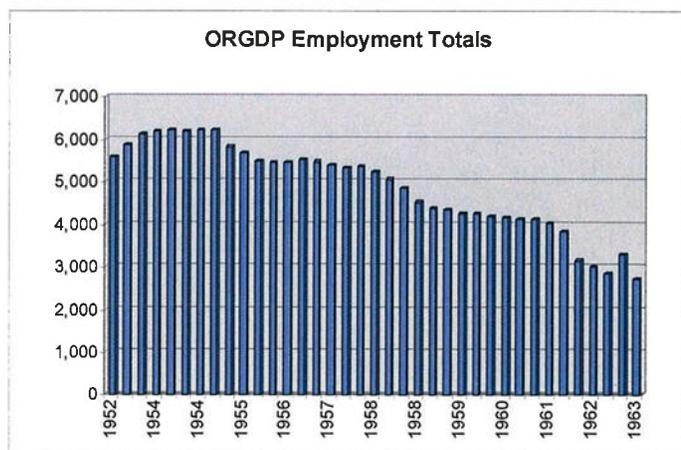


Fig. 5.4-1. ORGDP Employment Totals.

¹³ *ORGDP Quarterly Reports*, 1952 to 1963

Table 5.4-1. Personnel Exposures and Explanations Extracted from ORGDP Quarterly Reports

Fiscal Year	Quarter	Exposures	Exposure Explanation
1954	Q1		There continues to be no clinical evidence of permanent damage to personnel from exposure to atmospheric contaminants.
	Q2	15	15 film badge exposures above PAL occurred.
	Q3		Decreases in personnel exposure to penetrating radiation were noted as were reductions in the levels of both penetrating radiation and alpha contamination.
	Q4		Increase in plant penetrating rad levels and the number of over-PAL rad exposures, but average exposure for plant personnel decreased for second consecutive quarter. Alpha contamination also showed slight decrease.
1955	Q1		Penetrating rad levels showed a considerable decrease; Reductions were noted in the number of spot air samples which indicated air-borne uranium activity in excess of the PAL.
	Q2		Increase in the number of personnel exposures to penetrating radiation levels slightly in excess of the PAL; the average exposure of plant personnel of 8 mrep per week was ~ 1/2 the corresponding figure for 1953.
	Q3		plant rad and contamination indices and personnel exposures to penetrating rad decreased to the lowest values since 1952.
	Q4	1	1 exposure in excess of PAL; decon operations resulted in continued decreases in rad surface contamination, penetrating rad levels, and airborne radioactivity; average film badge exposure decreased to only 2 mrep as compared to an average of 7.8 mrep for 1954.
1956	Q1		Average film badge exposure decreased to 0.4 mrep/week.
	Q2	7	7 personnel exposures to penetrating radiation in excess of PAL brought the year's total to 9. The max individual indicated exposure of 7.8 rep, although the highest in several years, is not considered indicative of injury to the employee involved.
	Q3	10	10 personnel exposures to penetrating rad in excess of the PAL.
	Q4	6	Average personnel exposure to penetrating radiation remained unchanged; 6 exposures in excess of PAL.
1957	Q1	12	None
	Q2	0	Although penetrating rad levels have exhibited a general upward trend since 6/55 (as a result of normal accumulation of U daughter products in K-1131 feed plant), the average film badge exposure for the year was only slightly above that for 1955.
	Q3		The utilization in the K-1131 feed plant of reprocessed fuel materials having both unfavorable chemical properties and an unusually high content of U-238 daughter products, resulted in increased maintenance activities and in somewhat higher rad fields than normal. This is reflected by increases in the penetrating rad index, the average film badge exposure to penetrating rad, and the number of exposures in excess of the PAL, and in the number of positive urinary analyses for U and fluorides. However, none of the exposures noted were indicative of injury to employees.
1958	Q2	11	Radiation levels associated with normal accumulation of uranium daughter products in the K-1131 Plant increased during 1957. Personnel exposures to penetrating radiation in excess of plant acceptable limit. This was a decrease from 17 similar incidents in 1956.

Of particular interest is an entry for the second quarter of 1956 that documents an exposure of 7.8 rad equivalent person (rep) as the highest such exposure in “several years.” Three other discussions of interest are noted in the second and third quarters of 1957 and in the second quarter of 1958. All three of these entries mention exposures relative to ²³⁸U daughter-product accumulations from the use of reprocessed fuel materials at the K-1131 Feed Plant.

5.4.2 Urinalysis Data

Results of urinalyses for uranium, alpha activity, neptunium, plutonium and technetium are listed in an ORGDP historical database for the period of 1948 to 1992 providing evidence of a significant, established personnel monitoring program in the years that RU was processed. Throughout the plant history the primary tools (Table 5.4-2) for monitoring employee exposures appear to have been analysis for total alpha and analysis for uranium. Limited data is available

from plutonium and neptunium analyses, which may have been performed only in cases in which specific exposure was suspected. Results for technetium represent a large population, however available data was limited to years FY 1978 to FY 1993.

Table 5.4-2. ORGDP Urinalysis Testing – 53 Departments.

Analysis	Period for Which Data Exists	Average Number of Employees Tested Per Year	Average Number of Tests Per Year
alpha activity	1948 - 1993	965	3,548
uranium	1948 – 1991	995	3,618
plutonium	1954 - 1963	5	14
neptunium	1963	32	39
technetium	1978 - 1993	756	4369

Of the persons tested for alpha activity over 90% were also tested for uranium. The number of tests performed annually and also the number of persons tested at ORGDP varied over the time period from CY 1948 to FY 1992. Figure 5.4-2 depicts the number of tests performed for alpha activity and the number of personnel tested. Figure 5.4-3 shows the number of tests performed for uranium during the same time period.

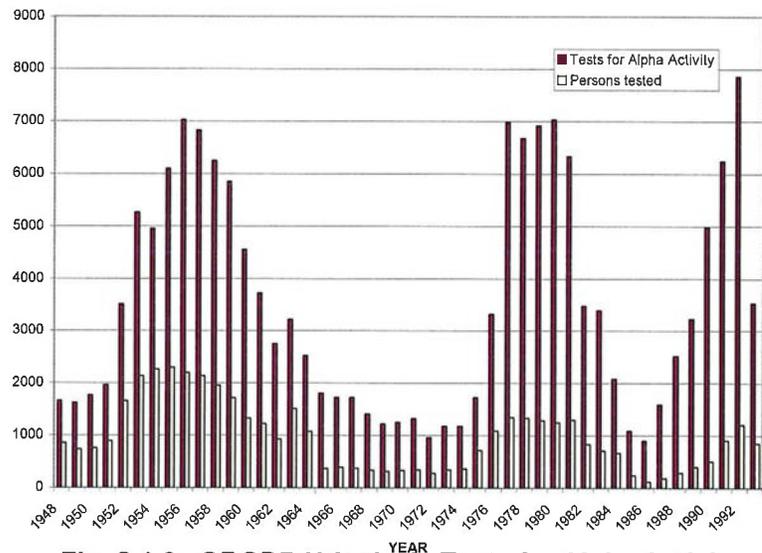


Fig. 5.4-2. ORGDP Urinalysis Tests for Alpha Activity (CY 1948 to FY 1992).

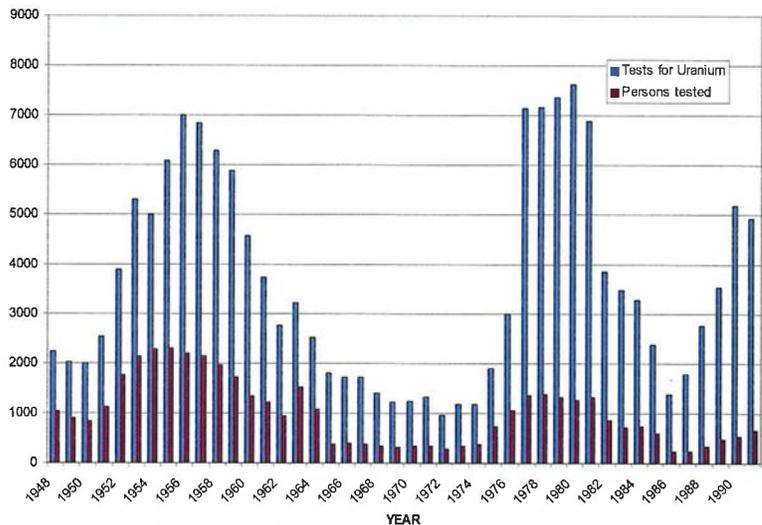


Fig. 5.4-3. ORGDP Urinalysis Tests for Uranium (CY 1948 to FY 1992).

Uranium Analysis

The analytical method for uranium analysis was fluorimetric. Urine samples were prepared and the fluorescence of the sample compared to that of known standards. This analysis was sensitive to the amount of elemental uranium in the sample and did not discriminate between uranium isotopes nor did it detect the presence of transuranics or technetium. Results by department reported in milligrams per liter are shown for CY 1948 through FY 1962 in Figure 5.4-4 and for FY 1963 through FY 1992 in Figure 5.4-5.

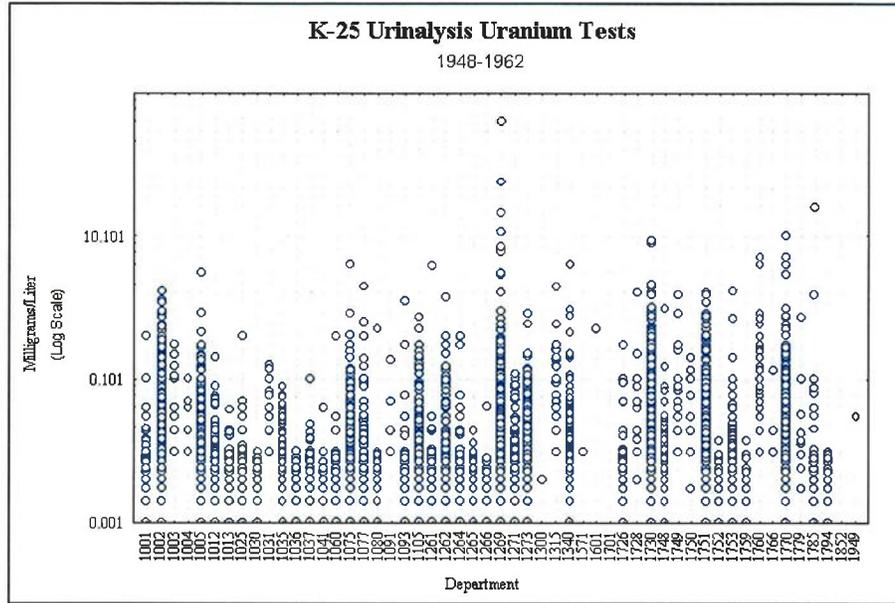


Fig. 5.4-4. Results of Uranium Analyses by ORGDP Department (CY 1948 – FY 1962).

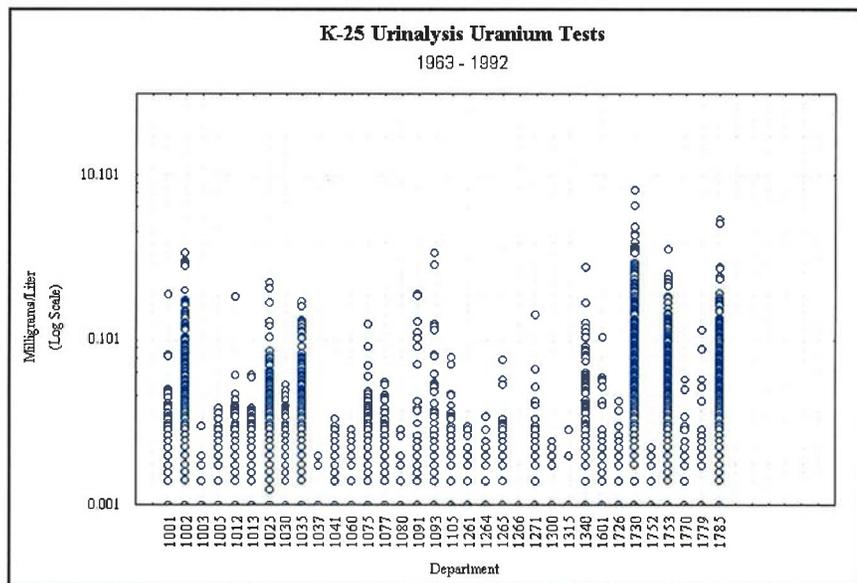


Fig. 5.4-5. Results of Uranium Analyses by ORGDP Department (CY 1963 – FY 1992).

Alpha Activity Analysis

Samples were prepared for alpha counting by evaporating 100 milliliters of urine to dryness with an excess of concentrated nitric acid and igniting the residue over a blast burner. The white salt residue was then dissolved a second time and the uranium present electroplated onto nickel discs. Counting instruments were checked and calibrated against known standards. Background radiation was determined by counting overnight for 480 minutes. Each sample was then counted on two different instruments to assure accuracy. The limit of uncertainty was +/- 1 count per minute. Control samples were counted three times per week. All alpha particles present on the disc were counted including any alpha from the transuranics. Both plutonium and neptunium are alpha emitters with a much greater specific activity (Table 5.4-3) than normal or enriched uranium.

Table 5.4-3. Specific Activity by Material Type.

Material	Specific Activity
Normal Uranium	1.5 dpm per microgram
²³⁵ U	5 dpm per microgram
Neptunium	1,550 dpm per microgram
Plutonium	138,000 dpm per microgram

Results by department reported in dpm/100 milliliters are shown for the years CY 1948 through FY 1962 in Fig. 5.4-6 and for years FY 1963 through FY 1992 in Fig. 5.4-7.

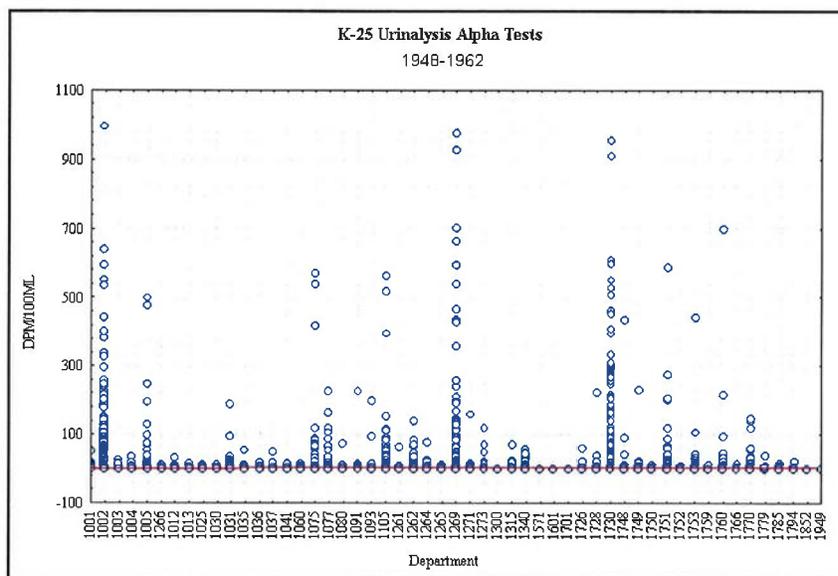


Fig. 5.4-6. Results of Alpha Activity Analyses by Department for CY 1948 to FY 1962.

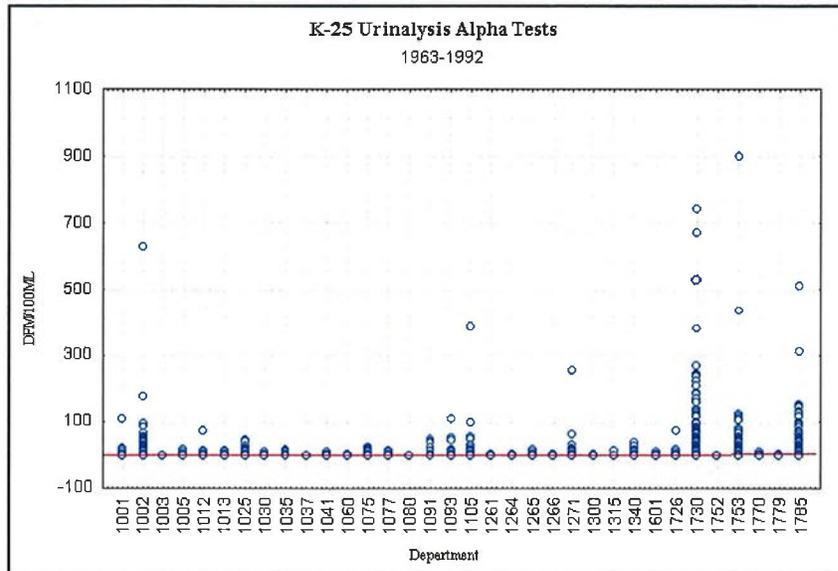


Fig. 5.4-7. Results of Alpha Activity Analyses by Department for FY 1963 to FY 1992.

Comparison of Data

Results from uranium analysis reported in milligrams uranium per liter can be converted to the same units as those reported for alpha activity, dpm per 100 milliliters, if a specific activity for the uranium is estimated. As noted in the table above, the specific activity of natural uranium is 1.5 dpm per microgram. Operations occurring early in the enrichment process such as feed plant activities would most likely be involved with uranium near this natural level of enrichment. Near the product withdrawal points at the top of the cascade the uranium would be enriched to nearly the level of the ^{235}U activity, 5 dpm per microgram. By converting the results of the uranium analysis to dpm per 100 milliliters and comparing to the analysis by alpha activity it can be determined if all the alpha activity present can be attributed to the uranium content of the sample. Alpha activity detected in addition to that of the uranium is contributed by any transuranics present emitting alpha particles, i.e. neptunium or plutonium. The results for the period 1948 to 1962 for two different departments have been sorted in ascending order of activity (dpm/100ml) and compared on Figure 5.4-8 and Figure 5.4-9. Department 1002 (630 employees) was the cascade maintenance department and Department 1035 (104 employees) the respirator service department. In the case of Department 1002 those tests reporting low exposure (about 2,000 analyses) show nominal correlation, that is the level of uranium reported accounts for the alpha activity reported. As the exposure level increases, however the level of alpha activity present is greater than that which could be attributed to uranium, thus implying the presence of transuranics.

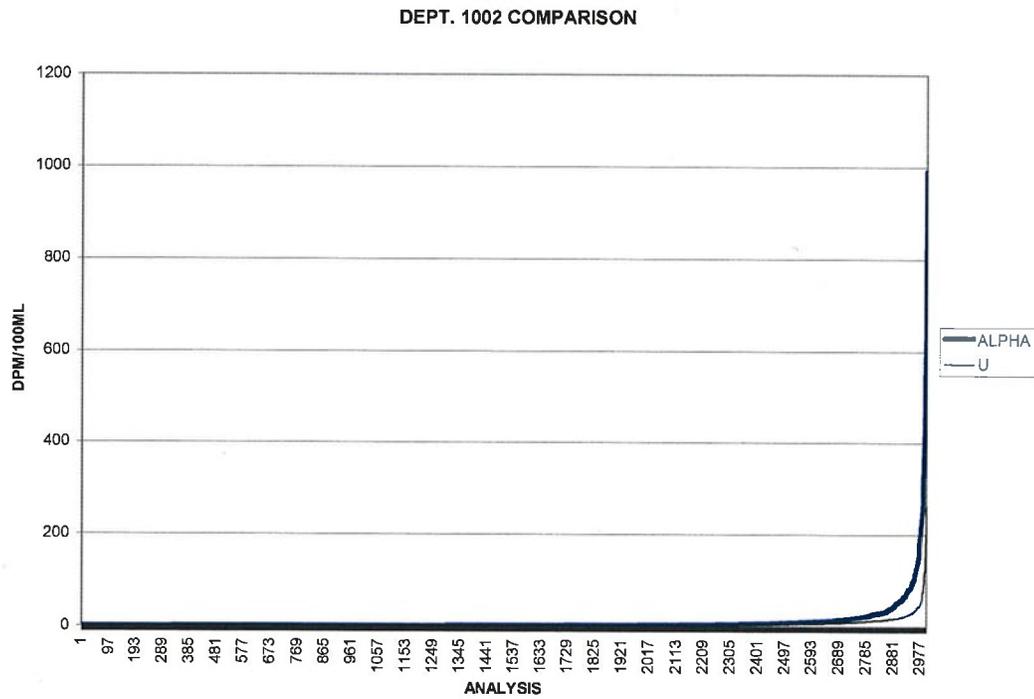


Fig. 5.4-8. Comparison of Uranium and Alpha Activity Results for Department 1002 – Cascade Maintenance.

For Department 1035 this difference is not present. Even as exposure increases the uranium present approximately accounts for the alpha activity reported.

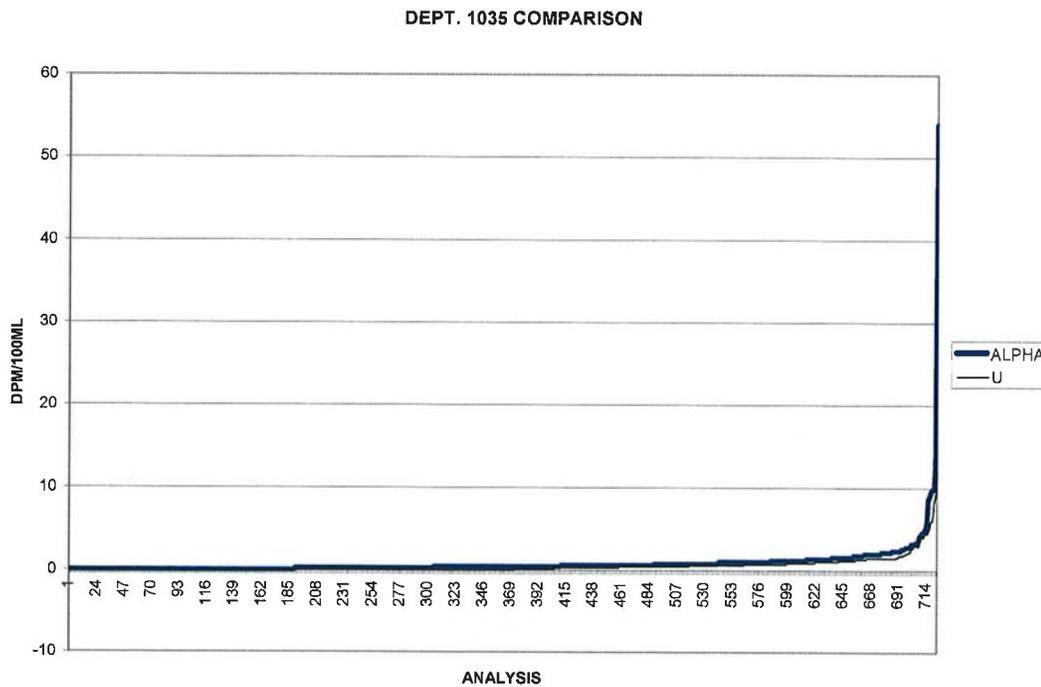


Fig. 5.4-9 Comparison of Uranium and Alpha Activity Results for Department 1035 – Respirator Service.

It should be understood that this comparison of data is of a preliminary nature. A more in-depth assessment will be required to support any conclusions. However, based upon this limited review, it appears that increased levels of alpha activity, due to any significant level of transuranic content in urine, could potentially be determined from the data.

5.4.3 Summary

The potential for worker exposure has been addressed in Table 2.4-1, *Activities Involving Potential Worker Exposure*. This potential was understood, monitored and controlled as evidenced by the use of film badges and the presence of an active urinalysis program for those workers potentially exposed. Further analysis may be warranted to evaluate worker exposure, including detailed dose assessments, as a follow-on to this RU Mass Balance Report.

5.5 POTENTIAL FOR ENVIRONMENTAL CONTAMINATION

5.5.1 Alpha, Beta, and Gamma Activity

General discussions of relative alpha, beta, and gamma activity extracted from the *Quarterly Reports* are shown in Table 5.5-1.

These discussions represent general statements relative to a previous point in time, but they do indicate that a program was in place to monitor activity levels in the plant. Two entries of note in the second and third quarters of 1959 refer to increased air borne contamination resulting from equipment repair and revision operations in K-1131 and K-1231 and to major equipment cleaning in K-1420.

5.5.2 Material Releases

A review of *ORGDP Quarterly Reports*, *Process Engineering Monthly Progress Reports*¹⁴, *Process Engineering Quarterly Progress Reports*¹⁵, and *Production Division Progress Reports*¹⁶ from 1953 through 1966 identified information on material releases. Excerpts from the reports on the material release descriptions, locations, and amounts (where documented) are listed in chronological order in Table 5.5-2.

A brief analysis of the data from June 1958 through December 1965 shows that the kgU and kg²³⁵U released per quarter averaged approximately 276 and 1.15, respectively. Several releases were reported in the K-1131 Feed Plant, K-1420, and in various portions of the cascade facilities.

¹⁴ *Process Engineering Progress Report*, Month of May 1958

¹⁵ *Process Engineering Quarterly Progress Reports*, 1959 through 1961

¹⁶ *Production Division Progress Report*, March through May, 1961

Table 5.5-1. Reported Activity Levels Extracted from *ORGDP Quarterly Reports*.

Year	Quarter	Alpha	Beta	Gamma
1954	Q1	The alpha contamination level in the plant rose primarily as a result of increased equipment changes, while the penetrating rad levels remained essentially unchanged. One film badge reading of 6 rep represented the highest level ever reported at K-25. A job survey indicated no significant hazard changes had occurred.	A significant decrease occurred in the average beta activity of treated sanitary water while a slight increase in airborne alpha contamination was noted.	
	Q2	Slight increase in alpha contamination attributed to increased maintenance, special tests in certain plant areas and the release of material following a cylinder rupture.	Increase in average beta activity in sanitary water as a result of releases of excessive quantities of fissionable material to the Clinch River.	
	Q3	Reductions in the levels of both penetrating radiation and alpha contamination.		
1955	Q1	Recent increase in alpha surface contamination was noted.		
	Q2		Beta activity in sanitary water increased	
1956	Q1		Beta-Gamma emitting U-daughter products resulted in increase in both rad fields	Beta-Gamma emitting U-daughter products resulted in increase in both rad fields
	Q2		Beta activity in sanitary water supply remained low.	
	Q3		The beta-gamma radiation index increased ~50% as a result of the continued normal accumulation of beta-gamma emitters in the feed production equipment.	A slight increase was noted in the gamma contamination index.
	Q4	Alpha surface contamination throughout the plant remained unchanged.		
1957	Q1	Decreases in airborne alpha activity, penetrating rad index, and the alpha contamination index were noted; A conference on alpha contamination was held for exempt personnel.	Beta activity in sanitary water remained low.	
1958	Q3	Reports occasional high air counts in K-601.		
1959	Q2	Continued increase in plant contamination index, largely associated with remodeling and repair activities in the feed plant and major equipment cleaning in K-1420. Associated increases in airborne alpha emitting materials were noted.		Reference test for correlating gamma survey data with cascade dynamic U-235 inventory.
	Q3	Although alpha contamination decreased ~20%, a marked increase in airborne U concentrations was associated with equipment - revision operations in K-1131 and K-1231 pulverizing building.		

Table 5.5-2. Material Release Information Extracted from ORGDP Reports

Fiscal Year	Quarter	Type Report	Material Release Description	Material Release - Building	Material Release (lbs/UF ₆)	Material Release (kg/U)	Material Release (kg/ ²³⁵ U)
1953	Q2	Plant Quarterly	2506 pounds of UF ₆ was released accidentally in K-402-1	K-402-1	2,506		
	Q4	Plant Quarterly	Page C-11: Cylinder explosion - 123 pounds of UF ₆ released to atmosphere - entire building contaminated - K-413, May 25, 1953	K-413	123		
	Q4	Plant Quarterly	June 1, 1953 - Building K-1131 - gland nut valve broke and 952 lbs were released	K-1131	952		
1954	Q1	Plant Quarterly	Five material releases were reported, but were of a minor nature in regard to their effect on working conditions				
1955	Q2	Plant Quarterly	Air activity increases during the calendar year were associate with a number of material releases involving a new product withdrawal area and the feed prep and production facilities				
1956	Q1	Plant Quarterly	Of 8 material releases, 3 involved small amounts of radioactive materials				
1957	Q1	Plant Quarterly	None of the 9 releases of corrosive materials or the 3 releases of U-bearing materials indicated significant problems				
1958	Q4	Engineering Monthly	K-1131 feed plant vent stack losses measured 12 days with normal material and 19 days with 6-range reactor tails material. Vented (kg): Normal 13 kgs U, 0.1 kgs U-235; Reactor Tails 11 kgs U, 0.1 kgs U-235				
1959	Q1	Engineering Quarterly				44.64	0.330
	Q2	Engineering Quarterly				193.00	1.400
	Q3	Engineering Quarterly	5 releases totaling 149,573 grams U and 1,032 grams U-235 (two releases in K-1420 and K-312-1; 2,800 and 20 grams, respectively)			150.00	
	Q4	Engineering Quarterly	6 releases of 73,310 grams U, 558 grams U-235			73.00	0.558
1960	Q2	Plant Quarterly				118.00	0.800
	Q3	Plant Quarterly	360,189 gram U and 2,917 grams U-235 released during quarter			360.00	3.000
	Q4	Plant Quarterly	340,908 grams U and 2287 grams U-235 released			341.00	2.000
	Q1	Engineering Quarterly	4 releases of 180,054 grams U, 1,288 grams U-235			180.00	1.300
	Q2	Engineering Quarterly	105,315 grams U, 748 grams U-235			105.00	0.748
	Q3	Engineering Quarterly				132.00	0.900
	Q1	Plant Quarterly	185,202 grams U and 1,270 grams U-235			185.00	1.000
1961	Q2	Plant Quarterly	70,242 grams U as UF ₆ , 651 grams U-235 as UF ₆			70.00	1.000
	Q3	Plant Quarterly	124,501 grams U, 996 grams U-235			125.00	1.000
	Q1	Engineering Quarterly	Table showing where releases were shows most came from K-1131 vent stacks	K-1131		148.00	1.000
	Q2	Engineering Quarterly	134,774 grams U, 957 grams U-235			135.00	0.957
	Q3	Engineering Quarterly	9 releases totaling 128,693 grams U, 1,028 grams U-235			128.69	1.028
	Q4	Production Div Quarterly				288.00	2.000
	Q1	Plant Quarterly	184,196 grams U, 1,475 grams U-235			185.00	1.000
1962	Q2	Plant Quarterly	212,769 grams U, 622 grams U-235			213.00	1.000
	Q3	Plant Quarterly	6,774 grams U, 2,609 grams U-235			7.00	3.000
	Q4	Plant Quarterly	348,085 grams U, 2,526 grams U-235 as UF ₆			348.00	3.000
	Q4	Plant Quarterly	3,955 grams U, 395 grams U-235			4.00	0.400
	Q1	Plant Quarterly	6,689 grams U, 91 grams U-235			7.00	
1963	Q3	Plant Quarterly	67 grams U, 14 grams U-235	K-1420			
	Q4	Plant Quarterly	Table G-1 shows 496 grams of uranium released				
	Q3	Plant Quarterly	4 material releases (see Table G-1) accounted for the release of 3,862 grams U and 95 grams U-235 to the atmosphere as UF ₆			3,862.00	
1964	Q4	Plant Quarterly	2 uranium releases - 22.6 kgsU and 0.068 kgs U-235 were vented to the atmosphere from K-902-1, cell 8	K-902-1		22.60	0.068
1965	Q2	Plant Quarterly				0.61	0.001
1966	Q2	Plant Quarterly	5,213 grams U, 194 grams U-235			5.21	0.194

ORGDP Material Release Reports from 1957 through 1961¹⁷ document the grams of uranium released during this time period. These data are presented graphically in Fig.5.5-1.

¹⁷ ORGDP Material Release Reports, 1957 through 1961

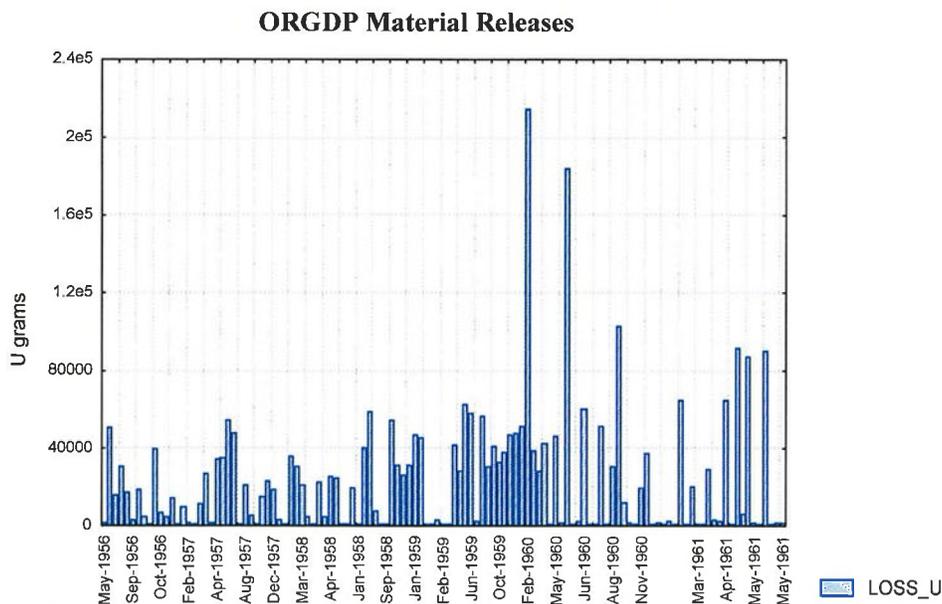


Fig. 5.5-1. ORGDP Material Releases.

5.5.3 Environmental Monitoring

As presented in Section 2.5, environmental monitoring of the air and water adjacent to the Oak Ridge Reservation has been an on-going program since the 1950s. The most exhaustive compilation of environmental data resulted from the Oak Ridge Dose Reconstruction Project, documented in a series of task reports in July 1999. The Task 6 report¹⁸ entitled *Uranium Releases from the Oak Ridge Reservation – a Review of the Quality of Historical Effluent Monitoring Data and a Screening Evaluation of Potential Off-Site Exposures* draws the following conclusion:

“...the K-25/S-50 uranium releases are candidates for further study, but (they) are not high priority candidates for further study.”

The Task 7 report¹⁹ entitled *Screening-Level Evaluation of Additional Potential Materials of Concern* performed qualitative and quantitative screening of various materials of concern at ORGDP (and the other ORR sites), including ²³⁷Np and ⁹⁹Tc. Based on the analysis of data, it was determined that Np did not warrant further study. Technetium was identified as one of the potential candidates for further study, but was not determined to be a high priority.

¹⁸ *Uranium Releases from the Oak Ridge Reservation – a Review of the Quality of Historical Effluent Monitoring Data and a Screening Evaluation of Potential Off-Site Exposures*, PD-02314; Reports of the Oak Ridge Dose Reconstruction, Vol. 5, The Report of Project Task 6, July 1999.

¹⁹ *Screening – Level Evaluation of Additional Potential Materials of Concern*, PD-02315; Reports of the Oak Ridge Dose Reconstruction, Vol. 6, The Report of Project Task 7, July 1999.

6.0 RESULTS AND CONCLUSIONS

6.1 EXPLANATION OF RECYCLED URANIUM FLOW PATHS

6.1.1 Flow of RU into ORGDP

RU entered ORGDP through three primary pathways. ORGDP received RU via:

- **Receipts of 16,268 MT** of RU oxide provided as feed to ORGDP by Hanford, Savannah River, and Harshaw Chemical Company. This oxide was processed in the ORGDP feed production facility.
- **Receipts of 1,294 MT** of RU as UF₆ feed from commercial enrichment customers (primarily nuclear utilities in France, the United Kingdom, and Germany). From 1969 to 1988, 807 MTU was fed to the ORGDP cascade; 486 MTU was shipped to PGDP in 1986; and 1 MTU was returned to France in 1988.
- **Receipts of 1,092 MT** of RU as UF₆ feed from PGDP, ORNL, and PORTS (99.2% from PGDP) during 1953 to 1970. This material was fed into the ORGDP cascade.

RU receipts totaled 18,654 MTU. In addition, ORGDP received:

- Partially enriched product from PGDP that contained ⁹⁹Tc and trace quantities of Np (although this PGDP enriched product was not technically RU). ORGDP received a total of 86,385 MTU as enriched UF₆ from PGDP during 1953 to 1985 that was fed into the ORGDP cascade.

The 18,654 MTU of RU received by ORGDP is estimated to have contained the following quantities of the RU constituents of concern:

- Pu: 71.5 g (based on data from RU receipts obtained from correspondence of the ORGDP Laboratory Superintendent). Of this 71.5 g, only 0.01 to 0.04 g is projected to have entered the ORGDP cascade. The overwhelming majority of Pu was concentrated in the ash from the feed plant, and a small fraction was retained as cylinder heels. This estimate is modestly higher than the Parks estimate of 60 g.
- Np: 9 kg (based on ORNL composite sample analysis prior to 1957 and PGDP sample analysis from 1957 to 1967). Of this 9 kg, 0.8 kg is estimated to have entered the ORGDP cascade, along with up to 0.17 kg of Np that was fed to the ORGDP cascade in PGDP enriched product. Approximately 75% of the Np received by ORGDP in RU UO₃ is estimated to have remained in feed plant ash and cylinder heels. Almost 1.5 kg of Np was shipped to PGDP in UF₆ from the ORGDP feed plant. Analysis for Np performed by ORNL in 1955 and early 1957 on composite samples of Hanford and Savannah River RU show much higher concentrations of Np (0.78 ppm Np average) than subsequent analysis reported by Smith (0.24 ppm Np average) for the period from mid-1957 through 1967. This estimate is based on using the ORNL analysis for estimated Np concentration during 1952 through

mid-1957 and the Smith analysis for the period from mid-1957 through 1963, when shipments from Hanford and Savannah River to ORGDP ceased.

- ⁹⁹Tc: 135 kg (based on measurements performed from 1959 to 1973 on Tc content in RU from Hanford and Savannah River). Of this 135 kg, 45 kg is estimated to have entered the ORGDP cascade in the RU feed stream—along with up to 165 kg of ⁹⁹Tc contained in PGDP enriched product (based on PGDP data for 1972–1982 and ORGDP measurements of ⁹⁹Tc in PGDP product during 1962–1963). Approximately 70 kg of ⁹⁹Tc was shipped to PGDP in UF₆ from the ORGDP feed plant. In the ORGDP cascade, ⁹⁹Tc tended to accumulate at the top of the cascade or to migrate to the purge cascade points at the high end of the plant configuration, where it was trapped and/or vented.

6.1.2 Flow of RU Out of ORGDP

RU streams exited ORGDP via:

- Shipment to PGDP and PORTS of RU converted to UF₆ or UF₄.
- Shipment of RU fluorination tower waste ashes to PGDP (which subsequently shipped them to Fernald)
- Shipment of product enriched in the ORGDP cascade to the Y-12 Plant, PORTS, and to private-sector companies fabricating fuel for commercial enrichment customers.
- Shipment of tails from the ORGDP enrichment cascade to PGDP for additional “stripping” in the PDGP cascade.
- Shipment of RU from commercial enrichment customers to PGDP after ORGDP was placed on standby (without re-enriching the RU in the ORGDP enrichment cascade).
- Shipment of cylinder heels at ORGDP to PGDP after ORGDP was placed on standby.

ORGDP shipped a total of 12,141 MT of RU to the following sites:

- | | |
|------------------|------------|
| • PGDP | 11,629 MTU |
| • PORTS | 301 MTU |
| • Y-12 Plant | 189 MTU |
| • ORNL | 8 MTU |
| • Savannah River | 11 MTU |
| • Fernald | 2 MTU |
| • Foreign | 1 MTU |

ORGDP fed 5,915 MT of RU into the ORGDP cascade. Cumulative losses and material unaccounted for (MUF) for RU material at ORGDP totaled 598 MTU. The RU mass balance for ORGDP is summarized in Table 6.1-1.

Table 6.1-1. ORGDP RU Mass Balance

Category	MT of RU
ORGDP shipments	12,141
Feed to ORGDP cascade	5,915
Cumulative losses and RU material unaccounted for (MUF)	598
Subtotal	18,654
ORGDP receipts	18,654

6.1.3 Potential Flow Pathways of RU within ORGDP

Once an RU stream entered ORGDP, RU constituents of concern had the potential to reach various facilities and equipment via pathways associated with:

- Oxide conversion to UF₆ for feed
- Cascade buildings and operations
- Uranium recovery operations
- Analytical laboratories

The potential pathways associated with each of these groups of operations are described in the following sections.

6.1.3.1 Oxide Conversion to UF₆ for Feed Pathways

The process of converting RU oxide to UF₆ for feed for the ORGDP enrichment cascade involved the following potential pathways:

- Unpacking, feeding, and sampling of UO₃
- Collecting ash for uranium recovery and cleaning fluorination tower filters
- Uranium recovery from ash
- Maintenance and repair of fluorination tower and associated equipment

6.1.3.2 Cascade Buildings and Operations Pathways

ORGDP enrichment cascade operations involved the following potential pathways:

- Feeding UF₆ from cylinders to cascade
- Inadvertent releases of UF₆ within cascade buildings or from piping
- Withdrawal of product
- Withdrawal of tails
- Venting process gas to atmosphere
- CIP/CUP and other equipment removal

6.1.3.3 Uranium Recovery Operations Pathways

Uranium recovery operations involved the following potential pathways:

- Cleaning heels from UF₆ feed cylinders
- Decontamination of equipment
- Processing of wastes for uranium recovery
- Handling of scrap metal from equipment
- Removal and storage of pond sludge
- Thermal drying and repackaging of pond sludge
- Recovery of uranium deposits from process equipment
- Servicing cascade chemical traps
- Discharge of wastes associated with recovery processes to holding ponds

6.1.3.4 Analytical Laboratories

Because of the protocols and processes involved in analytical laboratory analysis at ORGDP, these operations created no significant pathways for RU.

6.2 IDENTIFICATION OF PROCESSES OR FACILITIES THAT INVOLVED POTENTIAL WORKER EXPOSURE TO RU CONSTITUENTS

Processes and facilities that involved potential worker exposure to RU constituents coordinate closely with the pathways for the flow of RU within ORGDP described in Section 6.1.3. Table 6.2-1 summarizes the activities that were rated by the ORGDP Site Team as “High” in occupational exposure potential—and that consequently have significant implications for potential personnel exposure. For each activity, the table includes information on location, time frame, and RU constituents of concern. (A complete summary of activities at ORGDP with potential for worker exposure to RU is provided in Table 2.4-1.)

Table 6.2-1. Activities Rated High in Exposure Potential

Location	Activity	Time Frame	Constituents	Occupational Exposure Potential
1. Oxide Conversion				
K-1131 K-1420	1A. Unpacking, feeding of UO ₃ to process, operation and pulling samples * Exposure potential would have been high for brief periods in Jan-Apr 1953 when Pu ranged as high as 40 ppb in material from Hanford	1952-1961 1960-1963	Estimated levels in UO ₃ 520 ppb Np 4.4 ppb Pu 7,800 ppb Tc 170 ppm ²³⁸ U	Moderate*
K-1131 K-1420	1B. Collecting ash for uranium recovery and cleaning of tower filters	1952-1961 1960-1963	Estimated levels in ash 13,000 ppb Np 440 ppb Pu 40,000 ppb Tc 170 ppm ²³⁸ U	High
K-1231 K-1410	1C. U recovery from ash, processes included ash pulverizer	1952-1963 1952-1962	Estimated levels in ash 13,000 ppb Np 440 ppb Pu 40,000 ppb Tc 170 ppm ²³⁸ U	High
K-1131 K-1410	1D. Maintenance and repair of fluorination tower and associated equipment	1952-1961 1952-1962	Estimated levels 13,000 ppb Np 440 ppb Pu 40,000 ppb Tc 170 ppm ²³⁸ U	High

6.3 IDENTIFICATION AND EVALUATION OF PROCESSES OR FACILITIES THAT INVOLVED POTENTIAL ENVIRONMENTAL CONTAMINATION

Process knowledge and a review of documentation narrowed activities that involved potential environmental contamination by the RU constituents of concern to two activities:

- Venting of ^{99}Tc to the atmosphere from the ORGDP enrichment cascade
- Discharges of RU constituents in sludge primarily from the K-1420 decontamination facility to the K-1407-B and -C holding ponds

6.4 DISCUSSION OF DATA SOURCES

The project team searched a variety of data collections and libraries at ETTP and other Oak Ridge Complex locations to identify and retrieve data. Major data sources consulted and analyzed included:

- Nuclear Materials Control and Accountability (NMC&A) Material Balance Reports, including shipping, receiving, and inventory records.
- Nuclear Materials Management and Safeguards System (NMMSS) data.
- ORGDP historical site reports, including quarterly plant reports and engineering progress reports.
- ORGDP reports describing facilities and production processes.
- Plant records, including employment and health physics records.
- ORGDP production records.
- ORGDP analytical laboratory records.
- Correspondence between shippers and receivers.
- Historical DOE and contractor reports addressing RU
- More recent (i.e., post-1990) health physics reports on the site.
- More recent environmental survey reports on the site.
- Interviews with ORGDP personnel or with personnel with direct experience with enrichment operations.

Few gaps were identified in shipping and receiving data. Where NMC&A data was unavailable, NMMSS data was used. Team members worked with representatives of other DOE sites with which ORGDP interfaced via RU streams to verify shipping and receiving data and reconcile differences between sites. Any unresolved data discrepancies will be turned over to the DOE Working Group Team for assistance with resolution.

In addition to consulting the ORGDP analytical laboratory records, the team found it necessary to glean analytical data from a wide variety of sources, including the ORGDP

historical quarterly reports and health physics reports. Correspondence between shippers and receivers also provided a record of comparisons of sets of analytical data, the first set developed by the site shipping RU and the second by the site receiving the material. In addition, analytical data has been compared and shared with other appropriate DOE sites.

For some areas that presented gaps in data that could not at present be filled by research, the project team developed estimates for quantities of RU and/or constituents. These estimates are based on extrapolations from actual data and represent (1) application of known data from similar material and/or circumstances or (2) application of known data from a specific time period over a longer or a shorter period of time. All such estimates and their bases are specifically identified in this report.

The approach used in searching for and collecting data useful to the project team's purpose was suitably comprehensive in terms of targeting the broad range of likely sources and locations of data. However, because of limitations involving time and resources, the Site Team could not absolutely verify that all relevant and useable historical data and records were identified and reviewed.

As a result of the brief but intensive search, the project team determined that a significant amount of information exists to address the scope and objectives established for this phase of the RU project. Further, results of this current effort have extended previous evaluations and have, in some instances, served to confirm earlier work. With respect to constituent analysis, a significant quantity of data was found and evaluated.

6.5 CONCLUSIONS

6.5.1 Potential Personnel Exposure

The ORGDP Site Team's analysis of ORGDP activities that would have involved potential worker exposure to the RU constituents of concern identified three activities that the team rated "High" in occupational exposure potential and one other activity that was rated high for a brief period over four months in 1953 (Table 6.2-1). These activities represent the set of ORGDP processes that the Site Team believes involve significant implications for personnel exposure to RU constituents. All four activities were associated with oxide conversion to UF_6 for feed or with the maintenance of related feed plant equipment. The activities and the locations with which they were associated are:

- Unpacking, feeding, and sampling of UO_3 (K-1131)*
- Collecting ash for uranium recovery and cleaning tower filters (K-1131 and K-1420)
- Uranium recovery from ash (K-1231 and K-1410)
- Maintenance and repair of fluorination tower and associated equipment (K-1131 and K-1420)

* Only during January--April 1953 when K-1131 received UO_3 from Hanford that contained Pu up to 40 ppb.

With the exception of the unpacking, feeding, and sampling of UO_3 (which only presented "High" occupational exposure potential during a brief period), the occupational exposure potential resulted primarily from hazards posed by fluorination tower ash. An examination of

the activities with significant implications indicates that they occurred at the following four locations during the designated time frames:

- K-1131 feed facility (1952–1961)
- K-1231 ash pulverization and uranium recovery facility (1952–1963)
- K-1410 decontamination and uranium recovery facility (1952–1962)
- K-1420 feed facility (1960–1963)

Although both K-1131 and K-1420 performed feed facility functions, K-1131 processed much greater quantities of RU during 1952–1961 than the relatively small portion of K-1420 devoted to feed production did during 1960–1963.

Early in its existence, ORGDP implemented a worker protection program that included worker radiological protection (see Section 2.4.2). This program incorporated elements such as personnel protective equipment, personnel monitoring, environmental monitoring, work location surveys, work-time limits on jobs with penetrating radiation, excretion rate limits, periodic examinations of personnel, and Plant Action Level limits. The inhalation of radioactive materials was recognized as the most important source of possible exposure at ORGDP. Consequently, administrative controls were primarily designed to guard against associated hazards.

Worker protection measures in place at ORGDP likely provided substantial mitigation to the risks introduced by the activities rated as “High” in occupational exposure potential. However, dose assessment studies may be warranted as a follow-on activity to provide a more detailed assessment of worker exposure.

6.5.2 Potential Environmental Contamination

An Oak Ridge Dose Reconstruction Project was initiated in 1994 as follow-up to the Oak Ridge Dose Reconstruction Feasibility Study, which recommended a closer examination of past uranium emissions and potential resulting exposures (see Section 2.5). The Task 6 component of the project involved further evaluation of Oak Ridge uranium operations and effluent monitoring records to determine if uranium releases from the ORR likely resulted in off-site doses that warranted further study. The results were documented in the July 1999 Task 6 report entitled *Uranium Releases from the Oak Ridge Reservation—a Review of the Quality of Historical Effluent Monitoring Data and a Screening Evaluation of Potential Off-Site Exposures*. The Task 6 team concluded that earlier estimates of uranium releases had been underestimated. However, based on the decision guidelines from the Oak Ridge Health Agreement Steering Panel, the Task 6 team concluded that while ORGDP uranium releases are candidates for further study, they are not high-priority candidates.

The Task 7 component of the project involved performing qualitative and quantitative screening of various materials of concern at ORGDP and the other DOE Oak Ridge sites. Materials screened included Np and ⁹⁹Tc. Results were reported in the Task 7 report, *Screening Level Evaluation of Additional Potential Materials of Concern*. Based on the analysis of data, the Task 7 team determined that Np did not warrant further study. Although ⁹⁹Tc was identified as one of the potential candidates for further study, it was not determined to be a high-priority candidate.

These analyses, along with other information on environmental consequences from ORGDP operations, identify candidate environmental issues for additional study. However, candidate issues related to the processing of RU have not been determined to be high-priority candidates for further study.

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APPENDIX A

OCCUPATIONAL EXPOSURE POTENTIAL METHODOLOGY

The Occupational Exposure Potential (OEP), shown in Table 2.4-1, is a score derived from the product of three parameters qualitatively assigned by the Site Team. The parameters are: "Airborne Potential," "Constituent Level," and "Exposure Duration." Each parameter is assigned a numeric value according to prescribed criteria. The OEP score is then assigned according to the following scale:

Score	Likelihood
0	"No significant" occupational exposure potential
1	"Low" occupational exposure potential
2	"Moderate" occupational exposure potential
3	"High" occupational exposure potential

Airborne Potential is a subjective assignment of the likelihood of the contaminant to become airborne or concentrated in air. This judgement is largely based upon the form of the material and the nature of the particular operation. The associated numeric value is based on the following criteria:

Value	Likelihood
0	No likelihood of being airborne
1	Low airborne potential
2	Moderate airborne potential
3	High airborne potential

Constituent Level calculations for each of the various product streams were performed to estimate the additional dose presented by constituents present in irradiated uranium over that of the uranium alone. The DOE EH-3 team provided a standardized tool, in the form of an electronic spreadsheet, to perform the dose fraction calculations. The calculation and its technical basis are described in detail in the *Historical Generation and Flow of Recycled Uranium in the DOE Complex Project Plan*. An example of the output from the spreadsheet is shown in Figure A-1. To use the tool, the following information about the process stream being considered must be determined and input into the spreadsheet:

- chemical form
- level of enrichment in the ^{235}U isotope
- mass fraction of the constituents ^{238}Pu , ^{239}Pu , ^{240}Pu , ^{237}Np , ^{241}Am , ^{236}U and ^{99}Tc

The required inputs were determined by assumption of estimates based on available analytical data, process knowledge, and engineering judgement, and calculations were performed for the streams of interest. These streams are depicted in Figure A-2 (for the feed plant) and Figure A-3 (for the gaseous diffusion plant). Assumptions for the calculations and the results are summarized in Table A-1.

The calculated fraction dose was then compared against criteria for assignment of the respective numeric value. This criteria is:

Value	Likelihood
0	Sum of constituents clearly below de minimis levels (clearly less than 10% additional dose)
1	Sum of constituents likely to cause up to 20% total dose
2	Sum of constituents likely to cause more than 20% but less than 50% total dose
3	Sum of constituents likely to cause 50% or more of total dose

Exposure Duration pertains to the time of worker exposure on the job. As such, it considers whether or not a particular activity was conducted infrequently or was one that was carried out on a daily basis. This parameter also was based upon a set of criteria to arrive at a numeric value. The criteria is:

Value	Likelihood
1	50 hours per year or less
2	More than 50 hours per year but less than 500 hours per year
3	50 or more hours per year

The results of this rating system for ORGDP activities are summarized in Table A-2, which was used to provide the OEP ratings presented in Table 2.4-1.

Chemical Forms of Uranium					
Form	Code	Form	Code	Form	Code
U (metal)	1	UO3	0.83	UF6	0.68
UO2	0.88	UF4	0.76	UO2F2	0.77
U3O8	0.85	UCI4	0.63	UO2(NO3)2	0.6

U Enrichment (% U-235) =	<input type="text" value="0.64"/>	% U-235	U SpecAct uCi/g U	3.60E-01	Ratio
Chemical Form of U code =	<input type="text" value="0.83"/>	Code	DAC Value	3E-10	Act to DAC
SUM Constituent Act to DAC= 3.90E+08			Fraction Dose from Constituents =		0.3254

Constituent Data Units	uCi/g sample	uCi/g U	DAC Value	Act to DAC
Pu-238	<input type="text"/>	0.00E+00	3.00E-12	0.00E+00
Pu-239	<input type="text"/>	0.00E+00	2.00E-12	0.00E+00
Pu-240	<input type="text"/>	0.00E+00	2.00E-12	0.00E+00
Np-237	<input type="text"/>	0.00E+00	2.00E-12	0.00E+00
Am-241	<input type="text"/>	0.00E+00	2.00E-12	0.00E+00
U-236	<input type="text"/>	0.00E+00	3.00E-10	0.00E+00
Tc-99	<input type="text"/>	0.00E+00	3.00E-07	0.00E+00

	uCi/g U	DAC Value	Act to DAC
Pu-238	<input type="text" value="3.76E-05"/>	3.00E-12	1.25E+07
Pu-239	<input type="text" value="2.55E-04"/>	2.00E-12	1.28E+08
Pu-240	<input type="text" value="5.99E-05"/>	2.00E-12	3.00E+07
Np-237	<input type="text" value="3.67E-04"/>	2.00E-12	1.83E+08
Am-241	<input type="text" value="0.00E+00"/>	2.00E-12	0.00E+00
U-236	<input type="text" value="1.10E-02"/>	3.00E-10	3.67E+07
Tc-99	<input type="text" value="1.33E-01"/>	3.00E-07	4.42E+05

K-1131 Chemical Plant Stream 1 & 2

Assume

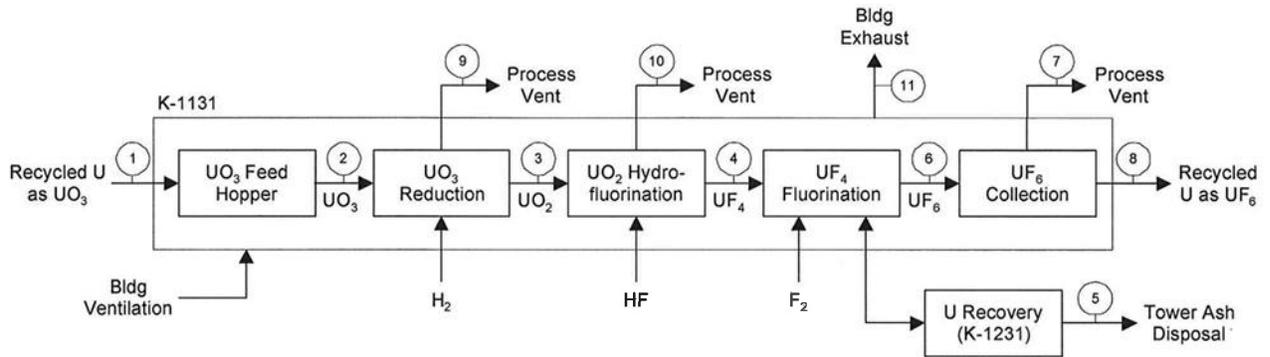
Pu ppb	4.4
Np ppb	520
Tc ppm	7.8
U-236 ppm	170

Assume UO3 @ .64 U-235

Assume Weapons Pu Dist

Pu-238	0.05
Pu-239	93.5
Pu-240	6
Pu-241	0.4
Pu-242	0.05

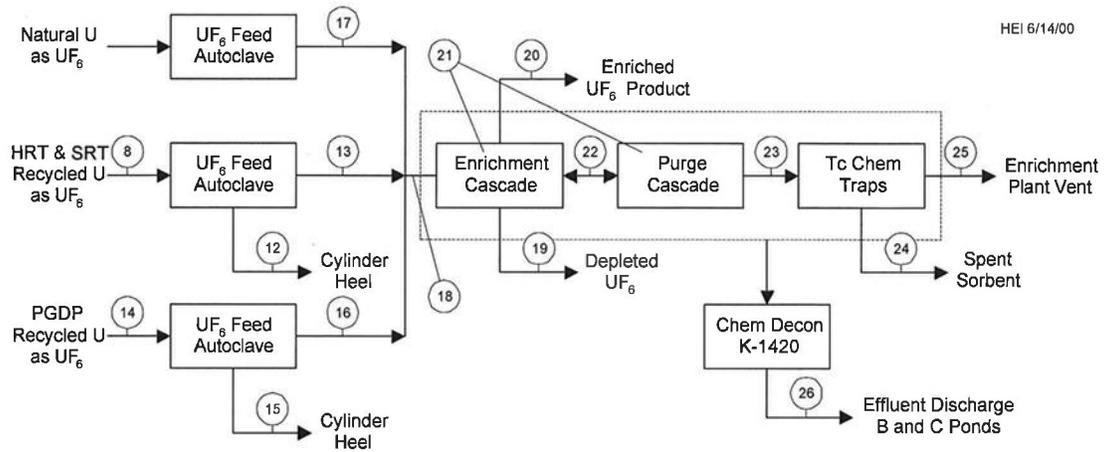
Figure A-1. Example Output of RU Dose Fraction Calculator.



Stream Component	Stream Composition										
	1	2	3	4	5	6	7	8	9	10	11
U, kg	1000	1000	1000	1000	10	990	1	989	0.1	0.1	0.01
Pu, mg	4.4	4.4	4.4	4.4	~4.4	0.04	0	0.04	~0	~0	~0
Np, mg	520	520	520	520	130	390	~0	390	~0	~0	~0
Tc, g	7.8	7.8	7.8	7.8	0.4	7.4	0.2	7.2	0.001	0.001	~0
²³⁸ U, g	170	170	170	170	1	169	0.2	169	~0	~0	~0

Basis: 1 MT U feed, 1,200 kgs UO₃, 1,130 kgs UO₂, 1,320 kgs UF₄, 1,480 kgs UF₆

Fig. A-2. Historical Generation and Flow of RU in the DOE Complex, Distribution of RU Components in the K-1131 Chemical Plant.



Stream Component	Stream Composition ^{1,2}															
	8	12	13	14	15	16	17	18	19	20	21 ³	22	23	24	25	26 ⁴
U, kg	989	10	979	1840	10	1830	1430	4240	3670	565	1	100	0.1	0.01	0.1	1
Pu, mg	0.04	0.04	0.004	0	0	0	0	0.004	0	0	0.004	~0	0	0	0	0.002
Np, mg	390	260	130	trace	trace	~0	0	130	0	trace	130	~0	~0	trace	~0	65
Tc, g	7.2	0.7	6.5	3.6	0.4	3.2	0	9.7	0	1.0	7.5	8.7	1.2	1.0	0.2	7.5
²³⁶ U, g	169	1	168	0	0	200	0	368	145	223	0.1	10	0.01	0.001	0.01	0.1

1. Basis: 1 MTU RU entering K-1131 feed plant of 200 kgs UO₂
 2. Trace = level of detection, 100 ppb U, 0.05 ppb Pu, 5 ppb Np, 10 ppb Tc
 3. Stream representing cascade accumulation of feed components with time
 4. Only during maintenance work involving converters and compressors taken from feed point (Pu, Np) and purge cascade (Tc)

Fig. A-3. Historical Generation and Flow of RU in the DOE Complex, Distribution of RU Components in the GDP.

Table A-1. Fraction Dose From Constituents For Process Streams

Process Stream Location (Refer To Flow Sheet)	Assumed Form	Assumed Assay (% U-235)	Assumed Constituent Level on U Basis	Fraction Dose From Constituents
1. K-1131 Chemical Plant Stream 1 & 2 (1) RU as UO3 to Feed Hopper (2) UO3 to UO3 Reduction	UO3	.64	520 ppb Np 4.4 ppb Pu 7.8 ppm Tc 170 ppm ²³⁶ U	0.3254
Same stream as above but Max Case Pu	UO3	.64	520 ppb Np 40 ppb Pu 7.8 ppm Tc 170 ppm ²³⁶ U	1.4718
2. K-1131 Chemical Plant Stream 3 UO2 to UO2 Hydrofluorination	UO2	.64	520 ppb Np 4.4 ppb Pu 7.8 ppm Tc 170 ppm ²³⁶ U	0.3254
3. K-1131 Chemical Plant Stream 4 UF4 to UF4 Fluorination	UF4	.64	520 ppb Np 4.4 ppb Pu 7.8 ppm Tc 170 ppm ²³⁶ U	0.3254
4. K-1131 Chemical Plant Stream 5 Tower Ash Disposal	UF4	.64	13,000 ppb Np 440 ppb Pu 40 ppm Tc 100 ppm ²³⁶ U	18.0084
Same stream as above but Max Case Pu	UF4	.64	13,000 ppb Np 4,000 ppb Pu 40 ppm Tc 100 ppm ²³⁶ U	132.6553
5. K-1131 Chemical Plant Stream 6 UF6 to UF6 Collection	UF6	.64	393.94 ppb Np 0.04 ppb Pu 7.47 ppm Tc 170.71 ppm ²³⁶ U	0.2654
6. K-1131 Chemical Plant Stream 7 UF6 to Process Vent	UF6	.64	0.00 ppb Np 0.00 ppb Pu 200 ppm Tc 200 ppm ²³⁶ U	0.0548
7. K-1131 Chemical Plant Stream 8 RU as UF6	UF6	.64	394.34 ppb Np 0.04 ppb Pu 7.28 ppm Tc 170.88 ppm ²³⁶ U	0.2657
8. K-1131 Chemical Plant Stream 9 UO3 Reduction to Process Vent	UO2	.64	0.00 ppb Np 0.00 ppb Pu 10 ppm Tc 0.0 ppm ²³⁶ U	0.0005
9. K-1131 Chemical Plant Stream 10 RU as UF6 UO2 Hydrofluorination to Process Vent	UF4	.64	0.00 ppb Np 0.00 ppb Pu 10 ppm Tc 0.0 ppm ²³⁶ U	0.0005
10. ORGDP Stream 12 UF6 Cylinder Heel	UF6	.64	26,000 ppb Np 4.00 ppb Pu 70 ppm Tc 100.00 ppm ²³⁶ U	15.5572
11. ORGDP Stream 13 Hanford & Savannah River UF6 Feed Autoclave to Cascade	UF6	.64	132.79 ppb Np 0.00 ppb Pu 6.64 ppm Tc 171.60 ppm ²³⁶ U	0.1097
12. ORGDP Stream 14 PGDP RU to UF6 Feed Autoclave	UF6	.65	5.00 ppb Np 0.00 ppb Pu 1.96 ppm Tc 0.00 ppm ²³⁶ U	0.0031

Table A-1. Fraction Dose From Constituents For Process Streams

Process Stream Location (Refer To Flow Sheet)	Assumed Form	Assumed Assay (% U-235)	Assumed Constituent Level on U Basis	Fraction Dose From Constituents
13. ORGDP Stream 15 PGDP UF6 Cylinder Heels	UF6	.65	5.00 ppb Np 0.00 ppb Pu 40 ppm Tc 0.00 ppm ²³⁶ U	0.0067
14. ORGDP Stream 16 PGDP UF ₆ to Cascade	UF6	.65	0.00 ppb Np 0.00 ppb Pu 1.75 ppm Tc 109.29 ppm ²³⁶ U	0.0198
15. ORGDP Stream 18 UF6 to Cascade	UF6	.66	30.66 ppb Np 0.00 ppb Pu 2.29 ppm Tc 86.79 ppm ²³⁶ U	0.0339
16. ORGDP Stream 19 Depleted UF6	UF6	.30	0.00 ppb Np 0.00 ppb Pu 0.00 ppm Tc 39.51 ppm ²³⁶ U	0.0071
17. ORGDP Stream 20 Enriched UF6 Product	UF6	3.0	5.00 ppb Np 0.00 ppb Pu 1.77 ppm Tc 394.69 ppm ²³⁶ U	0.0170
18. ORGDP Stream 21 Cascade Accumulation Stream	UO ₂ F ₂	1.0	130,000 ppb Np 4.00 ppb Pu 7,500 ppm Tc 100.00 ppm ²³⁶ U	35.5492
19. ORGDP Stream 22 Purge Cascade Stream	UF6	3.0	0.00 ppb Np 0.00 ppb Pu 87 ppm Tc 100.00 ppm ²³⁶ U	0.0060
20. ORGDP Stream 24 ⁹⁹ Tc Chem Traps Spent Sorbent Stream	UF6	3.0	5.00 ppb Np 0.00 ppb Pu 100,000 ppm Tc 100.00 ppm ²³⁶ U	2.1696
21. K-1420 Stream 26 Chem Decon K-1420 to Effluent Discharge B & C Ponds Stream	UO ₂ F ₂	1.0	2.00 ppb Np 0.02 ppb Pu 200 ppm Tc 100.00 ppm ²³⁶ U	0.2292
22. B & C Pond Sludge	UO ₂ F ₂	0.7	2.00 ppb Np 0.02 ppb Pu 200.00 ppm Tc 100.00 ppm ²³⁶ U	0.2256

Weapons grade isotopic distribution assumed:

Pu-238 0.05
Pu-239 93.5
Pu-240 6.0
Pu-241 0.4
Pu-242 0.05

Table A-2. Occupational Exposure Potential Worksheet

Location	Activity	Constituent Level 0-3	Airborne Potential 0-3	Exposure Duration 1-3	Occupational Exposure Potential 0-27
	1. Oxide Conversion				
K-1131 K-1420	1A. Unpacking, feeding of UO ₃ to process, operation and pulling samples	1	2	3	6 Moderate
K-1131 K-1420	1B. Collecting ash for uranium recovery and cleaning of tower filters	3	3	3	27 High
K-1231 K-1410	1C. U recovery from ash, processes included ash pulverizer	3	3	2	18 High
K-1131 K-1410	1D. Maintenance and repair of fluorination tower and associated equipment	3	3	2	18 High
	2. Cascade Buildings and Operations				
Cascade feed points	2A. Feeding UF ₆ from cylinder to the cascade	2	2	1	4 Moderate
Cascade buildings	2B. Inadvertent releases of UF ₆ within cascade buildings or from piping between cascade buildings	2	1	1	2 Moderate
Product withdrawal points	2C. Withdrawal of product from cascade into cylinders	0	2	1	0 No significant
Tails withdrawal points	2D. Withdrawal of tails from cascade into cylinders	0	2	1	0 No significant
Cascade purge locations	2E. Venting process gas to atmosphere from operating cascade through process stack	3	3	1	9 Moderate
Cascade feed points	2F. CIP/CUP and other work involving removal of converters, compressors, and valves associated with cascade feed points	3	3	1	9 Moderate
Cascade purge locations	2G. CIP/CUP and other work involving removal of converters and compressors, and valves associated with the purge cascade	3	3	1	9 Moderate
Cascade buildings	2H. CIP/CUP and other work involving equipment removal and maintenance activities other than near feed point or purge cascade	0	3	2	0 No significant
	3. Recovery Operations				
K-1410 K-1420	3A. Cleaning of heels from UF ₆ cylinders	3	2	1	6 Moderate
K-1303 K-1410 K-1420	3B. Decontamination of equipment associated with feed point and recovery of uranium	3	3	1	9 Moderate
K-1303 K-1410 K-1420	3C. Decontamination of equipment associated with purge cascade and recovery of uranium	3	3	1	9 Moderate
K-1303 K-1410 K-1420	3D. Decontamination of equipment associated with other than near feed point or purge cascade	0	3	3	0 No significant
K-1037 K-1303 K-1410 K-1420 K-1421	3E. Uranium recovery from and/or processing of contaminated oils, cleaning solutions, and other wastes	1	1	3	3 Moderate

Table A-2. Occupational Exposure Potential Worksheet

Location	Activity	Constituent Level 0-3	Airborne Potential 0-3	Exposure Duration 1-3	Occupational Exposure Potential 0-27
K-770 Scrap Metal Yard	3F. Handling of scrap metal from equipment	1	1	1	1 Low
K-1407-B K-1407-C K-1419	3G. Removal, transfer, and/or storage of sludge from facility treating constituents concentrated in sludge	2	1	3	6 Moderate
RUBB Buildings	3H. Thermal drying/repackaging of pond sludge for offsite disposal	3	3	1	9 Moderate
Cascade buildings and associated piping	3I. Recovery of uranium deposits from process equipment associated with cascade feed points following shutdown of ORGDP	3	2	1	6 Moderate
Cascade buildings and associated piping	3J. Recovery of uranium deposits from process equipment associated with purge cascade following shutdown of ORGDP	3	2	1	6 Moderate
Cascade buildings and associated piping	3K. Recovery of uranium deposits from process equipment other than feed points and cascade purge following shutdown of ORGDP	0	2	2	0 No significant
K-1031 K-1410 K-1420	3L. Service cascade chemical traps	3	3	1	9 Moderate
4. Analytical Labs					
Analytical laboratories K-1004A, B, C, D, J K-1006	4A. Analytical laboratory sampling	3	0	1	0 No significant