Office of Oversight
Environment, Safety and Health

Phase II
Independent Investigation
of the

Paducah Gaseous Diffusion Plant

Environment, Safety, and Health Practices
1952-1990

February 2000

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OVERSIGHT

FOREWORD

In the summer of 1999, Secretary of Energy Bill Richardson directed the Office of Environment, Safety and Health to conduct an independent investigation into serious concerns being raised about worker and environmental protection practices at the Paducah Gaseous Diffusion Plant (PGDP). What followed was one of the most thorough and comprehensive independent investigations in the department's history -- involving conduct of hundreds of interviews with current and former workers, review of thousands of historical records and documents, first-hand work place examinations, and environmental sampling and analyses. Together with an October 1999 report that examined recent conditions, this report presents the findings of that investigation. Similar investigations are being conducted at the Gaseous Diffusion Plants in Piketon, Ohio and Oak Ridge, Tennessee.

The investigation brings to light that Paducah -- like the other nuclear production facilities in the complex -- operated in climate of secrecy, with a strong sense of urgency and national need, and without external regulation of worker safety and health or environment. Workers at these facilities were exposed to very hazardous chemicals and in some locations, received significant radiation doses. Some workers may have become ill from those exposures. What sets apart the experience at the gaseous diffusion plants is that workers were unaware of trace quantities of radioactive transuranic elements and fission products contained in the reactor fuel recycled from Hanford, Idaho, and Savannah River, and are concerned about their potential exposures.

Along with the gaseous diffusion plant investigations, my office is conducting public meetings at major DOE sites to hear the experiences of workers in the nuclear weapons complex and learn about the health consequences of those experiences. What we are hearing is that these are hard-working people, with a strong sense of pride in playing a part in the nation's defense, and a great deal of courage in facing very serious hazards. As Secretary Richardson has made clear, it is our policy that where workers have been made ill by this work, we acknowledge our responsibilities, just as we do to our military veterans. This report, along with information from our public meetings and other health studies, will help us find the best way to meet that commitment.

David Michaels, PhD, MPH
Assistant Secretary
Environment, Safety and Health

Executive Summary

EVALUATION:	Office of Oversight Investigation—Phase II
SITE:	Paducah Gaseous Diffusion Plant
DATES:	October-November 1999

Background/Scope

In August 1999, in response to environment, safety, and health (ES&H) allegations and subsequent worker and public concerns, the Secretary of Energy initiated an independent investigation at the Paducah Gaseous Diffusion Plant (PGDP or Plant). These ES&H allegations and concerns included inadequate controls for workers exposed to uranium and transuranic elements, ineffective communication of hazards and radiation exposures to workers, and improper release, dumping, or burial of radioactive and other hazardous materials at unapproved onsite and offsite locations. This investigation was divided into two phases: first, to provide timely information on the status of current operations, and second, to perform a more lengthy investigation of historical operations.

The first phase of the investigation concentrated on the period 1990 to the present and included the current facilities, areas, operations, and activities that are the responsibility of the Department of Energy (DOE) and its current management and integrating contractor. Operations controlled by the United States Enrichment Corporation (USEC) were not evaluated. A report was published in October 1999. Immediate actions were initiated to address issues regarding inadequate posting (i.e., identification) of radiological hazards both on and off DOE property. More detailed, comprehensive, and long-term corrective action plans are currently being developed to address the more complex ES&H program weaknesses identified in the Phase I investigation.

The second phase of this investigation addressed historical conditions and activities from startup of the Plant in 1952 until 1990. In his testimony to Congress prior to the start of this Phase II investigation, Dr. David Michaels, Assistant Secretary for Environment, Safety and Health, stated, "We need to determine how well the workers knew of and understood the hazards they were working with, and how well they were protected from these hazards – even in very small amounts. We will learn much more as our investigation moves ahead and seeks to confirm – in today's regulatory environment – whether the presence of these materials represented a potential health risk at Paducah or any other DOE plant." The Phase II investigation focused on:

- Identifying the concerns and questions of current and former workers and their level of understanding of site hazards and ES&H practices
- Understanding the operations, activities, conditions, and hazards in the workplace
- Identifying the management practices and controls employed and the applicable standards and regulations
- Determining where management practices and controls may not have been effective in protecting workers, the public, or the environment.

A vast amount of information was collected and analyzed to accomplish these objectives. To better understand the various site operations and conditions, the investigation team interviewed hundreds of current and former workers and managers, reviewed thousands of historical records and documents, toured workplaces, and performed limited walk-over surveys of possible disposal sites. The team examined dozens of events, about 40 separate major operations and activities, and related ES&H practices.

The intent of this investigation was to identify and address the overall ES&H concerns and questions of current and former workers and the public, not to determine the validity of specific allegations. Several ongoing or proposed initiatives of the DOE Office of Environment, Safety and Health should provide greater understanding of certain aspects of these issues:

- The mass balance project will recreate the historical flow of recycled uranium and its contaminants across the DOE complex.
- The medical surveillance project will determine the presence and prevalence of adverse worker health effects from employment at gaseous diffusion plants.
- The exposure assessment project will determine how workers at the gaseous diffusion plants were exposed to radiation, to how much, and from what source.

Determining any long-term effects on employee health from working conditions and management practices at the PGDP will require study that is beyond the scope and resources of this investigation. Similarly, detailed examination of any work that PGDP might have performed for others in relation to weapons systems as well as the effectiveness of any associated ES&H practices was not part of the investigation.

Results

Certain external conditions and influences had a significant effect on the ES&H-related behavior and intentions of both management and workers at the PGDP during the 1952-1990 period. When the PGDP started operation, World War II had recently ended, the country was involved in a major conflict in Korea, and the Cold War was a reality. Many of the workers were military veterans. The work being done was classified, involved high technology, and was important to the national defense. The "need to know" was an ingrained security policy that had a major effect on attitudes toward sensitive operations and materials at the PGDP. The Plant was the biggest employer in the region, paying wages significantly higher than previously available in this rural farming area; people in Paducah and the surrounding area wanted these jobs. Management and the Atomic Energy Commission (AEC) were under pressure to maximize production. Workers in this environment were not inclined to ask many questions. While most of the hundreds of workers interviewed by the team indicated, in response to specific questioning, that they were unafraid to ask questions about safety and they had no fear of reprisals, a few interviewees did express concerns about both. Further, industries in the 1950s, including AEC facilities, were largely self-regulated, and guidance and regulatory requirements were minimal and evolving. Significant industrial and environmental legislation that would focus attention and actions toward greater protection of workers and the environment was not enacted until the 1970s.

During the period 1952 to the early 1980s, oversight by the governing Federal agencies—AEC, the Energy Research and Development Administration (ERDA), and DOE—was primarily directed at cost, schedule, and production, not ES&H. A March 1960 letter revealed that AEC and contractor management, including the PGDP Health Physics and Hygiene Department, were aware of the potential hazards presented by transuranic elements contained in the feed material the Plant received from Hanford reactor tails and the workers' lack of compliance with respiratory protection measures. The document stated that 300 persons at Paducah "should be checked out," but that management was hesitant to study the issue intensively for fear that the labor union would demand hazard pay.

Health and safety programs were always in place and functioning at PGDP, with a strong emphasis on industrial safety. Policies, procedures, and training were provided that addressed hazards in the workplace and specified recommended personnel protection and controls. Safety meetings were frequent, and job hazard analyses that described hazards and controls were soon developed for most work activities. The Health Physics and Hygiene Department, although minimally staffed for most of the 38 years covered in this investigation, was active in studying hazards and health effects, analyzing air monitoring results, surveying work areas, and recommending engineering and administrative controls for identified hazards. Fixed and portable ventilation and vacuum systems were installed in some areas to control workers' exposure to radiation and chemicals as well as the spread of contamination. Safety glasses, gloves, and hearing protection were made available to workers, and for certain work activities, the company supplied coveralls, shoes, caps, undergarments, and respiratory protection equipment. By 1960, all personnel exposures to radiation were monitored using film badges and, for targeted workgroups, bioassay techniques, including scheduled and event-driven urinalysis and lung counting. Workers showing high uranium excretion rates were removed from high exposure work. Workers who were excreting uranium over threshold limits were put on a recall urinalysis program until their excretion rates fell to baseline levels, usually within hours or days. Exposures to fluorides were also monitored through the urinalysis program.

Radiological and chemical hazards and exposure risks to personnel were much higher in certain work locations and activities at the Plant than in others. Significant external and internal exposure to concentrated transuranics was possible in handling feed production ash and in uranium, neptunium, and technetium recovery operations. Feed plant operations presented high exposures to airborne UO_3, UF_4, and to HF. Exposure to airborne UF_4, magnesium powder, uranium oxides, and HF was possible in the metals plant. Maintenance and modification activities involved potential airborne and point source exposures to UF_6, HF, UO_2F_2, transuranics, and uranium daughter products in many locations; these activities included bag house filter changeouts, converter modification work, and compressor and seal disassembly repair and replacement. Workers performing decontamination and cleaning operations in Building C-400 had significant exposures to trichloroethene (TCE) in addition to radioactivity.

Although the intent to protect workers from hazards was apparent, the protection programs were not always conservative or consistent. Air emissions, liquid effluents, and solid waste disposal were consistent with practices in general industry and the DOE complex at the time (e.g., dilution, burial, and burning) but resulted in significant adverse impacts on the environment. The following sections summarize the conditions, practices, and consequences in key ES&H areas.

Radiological Protection

The risks and hazards of exposure to uranium and transuranics were neither fully understood nor appreciated. PGDP considered that intakes of uranium were from soluble compounds and would be quickly excreted through the kidneys. This assumption may not have been accurate for all uranium compounds at the Plant, particularly aerosols generated in the feed plant and during maintenance operations such as grinding, buffing, or welding. The comfort level of PGDP technical staff regarding exposure to uranium is reflected in a research experiment, conducted in the late 1950s, where Health Physics and Hygiene staff members voluntarily inhaled and ingested known quantities of uranium compounds to measure excretion rates. In addition, in 1956, test subjects at the Plant, wearing different types of respirators, were exposed to several known concentrations of airborne uranium compounds to determine subsequent excretion rates.

External exposures were monitored using film badges. However, extremity dosimetry was not employed, even though requirements dating from the late 1950s mandated that such monitoring be conducted when the potential exposure could exceed 10 percent of the extremity limit. Over the 38 years of operations, only two exposures over regulatory limits were documented. However, due to high concentrations and variable dose rates in certain areas of the Plant, workers in these areas may have received significant unmonitored exposures to hands and feet during some operations. The concept of keeping exposures as low as reasonably achievable (ALARA) was, in various forms, AEC/ERDA/DOE policy. However, PGDP policies and practices focused on preventing personnel exposures from exceeding Federal Radiation Protection Guidelines, rather than keeping them as low as reasonably achievable.

Contamination controls at Paducah were limited, even into the early 1980s. Eating, drinking, and smoking in contaminated work areas was common practice. Although personnel wearing company clothing typically showered before changing into their personal clothes and leaving the site, the practice was not mandatory, and workers were not required to wash their hands and other exposed skin, or remove contaminated clothing, before entering cafeterias, break areas, and even the main site meeting area in the C-100 “Roxie theatre.” Friskers and whole body monitors were not employed until the mid-1980s. As a result, Plant workers probably took radioactive contamination outside site boundaries.

As early as 1957, the site became aware of the presence of transuranic elements (those with atomic numbers higher than uranium) and fission products in feed materials processed from spent reactor fuel at the Hanford and Savannah River Sites. Transuranics and fission products have a much higher specific activity than uranium and resulted in much higher dose to some workers. These materials were a concern where they were concentrated, such as in the “heels” remaining in empty UF_6 cylinders and in the uranium, technetium, and neptunium recovery processes, or where there was airborne exposure such as reactor tails feed material ash in the feed plant, metals production, and maintenance/modification activities. However, the presence of these materials, the increased risks involved, and the rationale for additional controls were not shared with workers. Workers’ incomplete awareness of these hazards contributed to and fostered inconsistent compliance with recommended protective measures.

Initial comprehensive operations training programs, which included radiation theory and control, quickly declined in scope and frequency as resources and attention focused on production. Information concerning workplace radiation and chemical hazards and protective measures was subsequently communicated primarily through informal on-the-job training, passed from experienced workers to new ones. Although exposure history information was collected from monitoring film badges, bioassays, and lung counts, it was not openly communicated, nor was its meaning explained to workers unless requested.

The Health Physics and Hygiene Department provided monitoring, investigation of elevated intakes and air samples, and recommendations for radiological controls. However, line management had ultimate responsibility for implementing radiation protection measures. In many cases, recommendations for controls or improved protection were the result of high exposures or sample readings, rather than conservative, proactive planning. Workers' compliance with recommended controls (engineering, procedural, and personal protective equipment or PPE) and management's enforcement of compliance were inconsistent. In many areas, individual workers or supervisors decided whether recommended PPE would be used, and early masks and respirators did not fit well, hindering vision in work environments. The inconsistent use of respirators was especially important because they were heavily relied on to minimize workers' inhalation of radioactive materials.

Chemical Hazard Exposure

Acute and chronic exposures to a number of hazardous chemicals used at the Plant were frequent occurrences, and the risks and long-term health effects of such exposures were not fully recognized by the Health Physics and Hygiene Department and consequently, by the workers. Exposures to polychlorinated biphenyls (PCBs), TCE, fungicides used on the cooling towers, and asbestos did not result in apparent, immediate health effects, nor was there recognition of adverse long-term health effects. National standards related to exposure to these materials did not appear until the 1970s or 1980s. An asbestos screening program for asbestos workers was initiated by the Oil, Chemical & Atomic Workers International Union in the mid-1980s. Exposures to caustic HF resulted in frequent burns and respiratory injury. The effects of these exposures were believed to be temporary only, when, in fact, there may be long-term consequences.

Airborne Emissions

Radioactive and fluorine emissions to the atmosphere from stacks, diffuse and fugitive emissions, accidents, and a small number of planned releases have occurred since Plant startup in 1952. Stack emissions were not monitored until the mid-1970s; process knowledge was used to estimate potential releases before then. Published reports estimated that approximately 60,000 kilograms of uranium were released to the atmosphere from 1952 to 1990, 75 percent of it before 1965. There is evidence that past estimates did not include all process gas releases, diffuse emissions, accidental releases, and unauthorized process gas venting. Consequently, the accuracy and conservatism of past public dose estimates are questionable.

Liquid Effluents

Liquid effluents from past operations have had a significant adverse impact on the environmental quality of onsite ditches and streams and groundwater sources in the vicinity of the site. Uranium, thorium, TCE, and small quantities of transuranics and fission products have been released to the environment, primarily from cleaning and decontamination in Building C-400. Significant amounts of chromates and fluorides were released to the environment, as approximately 500,000 gallons of recirculating cooling tower blowdown water were pumped into Little Bayou Creek every day. From the beginning of Plant operations, liquid effluent control was based on dilution, with the objective of ensuring no unacceptable impact on the Ohio River; there was much less concern about onsite and local waterways and groundwater. As a result of increasing regulatory requirements and an increased sensitivity to environmental protection, significant efforts were undertaken in the 1970s that improved the quality of area surface waters.

Waste Disposal

Radioactive and chemically hazardous materials were dumped and buried in numerous locations both inside and outside the site fence. Hazardous and radioactively contaminated materials were often mixed with normal trash and waste materials, and waste disposal was not well monitored, controlled, or documented. Large quantities of radioactive materials, including uranium metals and powders and contaminated waste, were packed in metal barrels and buried. Contaminated empty barrels remain piled in "Drum Mountain." Contaminated concrete rubble and roofing materials were disposed outside the Plant boundaries, some in wildlife areas where public use and access were authorized and encouraged. Contaminated sludge and floor sweepings were placed in landfills, and the sludge was applied to Plant lawns as fertilizer. Rainfall runoff and leaching have moved contaminants from the disposal sites into the surrounding environment. Federal environmental regulations were enacted in the 1970s, and the Material Terminal Management organization, established in the early 1980s, implemented an integrated waste management program that reduced the amount of radioactive waste disposed of on site and achieved greater control over waste segregation and disposal.

Summary

External conditions significantly affected the policies, practices, and performance of PGDP management (both the Federal owners and the contractors) and workers during the first 38 years of Plant operation. To put PGDP conditions and activities into perspective, it must be considered that almost 50 years ago there was a significantly smaller body of knowledge about radiation, chemical, and other industrial hazards and their effects on humans and the environment. While evidence reviewed indicates that managers were concerned with the safety and health of workers, management decisions and practices were not always conservative. Consequently, worker radiation exposures were higher than necessary, and some workers may have been exposed to hazards that were not adequately monitored or understood. Communication of hazards, the rationale for protective measures, and information about radiation exposure were inadequate. Further, workers were exposed to various chemical hazards for which adverse health effects had not yet been identified. Environmental practices prior to Federal and state legislation in the 1970s and 1980s resulted in many adverse impacts to the environment, both on and off Federal property.

1.0 Introduction

1.1 Purpose and Scope

The Department of Energy (DOE) Office of Oversight, within the Office of Environment, Safety and Health, conducted the second phase of its investigation of the Paducah Gaseous Diffusion Plant (PGDP or Plant) from October through December 1999. The purposes of the second phase of the investigation, and the subject of this report, were to determine whether environment, safety, and health (ES&H) activities and practices from 1952 to 1990 were consistent with the knowledge, standards, and local requirements applicable at the time and to identify any ES&H concerns that had not previously been documented. The first phase of this investigation, conducted from August through October 1999, addressed DOE and site contractor activities and ES&H issues arising since 1990.

This investigation was performed at the direction of the Secretary of Energy, who instructed the Office of Environment, Safety and Health to examine recent employee concerns about past operations and work practices, and current management of legacy materials (i.e., materials remaining from past operations) at PGDP. Both phases of this investigation were coordinated with other organizations that have regulatory authority at PGDP, including the Commonwealth of Kentucky, the Nuclear Regulatory Commission (NRC), the Environmental Protection Agency (EPA), and the Occupational Safety and Health Administration (OSHA). Excluded from this investigation were any activities currently under NRC jurisdiction (i.e., portions of PGDP leased to the United States Enrichment Corporation, or USEC).

The scope of this second phase includes activities from 1952 to 1990 that affect: (1) DOE- and predecessor agency-owned facilities and properties inside and outside of the security fence, (2) privately- or publicly-owned, non-DOE facilities and properties, (3) DOE and contractor personnel employed at PGDP, and (4) members of the public and the environment in proximity to the Plant. The objectives of this phase of the investigation are to more fully understand the nature of past operations at the Plant, as well as modifications of operations, processes, and activities; and to identify critical ES&H practices and events that did not, in the judgment of the investigation team, fulfill their mission of protecting workers, the public, or the environment. This phase of the investigation is not intended to be a comprehensive examination of the validity of each ES&H concern or allegation previously expressed or identified and is not intended to conflict or interfere with any ongoing litigation involving ES&H concerns at PGDP. The results of other related evaluations being conducted by DOE—such as the mass balance, exposure assessment, and medical surveillance projects—are also outside the scope of this investigation. Finally, detailed examination of any work that PGDP might have performed for others in relation to weapons systems, as well as the effectiveness of any associated ES&H practices, was not part of the investigation.

1.2 Current Site Operations

The PGDP is located in McCracken County, Kentucky, approximately ten miles west of the City of Paducah and three miles south of the Ohio River. The site occupies about 3,425 acres, 750 of which are within a security fence, and contains uranium enrichment process equipment and support facilities. The mission of the Plant is to "enrich" uranium for use in domestic and foreign commercial power reactors. Enrichment involves increasing the percentage of uranium-235 in the material used for creating reactor fuel (UF_6). Uranium-235 is highly fissionable, unlike the more common isotope uranium-238. The PGDP enriches the UF_6 from roughly 0.7 percent uranium-235 to about 2.75 percent uranium-235. Figures 1 and 2 are site maps showing current operations, facility leasing status, and major boundaries.

DOE is the site "landlord," owns the physical plant, and is responsible for operation of the Northwest plume and the Northeast plume pump and treat systems; for operation of a permitted

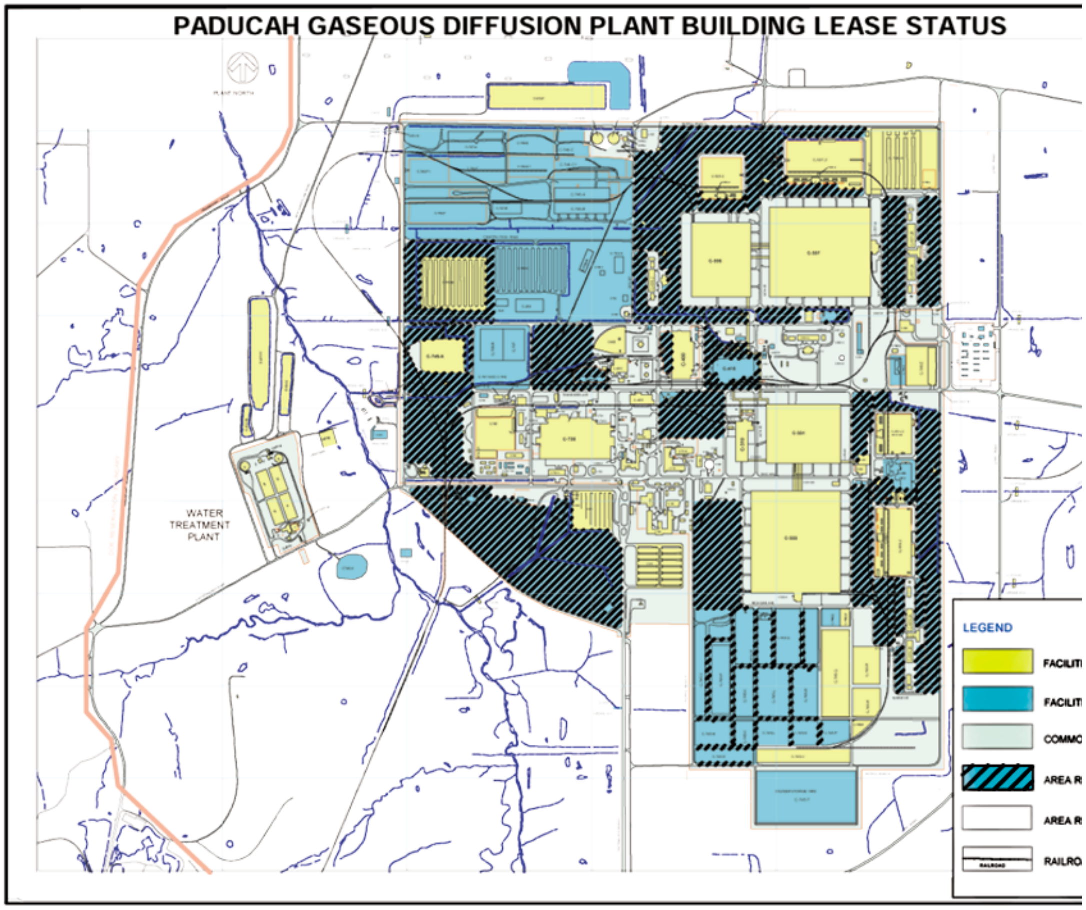


Figure 1. Map of Paducah Gaseous Diffusion Plant, Leased and Non-Leased Areas

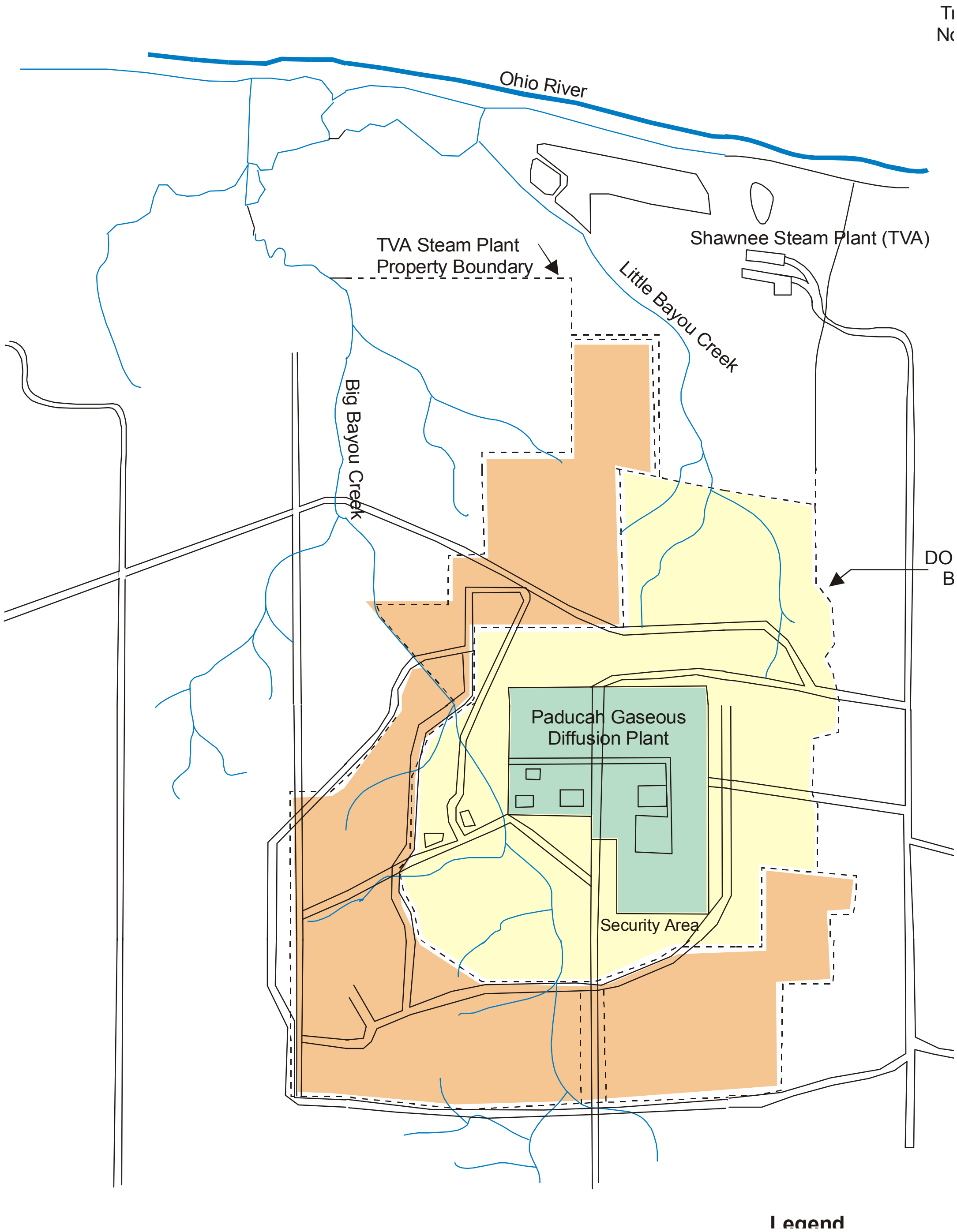
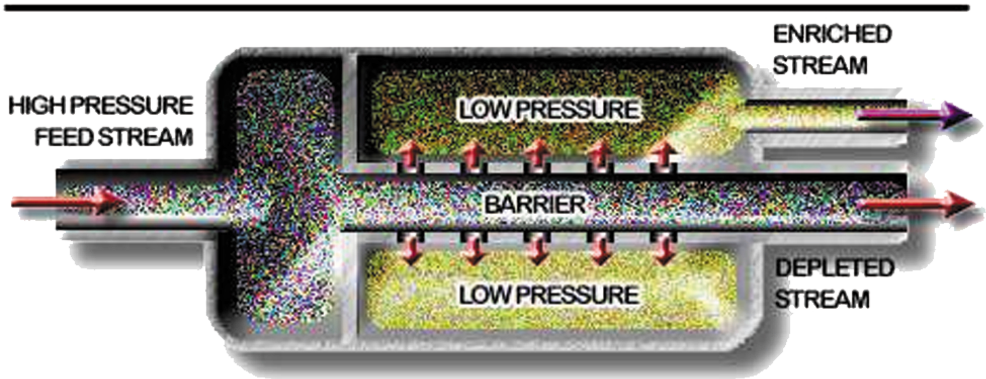


Figure 2. Map of Paducah Gaseous Diffusion Plant, Major Boundaries and Features

solid waste landfill; for operation of waste treatment and storage facilities; for waste characterization and disposal; for maintenance of non-leased roads, grounds, and facilities; for surveillance and maintenance of UF_6 cylinders; for construction of new cylinder yards; for maintenance of closed landfills and burial sites; for environmental monitoring; and for environmental restoration. Bechtel Jacobs is the management and integrating contractor for DOE, having been awarded this contract in April 1998. Bechtel Jacobs relies on subcontractors to conduct environmental restoration and waste management functions.

USEC leased the enrichment production facilities on July 1, 1993, and contracted with Lockheed Martin Utility Services as the operating and maintenance contractor until May 1999, when USEC assumed direct operation of the enrichment activities. The NRC performs regulatory oversight of USEC activities. The Occupational Safety and Health Administration regulates USEC occupational worker safety and health, and the Commonwealth of Kentucky and the EPA regulate USEC environmental activities. USEC-leased facilities consist of process buildings, electrical switchyards, a steam plant, a water treatment facility, a chemical cleaning and decontamination facility, and maintenance and laboratory facilities. Over its operating lifetime, PGDP has processed more than 1,000,000 tons of uranium. The process of enriching uranium at PGDP involves heating UF_6 into a gas, which is in turn fed through a series of diffusion stages; PGDP has over 1,800 diffusion stages. The diffusion process generates enriched uranium product and tails. The product (or slightly enriched material) is shipped to the Portsmouth Gaseous Diffusion Plant in Ohio, where it is normally enriched to 3 to 5 percent uranium-235. The tails, typically containing less than 0.5 percent uranium-235, remain on site in cylinders.

GASEOUS DIFFUSION STAGE



1.3 Investigative Approach

To support the overall objective of determining whether ES&H activities and practices that existed from 1952 to 1990 were consistent with the knowledge, standards, and local requirements applicable at the time, the Office of Oversight investigation team interviewed current and former site personnel, reviewed documents, walked down high hazard areas of the Plant, and conducted surveys of selected items of potentially contaminated equipment, materials, and waste storage areas.

The Oversight team conducted more than 200 interviews with current and former site employees, including Oak Ridge Operations Office (OR) and Paducah Site Office (PSO) personnel; USEC, Bechtel Jacobs, and previous contractor and subcontractor managers, supervisors, and workers; and stakeholders. Many of these interviews resulted from a solicitation that the investigation team placed in local newspapers requesting information on past (1952-1990) Plant operations, ES&H practices, and specific events that could have affected worker and public safety and environmental protection. These interviews also provided the investigation team with a preliminary indication of the degree to which ES&H practices and controls were consistent with and appropriate to the standards of the day throughout the Plant. This information allowed the team to identify certain ES&H practices for more detailed document and literature review.

The investigation team reviewed thousands of historical documents, including plans, procedures, operations logs, assessments, analyses, and memoranda. These reviews supplemented the information from interviews and clarified the chronology of events at PGDP. The team also examined documents addressing past standards to provide a framework for understanding ES&H requirements and expectations prior to 1990. Many records were obtained from PGDP archives documenting past releases of radioactive and hazardous materials and their potential impacts on workers, the public, and the environment.

To supplement the interview and document

Recent Sampling Activity

review processes, the investigation team walked down high hazard buildings and surveyed a variety of equipment, material, and waste storage areas. Radiological surveys were performed at a variety of locations, both inside and outside the perimeter security fence.

This extensive data collection process allowed the investigation team to proceed in a structured fashion to (1) determine whether ES&H activities and practices from 1952 to 1990 were consistent with the knowledge, standards, and local requirements applicable at the time, and (2) identify any ES&H concerns that had not previously been documented.

1.4 Data Considerations

The scope of the Phase II portion of the investigation required that the investigation team examine legacy data and information. This involved both the review and evaluation of archived material and the assessment of recorded interviews documenting individuals' recollections of previous events and conditions. The investigation team recognized the inherent difficulty of current and former workers' accurately recalling details related to activities and events happening 20 to 40 years ago. While the interview solicitation indicated the team's desire to speak with personnel who were involved in a variety of functions at the Plant, many individuals were self-selected for the interviews; that is, their participation resulted from their personal interest in the investigation. Accordingly, the team was cautious and conservative in its use of information recorded in interviews for judgments contained in this report.

The identification and review of historical documentation was a tedious and time-consuming process. Many historical PGDP documents were not catalogued or filed in central locations. Many documents could not be located, and some records that were examined were contaminated or located in abandoned, contaminated buildings. Due to the volume of records and other documentation generated over almost 40 years, it was not possible to locate and review all documents. Documents were examined based on focused subject searches and targeted sampling.

1.5 Report Structure

The balance of this document is structured to provide the reader with a comprehensive understanding of past activities at PGDP and a thorough description of operational, maintenance, and environmental management practices and their effectiveness in minimizing impacts on workers, the public, and the environment. To ensure that the full range of information is provided in an understandable manner, the balance of the report is organized into a series of discussions outlining various elements of the Plant's operation in the context of when and how they were conducted. Accordingly, Section 2 of the report provides a chronological description of past activities at PGDP within a series of functional areas that summarize key operations relating to the safety and health of workers, the public, and the environment. The objective of Section 2 is to provide to the reader an overall understanding of the major activities performed at PGDP and to indicate how these activities may have changed over time.

Section 3 describes in detail the hazards that existed at PGDP; operational and maintenance activities; practices used to identify, monitor, and control these hazards; and the effectiveness of these practices in addressing these hazards. Similarly, Section 4 describes past environmental management practices at the Plant and their effectiveness in mitigating impacts to the public and the environment. Section 5 provides the investigation team's findings regarding ES&H activities and practices from 1952 to 1990. The roster of the Office of Oversight investigation team is provided in Appendix A. Appendix B summarizes the principal hazardous activities conducted at PGDP during the period 1952 to 1990 and provides an assessment of the hazards presented by these activities, the controls used to mitigate the hazards, and the effectiveness of the controls.

2.0 Chronology of Activities at Paducah Gaseous Diffusion Plant

Past activities (1952 to 1990) at PGDP are presented in chronological fashion within a series of functional areas summarizing key Plant operations and activities and relating to the safety and health of workers, the public, and the environment.

2.1 Site Background

In August 1950, the U.S. government determined that it would need to double the capacity of domestic fissionable materials production that existed at the Oak Ridge K-25 Plant. The Atomic Energy Commission (AEC) selected a Plant option consisting of 400 stages modeled after the K-31 facility at Oak Ridge (which would become C-331 at the Paducah Plant) and 480 stages twice the size of the Oak Ridge K-31 stages (which would become C-333 at the Paducah Plant). Based on a decision to disperse the major portions of the new production capacity, eight areas were identified as candidate locations for the Plant, all in the southeastern U.S. From the application of additional criteria, three sites were identified: the Kentucky Ordnance Works (KOW) at Paducah, the Louisiana Ordnance Plant at Shreveport, and the Longhorn Ordnance Works at Marshall, Texas. From these, the AEC approved, on October 18, 1950, the KOW site as the location for the new gaseous diffusion plant.

PGDP construction spanned 1951 through 1956 and was conducted in two phases. Construction of the first phase began January 2, 1951, and included erection of the following process and production facilities: C-331 and C-333, the gaseous diffusion process buildings; C-410/420, UF_6 Feed Plant; C-310, Purge and Product Withdrawal Building; C-315, Surge and Waste Building; and C-300, Central Control Building. On January 6, 1951, the Tennessee Valley Authority began construction of the four-unit Shawnee Steam Plant near the Paducah Plant on the Ohio River to provide a portion of the needed electricity. On February 15, 1951, Electric Energy, Incorporated began construction of the Joppa Steam Plant, in Joppa, Illinois, to also provide electricity to PGDP. Authorization to proceed with the second phase of Plant construction was received on July 15, 1952. Two additional enrichment facilities, C-335 and C-337, were added, and construction was completed in 1956. Carbide and Chemicals Company (which became Union Carbide Corporation Nuclear Division) was named as the original site contractor based on the company's experience with gaseous diffusion operations at Oak Ridge. Carbide operated PGDP for the AEC, and its successor agencies the Energy Research and Development Administration (ERDA) and DOE, until 1984, when they were replaced through a competitive procurement by Martin Marietta Energy Systems, Inc.

Construction at PGDP

In the early 1950s, the Plant provided some of the better paying jobs in the area, if not the region. Workers believed that the mission of the Plant was important to national security, and they worked hard to meet expectations. Accordingly, being an employee of the Plant engendered respect and there was civic pride in the fact that Paducah was the location of a facility that played a role that was important to the nation. Many of the Plant's original operators and workers were military veterans and viewed the opportunity to work at PGDP as a way to continue their service to the country. This notion of service is reflected in the fact that a significant proportion of workers would become long-term Plant employees, transcending changes in Federal oversight organizations and transitions in contractors.

Demands on the Plant and the workers were high, given the requirements of the Cold War. Work was difficult, production schedules were challenging, and the work environment was often hot, loud, dirty, and laden with noxious fumes. The security demands of the Cold War also affected worker awareness of hazards in that, prior to 1989, documents discussing many aspects of operations were classified and, at the direction of line management and AEC security, detailed knowledge of work activities was based on a “strict need to know.” The workers’ sense of loyalty and service would also translate into acceptance of these security policies and the expectation that they would be told everything that they needed to know.

From the 1950s to the 1990s, government oversight of ES&H elements of PGDP contractor activities evolved. The primary offices of the Federal regulatory organizations for the diffusion plants — the AEC, ERDA, and DOE — have always been located in Oak Ridge, although there was a Federal presence at PGDP for most of the period 1952 to 1990. Records indicate AEC involvement in collaborative research activities related to radiation and health physics in the 1950s through the 1970s, but there is little evidence of direct observation of, or direction to, the PGDP contractor regarding ES&H, which was not an uncommon practice for a regulatory agency during that period. Carbide provided quarterly progress reports to the AEC summarizing operational, maintenance, construction, industrial hygiene, health physics, and accident data and analysis and responded to information requests on health physics issues. However, the interactions between the contractor and AEC clearly emphasized maintaining or increasing production. In the 1970s, as new environmental regulations were enacted, there is evidence of growing involvement by the Commonwealth of Kentucky and OR in site activities and in the effects of site activities on the environment and the public. In the 1980s, increased DOE oversight was evidenced by additional ES&H inspections by the local site office and OR. On September 18, 1985, then-Secretary of Energy John Herrington announced that DOE-wide environmental surveys would be conducted; the PGDP survey occurred in November and December 1987. These surveys led to changes in DOE and contractor ES&H programs. However, the 1990 DOE Tiger Team identified ineffective DOE oversight and unclear oversight roles and responsibilities as key management findings.

2.2 Operations

Although major construction activities would continue through 1956, Union Carbide began hiring approximately 1,700 permanent Plant workers in 1951. The first process buildings, C-331, C-333, C-310, and C-315, were completed and started operation in September 1952, and the first product was withdrawn in November. The purpose of the gaseous diffusion plant has been and continues to be the enrichment of uranium, initially for military applications and subsequently for commercial reactor fuel. PGDP enriches feed material in the form of UF_6 gas with approximately 0.7 percent uranium-235 to UF_6 with one to three percent uranium-235. The enriched product from PGDP was sent to other DOE sites at Portsmouth or Oak Ridge for further enrichment. Most UF_6 feed material came from the depleted tails produced during normal diffusion operations at PGDP and from Oak Ridge and Portsmouth. From 1952 through 1977, UF_6 feed material was also produced from uranium trioxide or UO_3 (called “yellowcake”) at PGDP in Buildings C-410 and C-420; this feed material was supplied by sources such as El Dorado Mining and Refining, Mallinkrodt Chemical Works, and General Chemicals (now Allied Chemical) and comprised less than 10 percent of the UF_6 fed to the cascade. From 1953 through 1964 and intermittently from 1968 through 1977, the feed plant also produced UF_6 from UO_3 from spent reactor fuel processed at the Hanford and Savannah River sites. After 1977, all feed came in the form of UF_6 from outside sources such as Oak Ridge, Portsmouth, and Allied Chemical.

Although natural uranium is not a highly radioactive material, it is toxic, both chemically and radiologically, when inside the body. The uranium exposure pathway of greatest hazard at PGDP was inhalation of uranium dust. Feed material was made from production reactor tails from 1953 until 1964, and intermittently from 1968 to 1977. The percentage of PGDP cascade feed material from reactor tails averaged 19 percent during the 19 years this material was used, ranging from 3 percent in 1975 to 65 percent in 1973. Processing of UO_3 into UF_6 was accomplished in three steps: reduction, hydro-fluorination, and fluorination (see Figure 3).

Reduction involved transforming UO_3 into UO_2 (commonly referred to as “black oxide”) using hydrogen gas. Hydro-fluorination of UO_2 into UF_4 (commonly referred to as “green salt”) was accomplished by adding anhydrous hydrofluoric acid (HF). Fluorination was

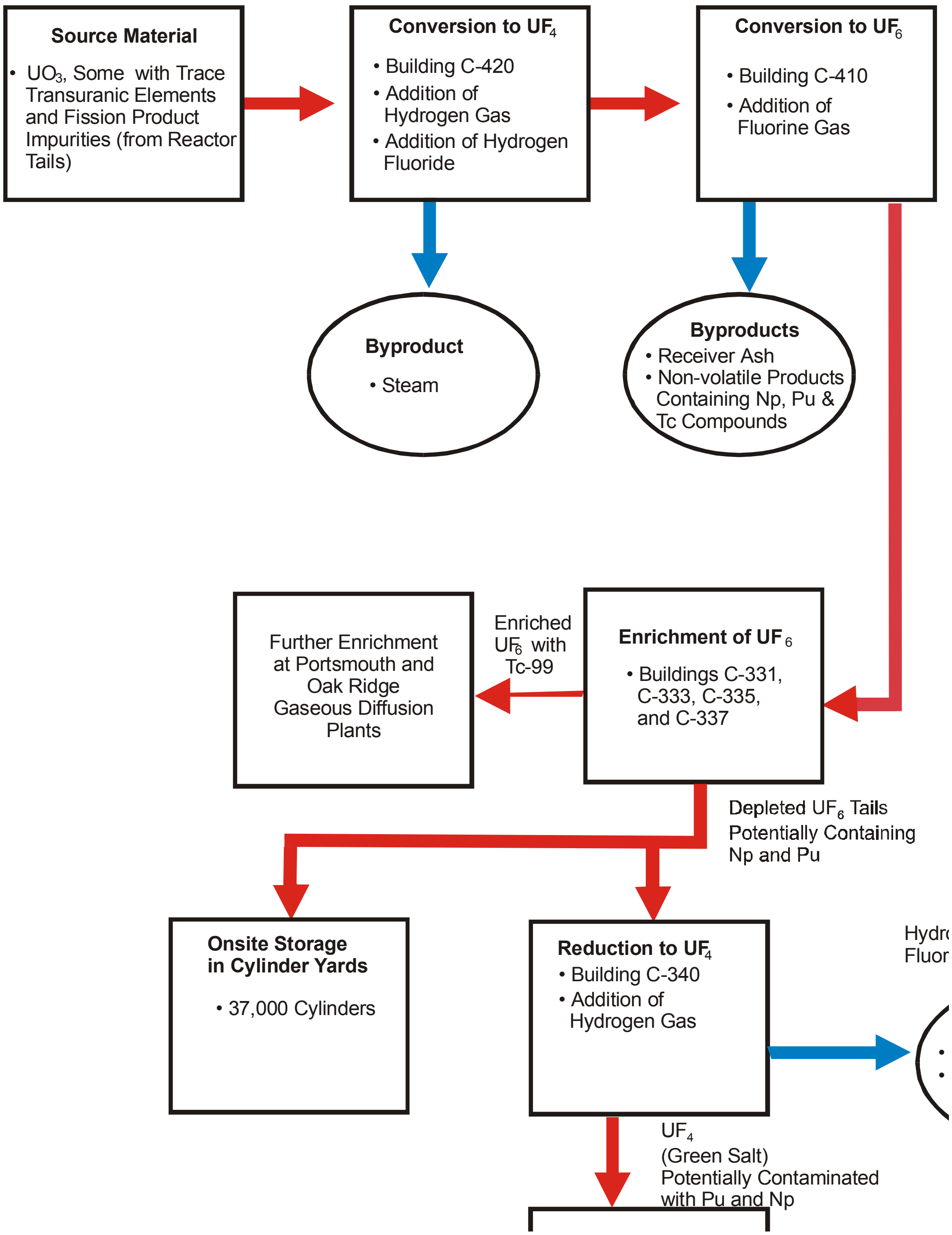


Figure 3. Historical Uranium Enrichment Process

conducted in C-410 using heated elemental fluorine gas in tower reactors. The first two steps were performed in C-410 on vibration tray reactors (shaker trays) from 1953 to 1956. In 1956, due to frequent equipment failures, spills, leaks, and the increased demand for feed, Building C-420 (commonly called the "green salt" plant) was completed and green salt production at C-410 was phased out. In C-420, the reduction was performed in two-stage fluidized bed reductors; the hydro-fluorination was performed in three sets of horizontal screw reactors or in a two-stage fluidized bed hydro-fluorinator. Working conditions in C-410 and C-420 were hot and loud; surface areas were coated with yellowcake, green salt, black oxide, and airborne uranium dust. High radiation areas existed near the fluorination towers and ash receivers. Respirators were specified for most work activities, but compliance was inconsistent. The feed plant was shut down in 1977.

Major Facilities at PGDP

- *C-331, C-333, C-335, and C-337 – Gaseous Diffusion Process Buildings*
- *C-410/420 – UF_6 Feed Plant*
- *C-300 – Central Control Building*
- *C-310 – Purge and Product Withdrawal*
- *C-315 – Surge and Waste Building*
- *C-340 – Metals Plant*
- *C-400 – Cleaning Building*

The main process buildings at PGDP (C-331, C-333, C-335, and C-337) contain the "cascades," which are a series of compressor and converter stages and supporting equipment arranged in cells and units that progressively enrich the UF_6 feed. Enrichment occurs as the UF_6 passes through barriers in the converters allowing isotopes of lower molecular weight to pass through. The series of converters results in two streams, or cascades, of UF_6: one of progressively higher-percentage uranium-235 that moves to the product withdrawal station in C-310, and one of progressively lower-percentage uranium-238 that moves toward the tails withdrawal station in C-315. Both the enriched product and the depleted tails are fed into cylinders and allowed to cool until solid, with the product shipped to Portsmouth and the depleted material either re-fed to the cascade or stored on site. The process building work areas were hot, but clean, except during maintenance or modification activities that required system entry. The process buildings were also the source of several major explosions, fires, and UF_6 releases and frequent smaller releases during connection and disconnection of sample bottles and feed and product cylinders. Generally, personal protective equipment (PPE) was only specified for maintenance or non-routine work activities.

In 1957, the presence of neptunium-237 and technetium-99 at PGDP was documented, and between 1959 and 1966 numerous studies related to the behavior, health effects, and controls for these elements were conducted by the Paducah Health Physics and Hygiene Department and the AEC. The percentage of transuranics, such as neptunium and plutonium, and fission products, such as technetium, in the reactor tails material was very small, estimated at approximately 0.2 parts per million (ppm) neptunium, 4 parts per billion plutonium, and 7 ppm technetium. However, these elements are much more hazardous than natural uranium and were concentrated by the cascade at certain specific locations, presenting increased hazards to certain workers. Neptunium has a specific activity up to 2,000 times greater than an equivalent amount of uranium, depending on the level of enrichment. Plutonium is significantly more radioactive than neptunium, but constituted a lesser hazard because it was present in much lower concentrations. Both plutonium and neptunium are significant radiation hazards if inhaled or ingested. Technetium is primarily a beta emitter with a higher specific activity than uranium, and is highly mobile in groundwater.

Approximately 25 percent of the neptunium in the feed material remained in the feed plant as dust or ash. Approximately 50 percent remained in cylinder heels after feeding, and approximately 25 percent was vaporized in the cascade, plating out toward the upper end of the cascade. Technetium tended to migrate to the top of the cascade, and much was drained off into the product or vented to the atmosphere. In 1958, a neptunium recovery process was initiated in C-400 to recover neptunium from the fluorination ash and cylinder heels for classified uses. In response to a demand for technetium for use at Oak Ridge, a program to recover technetium from the cylinder wash water and raffinate (e.g., solvents) from neptunium recovery operations began in April 1960. Due to the concentrated quantities of these materials, the recovery operations presented additional radiation protection problems requiring special protective measures. Air samples collected from areas contaminated with neptunium indicate the potential for high radiation doses to workers in these areas (e.g., reports of continuous sampling for February and March 1959 indicated an average of 10 and 27 dpm per m^3 respectively in the neptunium recovery area in C-710). In September 1961, magnesium fluoride pellet traps were installed in the feed plant to capture neptunium and technetium; in January 1963, similar traps were installed at the C-310 product withdrawal stations. By March 1962, neptunium recovery operations had ended, and in June 1963, technetium recovery operations also ceased. A different technetium recovery process was initiated in the mid-1970s to remove technetium from aqueous waste streams for the purpose of environmental protection.

Aerial View of PGDP Circa 1952

Before the mid-1970s, a complex uranium recovery process was operated in C-400 for separating uranium from waste and scrap materials, concentrating it, and converting it to an oxide. The uranium recovery system was not leak-tight, and leaks were common. However, steps were taken to control operators' exposure to process materials. Routine surveys were conducted to monitor the concentration of radioactivity on surfaces and in the air in C-400, and the health physics staff recommended changes in work practices based on the results of these surveys. In the mid-1970s, the solvent extraction process for uranium recovery was replaced with a simpler precipitation and filtration process. The filtrate, containing low concentrations of radionuclides, was discharged to the environment via the C-400 drains. Sludges and filter cake were processed at PGDP for uranium recovery or sent to Fernald for recovery.

From December 1956 through December 1962 and from January 1968 through October 1973, PGDP produced UF_4 and uranium metal in C-340 for weapons uses. The uranium metal production process involved reducing UF_6 (normally from the tails cylinder) to UF_4 by combining it with hydrogen in a heated tower. The UF_4 was mixed with magnesium and fed into lined firing reduction vessels (commonly referred to as "bombs"), placed in furnaces, and heated until it fired into a metal ingot, called a "derby." The derbies were removed from the bomb, cleaned, cut, and shipped to Oak Ridge. This process created a dusty environment in the metals plant with airborne UF_4 and magnesium powders, uranium metal oxides, radionuclide uranium daughter products, and magnesium fluoride dusts. The production of UF_4 continued until 1977, primarily to provide HF for feed operations. Working conditions were dirty, with airborne uranium and HF leaks. The use of army assault masks or respirators was specified for many metals plant activities, although workers did not always use them. The metals plant was responsible for much of the fluoride released to the environment at PGDP.

During the 1950s and 1960s, in order to retain certain skills and to maintain local employment levels after initial construction, a variety of non-enrichment work for other Federal agencies was performed. These activities included manufacturing missile components, superconducting electromagnets, and fuel shipping casks. In addition, until 1985, disassembly of weapons components and recovery of metals were performed at PGDP. While the work involved limited amounts of hazardous materials (e.g., lead), the primary exposure risk to workers on these projects was presented by normal Plant work activities in adjacent areas of the buildings. Nickel and aluminum recovery was performed in three smelters in C-746A; gold recovery occurred principally in the C-746A disassembly room and in C-400. Primary hazards in smelting operations were heat, working with molten metals, noxious fumes, and some potential for airborne radioactive contaminants.

2.3 Maintenance and Modifications

Much of the exposure to radioactive and hazardous materials at the PGDP resulted from system maintenance and improvement activities. The amount and complexity of equipment in continuous operation at high speeds, temperatures, and pressures resulted in frequent intrusions into piping systems to repair valves, compressors, motors, feed pulverizers and conveyors, and supporting piping and components. Opening of systems and components exposed residual UF_6 to moisture in the air, forming caustic HF gas and depositing uranium fluoride (UO_2F_2) around the immediate area. Changing of dust bag collection filters in process buildings and C-340, C-400, C-410, and C-420 could have exposed maintenance mechanics to concentrated inhalation and contamination hazards.

Several formal cascade improvement programs (CIPs) and cascade uprating programs (CUPs) involving replacement of major components to increase diffusion process reliability, capacity, and efficiency started as early as 1954. The second major CIP/CUP started in March 1973 and continued for eight years. This CIP/CUP process involved cell by cell removal of compressors and converters, process piping, and support system components while the remainder of the cascades remained in operation. After removal, compressors and converters were taken to C-400 for disassembly, cleaning, and decontamination and then to C-720, where they were modified and reassembled prior to reinstallation. In addition to releases of UF_6, these disassembly activities exposed maintenance workers to transuranics and fission products adhering to surfaces inside the system and to trichloroethene (TCE) during degreasing and decontamination. Workers could have received significant radiation exposures by inhaling neptunium-237 dust. At the completion of the CIP/CUP activities, converter and compressor disassembly remained a routine operation.

Between March and May of 1977, C-340 underwent a slow and deliberate shutdown for an indefinite period. During the shutdown period, which lasted until the mid-1980s, Building C-340 was used as a valve rebuilding shop and routine maintenance facility.

2.4 Unusual Occurrences and Accidents

During its first 40 years of operation, PGDP experienced numerous operational upsets, releases, exposures, and other accidents. Documentation, investigation, and reporting of these unusual events were very inconsistent and infrequent until the initiation of DOE's formal occurrence reporting systems in the late 1980s. One of the most frequent and notable unusual events was the release of UF_6 gas into work areas or the environment. The releases ranged from very small amounts, commonly referred to as "puffs," to significant amounts that resulted in HF burns, and uranium intakes requiring bioassay or medical attention for dozens of workers. The sources of these releases included the process system during system upgrade work, equipment failures, and maintenance activities; cylinder connection and disconnection activities at feed and withdrawal stations; and process equipment disassembly during shop maintenance activities in C-400 and C-720.

Several evaluation reports on UF_6 releases and their effects, as well as other site documents, identified approximately 50 UF_6 releases, each in excess of 10 pounds of uranium. However, reviews of health physics reports and the site quarterly progress reports from the early 1960s revealed references to many hundreds of releases of varying sizes (described often only as minor, large, or major). These reports identified many employees who were exposed from these releases and required medical examinations and bioassay. Burns and respiratory tract bleeding from exposures to or inhalation of HF were frequent occurrences. Many health physics reports indicated that these releases were not documented in operations shift logs and were often not addressed in the Plant's quarterly progress reports to the AEC, which was the regulatory agency at that time.

At least 15 events were identified in the first ten years of Plant operation that each released a minimum of 100 pounds of uranium, with a 1960 event releasing approximately 6,800 pounds and a 1962 event releasing approximately 3,400 pounds. As better equipment was installed and major system upgrade work ended, operational practices improved and the number and quantity of UF_6 releases decreased significantly. In the 1980s, reported releases were on the order of one to five per month and were measured in grams instead of pounds. The number of persons placed on recall for bioassay decreased from 30 or more per month in the 1950s to one to six per year in the 1980s.

C-337 Fire and Explosion - December 1962

Other significant Plant events included a major fire in Building C-310 in 1956, overexposure of two maintenance mechanics to beta radiation, and an explosion and fire in C-315 in 1978. Major releases affecting groundwater included a spill of 17,000 gallons of diesel oil migrating as far as 2 miles from the site boundary via surface water and the identification of significant volumes of TCE leakage from C-400 to the site sewer system, discovered in June 1986. Three fatalities were reported as a result of Plant events: an explosion and fire in C-340 in 1962, electrocution of an electrical maintenance trainee in 1977, and the suffocation of an operator in the collapse of a coal bridge at the steam plant in the 1970s. In addition, in June 1958, a release of HF severely burned a worker who did not return to work.

2.5 Industrial Hygiene and Radiation Protection

Programs for industrial hygiene and radiation protection were in existence from the beginning of Plant operation. Initial Plant training classes included theory and protective actions for working with radioactive and hazardous materials. There were policies and procedures that addressed the radiological protection of workers. PPE was provided and available to workers and in work areas where hazards were deemed greatest and protection was deemed necessary. The amount of formal training given to employees diminished after Plant startup, and much of the knowledge concerning both operations and hazard communication and controls resulted from on-the-job training of new workers by more experienced personnel and by supervisors. Starting in the early 1960s, job hazard analyses (JHAs) were prepared for most work activities and addressed many safety hazards, but not all JHAs adequately addressed radiation protection. Safety committees and regularly scheduled safety meetings, which included radiological subjects, were important elements of the process of hazard communication.

Non-radiation hazards, such as industrial and chemical exposures (primarily HF), were evaluated and addressed throughout the history of the Plant. The evolution of awareness and the application of protection and controls for significant hazards, such as asbestos and polychlorinated biphenyls (PCBs), essentially paralleled that of the regulatory bodies and general industry. Air monitoring of hazardous job sites existed from Plant startup, and health physics personnel monitored air and surface contamination in work areas and recommended additional or modifications to engineering controls or PPE, if deemed necessary. As early as 1952, Plant health physics personnel were aware of the potential hazards of personnel contamination and instituted measures such as monitoring work areas, providing company clothing, and providing frisking devices for workers to monitor themselves before eating or leaving work. However, survey records from the early 1950s indicated that few workers performed self-monitoring.

Identification of asbestos and PCB hazards did not emerge until the 1970s or later. During the fourth quarter of 1973, some of the first air samples for asbestos were taken and sent to Oak Ridge National Laboratory (ORNL) for analysis; however, no formal asbestos program existed until 1987. During this period, OSHA adopted 14 carcinogen standards. In 1975, preparations were under way for a two-year program to provide formal respiratory training on a sitewide basis. There was less concern over worker exposure to PCBs through absorption, and many workers wore PCB-contaminated clothing. Some workers considered PCBs to be an effective remedy for dry skin.

The health physics staff provided exposure monitoring services, recommended training and protective measures for supervisors, maintained exposure and radiation measurement records, administered a bioassay program, investigated air samples and personnel exposures that were outside of specifications, studied Plant hazards and needed controls, and performed Plant environmental monitoring. However, the size of the Health Physics Section (i.e., two to six people during the first 37 years of operation) limited the amount and effectiveness of surveillance and monitoring of hazardous conditions and activities for the approximately 1,200 to 2,500 people in numerous and diverse work environments. While line supervision had always been responsible for implementing recommended controls and protective measures, supervisory oversight and worker implementation of PPE and related measures were inconsistent. Non-compliant PPE use by workers can in part be attributed to the pressures to maintain normal process operations, a lack of knowledge and understanding of the risks involved and why the protection was needed, and the physical discomfort and vision impairment associated with wearing PPE, such as respirators, in hot, dirty environments.

Safety Equipment

Most radiological work controls, including time limits on worker exposures to uranium, were based on the assumptions that the primary risks for uranium exposure were chemical, not radiological, and that uranium was soluble and would be eliminated by the body quickly through the kidneys. Thus, inhalation protection was encouraged, and bioassay urinalysis was employed from Plant startup to monitor intakes by workers who might be exposed to uranium or fluoride materials. However, the solubility assumption may not have been appropriate for some Plant areas, such as the metals plant and grinding and welding operations, where small particle sizes and relatively insoluble uranium compounds were present.

Limitations were established for uranium and fluoride levels and excretion rates, and personnel were removed from work areas with potential exposure until concentrations returned to acceptable levels. In 1968, in vivo radiation monitoring by lung counting was initiated, first by sending workers to Fernald or to Oak Ridge and later using a mobile counter periodically sent to PGDP from Oak Ridge. The intent of in vivo counting was to determine the activity of radionuclides trapped inside the body; for uranium, insoluble forms concentrate in the lungs and remain there for a relatively long time. Urinalysis would not detect intakes of insoluble uranium reliably and at sufficient sensitivity. However, lung-counting methods are not particularly sensitive and are suitable only for assessing relatively large intakes retrospectively. In vivo monitoring was performed on a sampling basis and, in the early years, typically relied on volunteers from work areas subject to uranium exposure. Film badges were used from the beginning of Plant operation to monitor personnel exposures to beta and gamma radiation, although prior to 1960, only selected workers were included in the film badge service based on their work activities.

In the mid- to late 1970s, health physics surveys of work practices, continuous airborne activity monitor analysis, and contamination surveys were routinely documented. Health physics personnel were aware of the presence of and hazards associated with neptunium-237, plutonium-239, and technetium-99, and actively encouraged proper respirator use, identifying instances of improper respirator use and recommending other changes to improve ventilation and minimize exposures. The sophistication and rigor of health physics surveys improved during the late 1970s; uranium, uranium daughter products, neptunium-237, plutonium-239, thorium-230, and technetium-99 were monitored, reported, and discussed with personnel. In the mid-1980s, the NRC and DOE were promulgating more stringent regulations for radiological control, and practices related to respiratory protection, contamination control, and personnel monitoring improved considerably.

2.6 Waste and Material Management

Over the years, solid wastes were disposed of in various locations including two landfills, four scrap yards, and three radioactive materials disposal sites. In addition, there were a number of smaller holding areas and special disposal sites. A burn pit in the northwest corner of the site was used for combustible waste until 1967. The landfill used for early construction rubble north of the Plant continued in operation as the Plant came on line, and another landfill outside the fence southwest of the Plant (known as the C-746 K Landfill) was created for steam plant ash disposal and evolved into a general landfill. Although there were some early specifications limiting placement of radioactive material in the landfills, there is no record of sampling to demonstrate compliance. Further, since records indicate that floor sweepings were disposed of in the landfills and spills of green salt and yellowcake were routine in several areas of the Plant, it is clear that radioactive materials were improperly sent to the sanitary landfills. In addition, waste materials (including radioactively contaminated materials) were disposed of in various areas outside the Plant boundary in what is now the Kentucky Wildlife Area. These areas are accessible to the public for recreational use. Unauthorized salvaging of scrap materials also occurred.

Some of the materials disposed of outside the Plant boundary have been identified as radioactive by subsequent site surveys or investigations carried out under the Federal Facility Agreement and by this investigation team. Scrap metals from C-340, the cascades, the feed plant, and the C-720 maintenance shop went to C-746F (classified burial), C-746E (contaminated material yard), C-746C (clean materials), or unclassified burial yards all within the security fence. From the beginning of Plant operations, efforts were made to control the spread of contamination and to separate contaminated materials from other waste. However, records and interviews indicated that compliance was inconsistent and monitoring minimal. Pyrophoric uranium metal shavings were disposed of in the C-749 burial ground from 1957 to 1977. In the 1950s, uranium powder scrap from C-340 was dumped into onsite pits. The primary radioactive waste disposal site was the original C-400 holding pond, which was converted into a solid waste disposal area in 1957. By 1977, over 6 million pounds of uranium had been put into drums and placed in this disposal area.

PGDP had no integrated waste management program until the early 1980s. Before then, waste disposal was performed by each organization performing work in conjunction with the Maintenance Department, which operated several disposal sites. When requested by the operating departments, limited guidance was provided by the site safety and health organization.

In 1978, the site Environmental Control Department conducted a study of PGDP waste management practices. The report recommended better management of solid waste, closure of miscellaneous burial areas, improved management of existing facilities, provision of additional space for facilities, and construction of facilities for recovery and reduction of waste. The report stated that the passage of the Resource Conservation and Recovery Act (RCRA) in 1976 required Federal facilities to comply with all state solid waste regulations and that the Plant "is only partially meeting both present and planned regulations." In part, this study led to the creation of the Material Terminal Management (MTM) Department within the Maintenance organization. The MTM Department implemented the integrated waste management program by gaining control of waste management facilities and developing waste management procedures for the Plant.

The 1978 study and the formation of the MTM Department also impacted the disposal of radioactive waste on site. In 1978 and 1979, the amount of radioactive waste disposed of on site was 330,690 pounds annually, but this declined significantly to 18,000 pounds per year in the 1980s. An overriding assumption regarding the stability of the radioactive disposal sites was that the underlying clay layer would prevent contamination from leaching into the groundwater and travelling off site.

In the early 1980s, the MTM Department began addressing hazardous waste disposal practices by working with waste generators to ensure that waste streams would be in compliance with RCRA requirements and by implementing standard practice procedures for waste management. Concurrently, the MTM and the Environmental Control Departments worked with regulators to obtain permits for storage, treatment, and disposal facilities, including the C-400 gold dissolver precipitation system and C-410 neutralization pit. Legacy hazardous waste was brought to several locations, including the C-733 Hazardous Waste Storage Area, the C-746R Waste Solvent Storage Area, and the C-746Q Hazardous Waste Storage Area. However, the absence of sufficient characterization to ensure long-term storage and compliance with disposal acceptance criteria has led to existing hazardous waste storage problems and the need for significant recharacterization.

PCBs, which were in widespread use by the Plant throughout its early history, were not considered a hazard nationwide until the early 1980s. In 1980, the newly formed MTM Department performed the first sitewide PCB inventory in response to new Toxic Substances Control Act (TSCA) regulations on PCBs. By 1982, a PCB program was established that addressed PCBs as an environmental contaminant and a regulated waste.

Based on site records, there was a clear understanding in the 1950s that materials contaminated above certain limits could not be released to the public. Procedures were used to govern the handling of scrap materials, which were generally categorized into one of four groups: classified scrap, unclassified clean scrap, unclassified contaminated scrap, and unclassified nonmetal scrap. However, there was a concern in the mid-1970s that the contaminated items were being released to public parties as part of equipment and scrap sales. In mid-1975 a Scrap Handling Committee was established to evaluate onsite solid waste disposal problems. The source of these problems included the ongoing upgrade program, lack of awareness of the proper procedures – especially among new workers and supervisors – and an increase in the number of entities hauling waste to the scrap yards. The Scrap Handling Committee also examined the effectiveness of equipment and scrap sales to the public, and despite recommendations for improvements, continued problems were evident in 1977. The extent to which proper procedures were not followed, combined with the small number of health physics personnel, suggests that materials exceeding proper radiological limits were likely released off site until the late 1980s.

2.7 Air and Water Emissions

Radioactive air emissions began with startup operations in 1952 and have continued to present. Air emissions from the site were released from process stacks, diffuse and fugitive emission sources, accidental releases, and a limited number of planned releases. No evidence of measurements or monitoring of stack emissions was found prior to 1975. From 1959 to 1974, the air emission reports consisted of ambient air monitoring. Starting in mid-1960, continuous ambient air samples were taken at four locations at the perimeter fence and were analyzed for alpha and beta contamination to provide input for annual reports on ambient air concentrations. In 1961, four additional ambient continuous air samplers were installed one mile outside the perimeter fence, although actual stack monitoring of emissions did not occur until the mid-1970s.

From 1975 through 1990, annual discharges to the atmosphere based on stack measurements were reported in annual emission reports. It has been estimated that from 1952 to 1983, 60,000 kg of uranium were released to the atmosphere, 75 percent of this prior to 1965 and most from C-410 and C-340. A number of accidental releases of UF_6 occurred (perhaps as many as 15), during which more than 50 pounds of UF_6 were released. Dust and fugitive emissions were generally not calculated for the site from 1952 to 1990.

Fluorine emissions to the atmosphere also commenced with startup operations in 1952 and have continued to the present. These emissions were from process stacks, diffuse and fugitive emission sources, accidental releases, and a limited number of planned releases. During the period from 1959 to 1990, the air emission reports consisted of ambient air monitoring results for fluorides. Starting in mid-1960, continuous ambient gaseous air samples were taken at four locations at the perimeter fence and were analyzed for gaseous fluorides to provide input for annual reports on ambient air concentrations. Only limited information could be found for stack emissions of fluoride prior to 1986. The first environmental reporting of stack emissions of fluorine that was found addressed 1986 emissions. For the period 1986 through 1990, discharges to the atmosphere based on stack measurements were reported in annual emission reports.

Construction of the PGDP incorporated systems and strategies for disposing of liquid effluents from production and support operations. Liquid effluents were released in a number of ways, including via the

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sanitary sewage and storm water drainage systems. The C-615 sewage treatment plant was used from the beginning to treat sanitary and sink wastes from production buildings. Other effluents were discarded either in batches or through continuous feed into ditches, ponds, and streams, with subsequent flow into the Big and Little Bayou Creeks, ultimately reaching the Ohio River.

Liquid effluent discharge limits for radionuclides have always been controlled under the AEC and ERDA regulations and later DOE orders as maximum permissible concentrations (MPCs) or radiation concentration guides (RCGs) in water. A review of historical correspondence identified instances where specific decisions were made to discharge waste materials containing uranium, transuranics, and fission products directly to local ditches.

Federal and Commonwealth of Kentucky requirements on chemical discharges from the Plant did not exist during the early years of operations, and the Plant discharged significant amounts of hazardous chemicals, such as TCE and chromium. One of the major components of liquid process waste during early Plant operations was recirculating cooling tower blowdown water—approximately 500,000 gallons per day, with a 20 ppm concentration of chromium, was pumped to the Little Bayou Creek. As a result, there was a time when parts of the Little Bayou were dead and colored yellow from the chromium.

In the early 1970s, the Clean Water Act established the National Pollutant Discharge Elimination System (NPDES), which administered effluent limitations and water quality requirements for chemical releases. A total of 18 outfalls were permitted at the site. In response to changing expectations for environmental protection, in 1977 the C-616 Wastewater Treatment Plant came on line. Major liquid effluent streams that feed into the North-South Diversion Ditch were then routed by a lift station to this facility, resulting in significantly better water quality in local streams.

The most significant liquid effluent discharge source at the site was from the C-400 decontamination building. Wastes from this source included TCE from degreasing operations, contaminated liquids from cleaning operations, and various contaminated raffinate solutions from uranium, neptunium, and technetium recovery operations. Essentially all isotopes at the site were present in various portions of this facility and in its liquid waste streams, including uranium, neptunium, plutonium, thorium, and technetium.

In 1988, concerns over residential water quality led to sampling of residential wells north of the Plant.

TCE, an industrial degreaser, and technetium-99, a radionuclide fission product from nuclear fuel, were discovered in the wells. This discovery prompted the government to provide municipal water free of charge to all residences and businesses in an area bounded by the Ohio River to the north, by the DOE property to the south, by Metropolis Lake Road to the east, and by Bethel Church Road to the west. Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), DOE and the EPA developed an Administrative Consent Order, effective November 23, 1988, that established a schedule to investigate and remediate offsite groundwater contamination. Phase I of the CERCLA review, conducted in 1989 and 1990, identified contaminants of concern and solid waste management units (SWMUs) that could have contributed to offsite contamination, outlined the physical characteristics of the SWMUs, and described the risk of offsite contamination. Phase II of the CERCLA review, conducted in 1990 and 1991, further assessed the risk of offsite contamination, characterized SWMUs that could have contributed to offsite contamination, and identified migration pathways for contaminants.

2.8 Key External Assessments

In April 1985, a DOE task force evaluated the adequacy of practices to support handling of radioactive contaminants in uranium recycle materials at the Oak Ridge Y-12 Plant, the Feed Materials Production Center (in Fernald, Ohio), and the RMI Company (in Ashtabula, Ohio), and examined past operations at the PGDP and the Portsmouth Oxide Conversion Facility. The task force concluded that an in-depth examination of PGDP handling and processing practices was warranted, that quantities of recycle materials with undetermined levels of contaminants were present at PGDP, and that PGDP was periodically receiving commercially-produced UF_6 containing trace levels of transuranic elements. This study recommended that PGDP line management assess worker exposures to transuranic elements and fission products from processing of recycled materials and recommend a feasible method for disposing of uranium recycle material.

An overall concern regarding ES&H conditions at all DOE sites led then-Secretary of Energy Watkins to establish the Tiger Team program and to conduct a Tiger Team assessment of PGDP in June and July 1990. The assessment concluded that ceasing PGDP operations was not warranted, that compliance issues were known by those Federal and State agencies that issue permits, and that the following ES&H and management issues required prompt attention: (1) environmental monitoring and evaluation programs were not being effectively implemented due to a lack of technical direction, formal procedures, and a coordinated quality assurance program; (2) formal procedures for implementing environmental protection activities were lacking, and quality assurance programs had not been implemented for many environmental activities; (3) compliance with DOE orders and mandatory standards for worker safety and health was deficient, as was the system for managing administrative control documents; (4) training and certification programs did not meet site needs; (5) instrument calibration practices did not always meet minimum standards; (6) there was no long-range plan for safe storage of UF_6 cylinders; (7) no integrated sitewide management system was available to track and correct identified deficiencies; (8) DOE was not effectively performing oversight to ensure that ES&H initiatives were being implemented; and (9) the site contractor did not have a corporate strategic plan to accomplish DOE's ES&H objectives.

These issues became the framework for the site's ES&H activities for much of the decade of the 1990s. The site's effectiveness in addressing these concerns, the current ES&H posture of the site, and the transition of the site's uranium enrichment operations to a privatized enterprise (USEC) are documented in the Office of Oversight's report from the first phase of this investigation (*Phase I Independent Investigation of the Paducah Gaseous Diffusion Plant: Environment, Safety, and Health Issues,* October 1999). A detailed discussion of historic hazards at PGDP; operational, maintenance, and environmental activities and practices; and the effectiveness of these practices in addressing historic hazards is provided in Sections 3 and 4 of this report.

SIGNIFICANT PADUCAH PLANT MILESTONES AND EVENTS – 1950 TO 1999

October 1950	*Paducah selected as site for new gaseous diffusion plant*
January 1951	*Construction begins*
July 1952	*First uranium received at Paducah*
September 1952	*Cascade Buildings C-331 and C-333 begin operation*
November 1952	*First product withdrawn*
April 1953	*C-400 cleaning building activated*
July 1953	*Use of reactor tails feed materials begins*
April/July 1954	*C-335 and C-337 cascades begin operation*
August 1954	*First Cascade Improvement Program/Cascade Uprating Program (CIP/CUP)*
August 1956	*C-420 expansion to feed plant completed*
November 1956	*Major fire in C-310 product withdrawal area*
December 1956	*C-340 UF_6 to UF_4 conversion process on stream*
January 1957	*C-340 uranium derby production started*
1957	*Presence of neptunium in reactor tails feed at PGDP known*
November 1958	*Neptunium recovery program begins*
April 1960	*Technetium recovery program begins*
June 1961	*First CIP/CUP completed*
September 1961	*Magnesium fluoride traps installed for neptunium and technetium*
March 1962	*Explosion and fire in C-340; one fatality*
December 1962	*Explosion and fire in C-337*
January 1963	*Technetium traps installed*
June 1963	*Technetium recovery ends*
April 1968	*Radiation overexposure to 2 maintenance workers*
March 1973	*Second CIP/CUP started*
October 1973	*C-340 uranium derby production discontinued*
January 1975	*NRC and ERDA assume regulatory responsibilities for AEC activities*
mid-1975	*Scrap Handling Committee formed*
February 1977	*Maintenance worker electrocuted in C-331*
May 1977	*Feed plants cease operation*
October 1977	*DOE assumes regulatory responsibilities from ERDA*
January 1978	*Explosion and fire in C-315*
1978	*Material Terminal Management function established*
September 1981	*Second CIP/CUP completed*
April 1984	*Martin Marietta replaces Union Carbide as site operating contractor*
February 1985	*DOE submits RCRA Part A permit*
June 1986	*Discovery of major leak of TCE to ground from C-400*
November 1988	*DOE and EPA sign Administrative Consent Order*
June/July 1990	*DOE conducts Tiger Team Assessment of Paducah*
August 1991	*DOE RCRA Part B Permit effective*
1992	*USEC established*
February 1992	*Toxicity Characteristic Characterization Procedure Federal Facility Compliance Agreement effective*
July 1993	*USEC leases enrichment production facilities from DOE, and Lockheed Martin Energy Systems becomes USEC operations and maintenance contractor*
July 1993	*Lockheed Martin Energy Systems becomes DOE management and operations contractor for environmental management*
May 1994	*PGDP placed on National Priorities List*
June 1995	*Martin Marietta becomes Lockheed Martin*
October 1995	*Site Treatment Plan effective*
November 1996	*NRC grants certificate of compliance for enrichment operations*
March 1997	*Regulatory oversight of enrichment transferred from DOE to NRC*
February 1998	*PGDP Federal Facility Agreement signed by EPA, Commonwealth, and DOE*
April 1998	*Bechtel-Jacobs awarded DOE management and integration contract*
May 1999	*USEC takes over direct operation of all enrichment activities*

3.0 Operational ES&H Practices

This section of the report focuses on the work activities and hazards encountered by workers at the Plant from 1952 through 1990. While not exhaustive, it is intended to provide specific information on the majority of the activities and chemical and radiological hazards encountered during normal operations and maintenance. It is structured in two parts. Section 3.1 discusses the general hazards, including industrial, chemical, and radiological hazards, present at the Plant and the programs in place to address those hazards. Section 3.2 discusses the specific activities performed by workers, emphasizing the specific hazards encountered during the course of those activities, and controls implemented to reduce the hazards to workers. Appendix B summarizes the principal hazardous activities, the controls used to mitigate the hazards, and their effectiveness.

In general, it was apparent from interviews and records that the AEC, its successor agencies, and the operating contractors understood the unique hazards associated with operating a gaseous diffusion plant. They identified a variety of controls, such as respirators, special clothing, and procedural requirements, to address those hazards. However, primarily due to the classified nature of much of the work, workers were not always made fully aware of the extent of those hazards. The contractors, from the outset, did not normally provide exposure data to workers unless specifically requested, nor did they inform workers that exposure data was available upon request. Consequently, workers believed they were not receiving any appreciable exposure. This led to a belief among workers that the identified controls were not really necessary. Foremen and supervisors did not emphasize the need for these controls, leading to an undisciplined application of controls such as self-monitoring, use of respirators, and showering before leaving the Plant.

Exposure to radiological and chemical hazards was more likely in certain areas of the Plant. Feed production operations in C-410 and C-420, neptunium and technetium recovery operations in C-410, cleaning operations in C-400, tails reduction to green salt and uranium metal in C-340, filter bag replacement, and repairs and modifications of compressors and converters were some of the more hazardous tasks. Records showed that high airborne concentrations of radioactive materials in these areas were common, and evidence suggests that worker exposure monitoring may not have been adequate in these areas. Full-time hourly employees (e.g., security, groundskeeping, and maintenance) performing tasks in a variety of buildings were considered transient workers and were generally not afforded the same level of protection as individuals dedicated to specific Plant areas whose exposures were more predictable. As a result, contamination protection may not have been adequate, and Plant-wide dose statistics may have been underreported.

Finally, although recent worker concerns have focused on radiological hazards, the chemical hazards faced by workers on a daily basis were significant. In certain areas, HF was probably continuously present. The number of workers recorded as reporting regularly to the medical facility for HF burns reflects this hazard. Even more workers were exposed on a regular basis to HF than reported to the medical facility.

3.1 Hazards and Controls

3.1.1 Hazards

- *Radiological Hazards*
- *Chemical Hazards*
- *Industrial Hazards*

The PGDP operations exposed workers to a wide variety of radiological, chemical, and industrial hazards. Some of these hazards and their health effects were known from the early years of the Plant's history. For example, most physical hazards, such as working on scaffolding and vehicle safety, were recognized early in the Plant's history and addressed through procedures, safety bulletins, safety committees, and JHAs. Many of the radiological hazards were also identified in the early years of the Plant. However, the health effects and hazard controls were often not effectively communicated to workers by line management, nor did line management or workers adequately implement the hazard controls. Some chemical hazards and their health effects, such as fluorides, carbon tetrachloride, and TCE, were recognized early in the Plant's history. However, the hazards of some substances in use at the Plant since startup, such as PCBs and asbestos, were not recognized until the 1970s, as was the case nationwide. This section summarizes the principal radiological, chemical, and industrial hazards to which workers at PGDP were exposed between 1952 and 1990.

Radiological Hazards

- *Uranium*
- *Uranium Daughters*
- *Transuranic Elements*
- *Fission Products*

Since the early 1950s it was known that the operation and maintenance of gaseous diffusion plants, metals production facilities, and auxiliary units involved processing large quantities of radioactive materials. Such materials included uranium, concentrations of uranium decay products, and concentrations of transuranics and fission products. From 1957 into the mid-1960s, numerous studies were performed on the radiological effects of neptunium, plutonium, technetium, and other fission products and transuranic elements on workers. The studies found low concentrations of impurities in the incoming reactor tails. However, these impurities tended to concentrate in certain areas and processes of the feed plant and the cascade. Twenty-five percent of the incoming neptunium was deposited in the ash, filters, and dust of the feed plant. Fifty percent remained in the cylinder heel or on the cylinder walls, and the remaining 25 percent was vaporized to the cascade and plated out primarily in the upper stages of the cascade. Ninety-nine percent of the plutonium was deposited in the ashes, filters, and dust of the feed plant. Approximately 0.9 percent remained in the cylinder heel or on the cylinder walls, and the remaining 0.1 percent was vaporized to the cascade and plated out primarily in the first stage of the cascade it encountered.

The policy in place at PGDP to protect personnel from the hazards inherent in the handling of radioactive materials from the outset was based on preventing personnel exposures from exceeding the Radiation Protection Guides (RPGs) established by the Federal Radiation Council, the provisions of AEC manual chapters (subsequently, ERDA and DOE orders), or those established by the National Committee on Radiation Protection and Measurement (NCRP). The AEC policies in place at the time further encouraged the maintenance of radiation doses as far below applicable standards as was practical. The appropriateness and application of these policies from 1952 to 1990, and the expectations that employees would adhere to guidelines, were key factors in how well PGDP identified and controlled hazards.

Uranium. Uranium is an element that naturally occurs in the earth and is mined for commercial purposes. Natural uranium is 99.3 percent uranium-238 and 0.7 percent uranium-235; uranium-235 is used as nuclear reactor fuel. Enriched uranium contains more uranium-235, and depleted uranium contains less U-235, than natural uranium. U-238 has a radioactive half-life (the period of time for material to decay to half of its initial radioactivity) of 4.47 billion years. Once in the body, uranium may concentrate in the kidneys and bones or lungs, depending on its solubility. As a heavy metal, uranium is toxic and can damage the kidney. At enrichments less than 10 percent (PGDP's maximum enrichment is less than 5 percent), for soluble compounds, uranium's chemical toxicity to the kidney predominates over its radiological hazards. For insoluble forms, radiation dose to the lung can be the predominant concern. The principal sources of internal uranium exposures at PGDP relate to the inhalation or ingestion of both soluble and insoluble compounds. During enrichment, UF_6 was used as a gas for processing, as a liquid for feeding and withdrawing, and as a solid for storing and transporting. When released as a gas, UF_6 hydrolyzes with moist air to produce HF (which can cause chemical burns and is an eye and respiratory irritant) and UO_2F_2. Additionally, other compounds of uranium, such as UF_4 and UO_3, were present in significant quantities in many PGDP processes.

Uranium Daughters. The beta radiation dose rate at the surface of uranium metal is typically 230 millirems per hour or less. However, when uranium is melted or separated by chemical or physical means, less-dense daughter products of uranium, primarily thorium-234 and protactinium-234m, can be concentrated. When the uranium is further processed, significant quantities of these daughter products can remain behind in the form of oxides or ash or on the surface of process vessels. Locations of daughter products at PGDP include: the feed plant fluorination towers (primarily from ash receivers and the sintered metal filter baths), in C-400 and C-720 from converter disassembly work, in C-400 at the cylinder wash facility, in C-310 and C-315 in cylinder heels (feed and withdrawal), in C-340 from shell and crucible cleaning, and in C-400 and C-710 in the neptunium and uranium recovery process raffinate. The beta radiation dose rate from these residual daughter products is much higher than that of the original uranium. In addition, these daughter products are loose and easily transferred by contact. Exposure to these daughter products as a result of transfer to clothing, tools, or other items is likely to result in unanticipated beta radiation doses to workers. Protactinium-234m emits a high-energy beta particle, which contributes most of the beta dose from the uranium-238 daughter products.

Transuranic Elements. Transuranic elements have atomic numbers greater than 92 (i.e., greater than uranium). They can be produced when U-238 absorbs neutrons as part of a nuclear reaction. Among the transuranic elements are neptunium and plutonium. Transuranics were introduced to PGDP when feed material from processed spent reactor fuel was received from the Hanford and Savannah River sites.

- Neptunium-237 – Neptunium-237 has a radioactive half-life of 2.14 million years and is far more hazardous than natural uranium. The specific radioactivity of neptunium-237 (7.01×10^{-4} Ci/g) is 2,000 times higher than the radioactivity of depleted uranium. Neptunium, at the low concentrations found in reactor tails feed material (about 0.1 gram of neptunium per ton of UO_3), was not a significant radiological hazard. At such levels, the controls applied to protect against uranium exposure provided ample protection from neptunium. However, neptunium tended to concentrate at certain points in the uranium conversion, enrichment, and recovery processes. The highest concentrations of neptunium were associated with neptunium recovery processes that operated intermittently at Paducah from 1958 until the late 1970s, in C-400 and C-710. Neptunium recovery was a classified program, and neptunium was referred to by the code name "Trace."

  Although neptunium had been present in PGDP feed materials since 1953, it was not detected at the Plant until 1957. The detection of neptunium was significant to the Paducah health physics staff. They knew that traditional uranium controls would not be sufficient for areas where neptunium would concentrate because of the quantity present combined with neptunium's relatively high specific radioactivity and radio-toxicity. The personnel exposure pathway of principal concern was the inhalation of particulate material contaminated with neptunium. Analysis of radiation dose due to inhalation required knowledge of particle size and solubility. A 1959 solubility analysis by ORNL found a sample of PGDP dust contaminated with neptunium to be insoluble in blood serum. A 1961 analysis of particle size determined the mass median particle size to be three microns. A value of 10 dpm/m^3 was selected as the airborne concentration of neptunium considered safe for continuous occupational exposure. This value was appropriate in that it was about the same as the MPC specified for soluble neptunium-237 by the 1959 edition of National Bureau of Standards (NBS) Handbook 69, and was only about five percent of the Handbook MPC for insoluble neptunium-237.

  In mid-1959, neptunium contamination was first discovered on a piece of cascade equipment. That year, four Plant personnel who worked with neptunium-237 solutions were sent to the In Vivo Radiation Monitoring Laboratory (IVRML). The whole body counts were negative. A 1960 memorandum between AEC, OR, and PGDP describes discussions with an AEC representative who visited the site and provides insights into neptunium exposure problems at PGDP. The memorandum notes a significant exposure potential to neptunium and states that there were "possibly 300 people at Paducah who should be checked out but they hesitate to proceed to intensive studies because of the union's use of this as an excuse for hazard pay." In 1962, 14 workers from various Plant locations, including those who were believed to have the greatest potential exposure to neptunium-237 and uranium, were sent to the IVRML. Whole body counts did not reveal neptunium-237 body burdens as significant as one-half the allowable body burden, and the urinalyses were inconclusive.

  Air in neptunium processing areas was continuously sampled and analyzed for radioactivity on a monthly basis. The sample results reviewed by the investigation team revealed that airborne radioactivity in neptunium processing areas was, at times, higher than the maximum permissible concentration for neptunium. For example, reports of continuous sampling for the months of February and March 1959 indicated an average of 10 and 27 dpm/m^3 respectively in the neptunium recovery area in C-710. Judging by today's dose models, workers exposed in these areas during these two months could have received significant radiation doses. The doses would not have been significant if the source has been uranium. Little is known about respirator use during maintenance and operation of the neptunium recovery system. Interviews with several workers assigned to other areas where neptunium hazards existed, and documented findings in these areas by the AEC, indicate that respirators were not consistently worn when they were needed. Further, a health physics inspection report documented that respirators were not worn during dismantling of the neptunium recovery system in 1974.

- Plutonium-239 – Plutonium is significantly more radioactive than neptunium, but constituted a lesser hazard at PGDP because it was present in much lower concentrations. Recent estimates indicate that only 328 grams of plutonium were present in approximately 89,000 metric tons of uranium fed into the PDGP cascade. Plutonium concentrated in the UF_6 feed production facility. Because it remained with the ash material, most was removed with the ash residues and particulate filter in the conversion of UF_4 to UF_6. Individuals who could have been exposed to plutonium at PGDP are most likely those who were exposed to dust while changing the particulate filter and emptying the ash collector. Other possible exposures to plutonium could have occurred in the feed cylinder wash area, the uranium recovery system raffinate, and the filter wash and reside waste packaging area. Workers in the cascades, product withdrawal, or tails withdrawal areas were essentially not exposed to plutonium.

  Plutonium-239 has a radioactive half-life of 24,065 years. The specific activity of plutonium is 6.22 x 10^{-2} Ci/g. Of particular importance for radiological safety considerations are the solubility, particle size, and surface area of plutonium compounds. These properties play an important part in the transportability of plutonium in the environment and in the body. Currently, all plutonium compounds, except the oxides, are assumed to be mostly soluble in the lung; the oxides are assumed to be mostly insoluble. Unfortunately, few data on particle size are available, and those that have been generated focus on the reactivity of the materials in the separation and conversion processes. Much of the data is reported as crystallite size, which relates to surface area and solubility but not necessarily to the way the particles would be dispersed in the air. Factors affecting plutonium's biological effects include its mode of entry into the body and its distribution in the body. Once plutonium reaches the bloodstream, it accumulates primarily in the liver and skeleton. Plutonium exposure may produce acute health effects (e.g., inhalation may lead to pulmonary edema, and ingestion may lead to damage to the walls of the gastrointestinal tract) or long-term effects, such as increased risk of cancer. Ingestion of about 0.5 gram of plutonium would be necessary to deliver an acutely lethal dose. The literature indicates that inhalation of about 20 milligrams of plutonium dust of optimal size would be necessary to cause death within roughly a month from pulmonary fibrosis or pulmonary edema. Inhalation of less than acutely lethal quantities of plutonium increases the probability of cancer. When plutonium is inhaled, the lungs are exposed to alpha-particle radiation, increasing the risk of lung cancer, and the plutonium is eventually carried to other organs, where the radiation can cause cell damage and increase the likelihood of biological effects.

Fission Products. Fission products are elements created when uranium-235 is split by neutrons as part of a nuclear reaction. They typically have atomic mass numbers in the range of 80 to 108 and 125 to 153. The predominant fission product at PGDP was technetium.

Technetium-99 has a radioactive half-life of 213,000 years and was received at PGDP in recycled feed from the Hanford and Savannah River Sites. Technetium passed through the PGDP cascade as a volatile compound of fluorine, depositing on internal surfaces of the cascade and contaminating the enriched uranium product. The AEC did not specify a limit for technetium in UF_6 feed but controlled the concentration of technetium indirectly to about 10 ppm by limiting gross beta due to fission products. Technetium is a weak beta emitter (0.29 MeV); the primary exposure pathways are dose to the skin due to skin contamination or internally due to ingestion or inhalation. Although technetium was not a significant radiological hazard during most PGDP operation and maintenance activities, it presented a more significant hazard when concentrated in recovery processes in C-400.

Chemical Hazards

- *Fluorine*
- *Trichloroethene*

- *Chlorodiphenyl*
- *Fungicides*

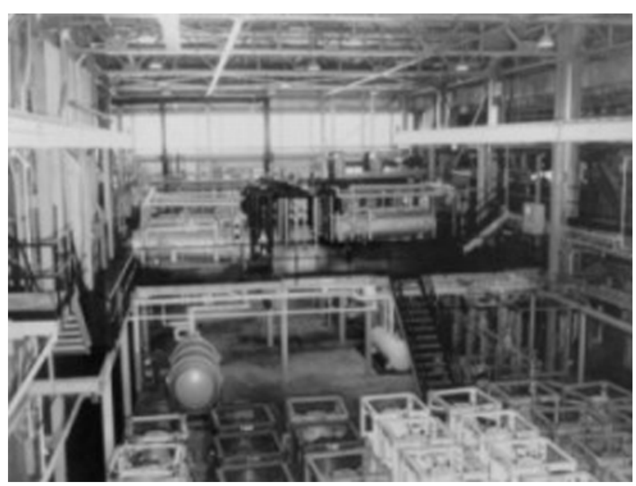
Many chemical hazards, other than fluorides, were not recognized nationwide until the early 1980s for two fundamental reasons. First, the hazards and health effects of some chemicals (e.g., PCBs) were not well known. In the 1960s, for example, there was limited knowledge about the hazards of many Plant chemicals, with a few exceptions such as fluorides, carbon tetrachloride, and TCE. More important, there were few regulations requiring that workers be informed of chemical hazards in the workplace. The issuance of the OSHA Hazard Communication Standard in the early 1980s was the single most important regulation affecting chemical hazard identification at the Paducah Plant. The Hazard Communication Standard required the identification of chemical hazards in the workplace, labeling of chemicals with their health hazards, documenting a chemical hazard program, training workers, and most importantly requiring manufacturers to develop and disseminate Material Safety Data Sheets to chemical purchasers. The implementation of the Hazard Communication Standard (procedure development, worker training, chemical inventorying, and labeling) was the most significant activity for the Paducah Industrial Hygiene Department during the early 1980s.

Although the Hazard Communication Standard was of significant importance in establishing chemical hazard identification and worker protection programs, there had been chemical standards, requirements, and some knowledge of the hazards of chemicals at the Paducah Plant since the early 1950s. For example, Plant Concentration Guides for some chemicals were evident in the 1950s. As early as 1956, industrial hygienists were evaluating the substitution of less-hazardous chemicals for a variety of work activities, such as substituting Samae (a cleaning solvent) for nitric acid, and TCE in lieu of carbon tetrachloride. In the 1960s, Paducah adopted the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs) for those chemicals that had established TLVs. The adverse health effects of carbon tetrachloride had been widely known since the 1920s. During the first quarter of 1960, industrial air sampling for chemicals was first documented in the Health Physics and Industrial Hygiene Quarterly Report. Chemicals reported were ammonia, hydrogen sulfide, mercury, nitrogen dioxide, phosgene, and TCE. Arsenic was present due to impurities in the feed material. Measured airborne chemical concentrations were compared to Maximum Airborne Concentration (MAC) Guides. Since 1960, however, the ACGIH TLVs for most of these chemicals have been lowered, some by as much as by a factor of 4 or more. As a result, some airborne chemical concentrations reported as acceptable in 1960 would be considered an overexposure by today's standards. For example, in 1960 a reported worker exposure to 60 ppm of TCE was well within the MAC Guide of 200 ppm. However, the TLV for TCE today is 50 ppm, and 60 ppm would be considered an overexposure. Similarly, in 1965, an exposure to TCE at concentrations of 150 ppm in C-600 was recorded as acceptable by comparison to the Plant Concentration Guide of 350 ppm.

Some offsite chemical hazards were identified as early as December 1957, when a program for monitoring gaseous fluorides at the Plant perimeter commenced. This program was an addition to the monitoring of fluorides in grass, which had begun some time earlier. Reporting of site boundary and offsite releases of fluorides continued through the 1960s and 1970s.

Fluorine. Fluorine is a pale-yellow to greenish gas with a pungent, irritating odor. Hydrogen fluoride or hydrofluoric acid (HF) is a colorless gas or fuming liquid with a strong, irritating odor. Exposure routes include inhalation, skin absorption (liquid), and skin and/or eye contact. Exposures can result in a variety of symptoms, ranging from irritation of mucous membranes to severe burns.

Fluorine and its compounds, such as HF, UF_4, and UF_6, were used throughout the Plant processes, particularly in C-340, C-410, C-420, and throughout the cascade process buildings. Fluorine and anhydrous HF were used in the fluorination of uranium dioxide. HF was a common byproduct when UF_6 was inadvertently released to work spaces and combined with moisture in the air. HF was also a byproduct of metal production.



Fluorine Plant

Fluoride hazards were identified early in the Plant's history. Most quarterly Health Physics and Hygiene reports from 1953 through 1972 routinely reported urine levels of uranium and fluorides in selected groups of workers. The third quarterly report for 1954 indicated that HF burns were a concern, but that long-term health effects were not known. After this period there is limited recorded evidence of worker exposures to fluorides until the 1980s, when there was a re-emergence of interest in HF exposures. During the first three decades of Plant operation, safety and health professionals were more concerned with uranium exposures than exposures to fluorides, since the latter were perceived as "repairable." For most of this period, fluoride levels, as measured in urine samples, remained constant at around 1 mg/L. Typically, one to four workers per quarter exceeded the Plant Concentration Guide of 4 mg/L and were placed on restricted duty. As late as 1971, overexposures to HF were being reported. Today, urine samples continue to provide a valuable indication of exposure to fluorides, but principally as a supplement to monitoring the air in a worker's breathing zone. During this period, exposure-monitoring practices shifted from monitoring workers after exposure to a contaminant to sampling air before or during exposures. The 4 mg/L Plant Concentration Guide adopted at Paducah (i.e., 1.3 mg/g to 8 mg/g creatinine) would appear to be conservative by comparison to today's standards. However, a number of variables (e.g., sampling frequency, exposure time, and analytical methods) make this comparison of marginal value.

Trichloroethene (TCE). TCE is a colorless liquid with a chloroform-like odor that is often used as an industrial degreaser. TCE is a mild irritant to the respiratory tract and the skin and is considered by some as a potential carcinogen, based on animal studies. Critical exposure pathways are inhalation, ingestion, and skin or eye contact. When humans are exposed, TCE concentrates in the respiratory system, heart, liver, kidneys, central nervous system, and skin.

During PGDP construction, all process piping was degreased presumably with TCE. Prior to startup of C-400, some of this work apparently occurred south and east of the Building C-333 and is suspected as being a TCE source of the Northeast plume. Since the commencement of operations, TCE was used throughout the Plant in varying quantities. The most significant use of TCE was in Building C-400, in which large components (valves and converter parts) were degreased in TCE vats, which were accessed through an overhead crane. Other components were cleaned and degreased in smaller vats of TCE in Building C-720. Significant amounts of TCE were used in the PGDP electrical switchyards. In addition, maintenance and operations workers routinely used smaller quantities of TCE throughout the Plant as a general-purpose cleaning agent. TCE releases to the surrounding area were evident throughout the history of the Plant, with elevated concentrations of TCE being recorded in outfalls as further discussed in Section 4.3. Investigating the contribution of TCE sources to groundwater contamination has been a major focus of the Administrative Consent Order and the Federal Facility Agreement.

Chlorodiphenyl or PCBs. PCBs are colorless to lightly colored, viscous liquids with a mild odor. They are generally used as a cooling medium in transformers and at PDGP in ventilation system gaskets as a fire retardant. The critical pathways of exposure are inhalation, ingestion, and absorption. When humans are exposed, PCBs concentrate in the skin, eyes, and liver.

During the mid-1970s, recognition of PCB hazards at PGDP emerged—about the same time as in commercial industries. OSHA also adopted 14 carcinogen standards that addressed PCBs as well as other hazardous materials. In 1975, preparations were under way for a two-year program to provide formal respiratory training on a sitewide basis. PCBs, which were in widespread use by the Plant throughout its early history, were not considered a hazard until the early 1980s. In 1980, the newly formed Waste Management Group performed the first Plant-wide PCB inventory in response to new TSCA regulations on PCBs. By 1982, a PCB program was in place to consider PCBs as an environmental contaminant and a regulated waste. However, there was little concern over worker exposure to PCBs through absorption, and many workers wore PCB-contaminated clothing. Some workers considered PCBs to be an effective remedy for dry skin.

Fungicides. Fungicides were occasionally used during the Plant's history as an organic material preservative. Fungicides (and pesticides) can enter the body through ingestion, inhalation, and absorption pathways, with skin absorption being a primary concern. Health effects can vary from minor headaches and nausea to debilitating conditions of the central nervous system.

Paducah's 14 cooling towers are protected from microbiological and chemical attack by a comprehensive program of water treatment, tower maintenance, and fungicide spraying. The towers are treated annually with fungicides, principally to protect wooden components from fungal attack and deterioration. In 1958, a variety of fungicide sprays containing zinc sulfate, arsenic acid, and potassium chromate were tested. In the early 1980s, a modified in-place fungicide treatment process was developed that was based on pentachlorophenol, a common wood preservative, fungicide, and algacide often used for treating cooling towers. The application of these fungicides usually requires PPE consisting of chemical suits and self-contained breathing apparatus and/or local ventilation. Pentachlorophenol, for example, is highly toxic and considered to be both a carcinogen and a possible teratogen (causes fetal malformations).

At PDGP, workers in air-supplied hoods and chemical suits performed fungicide-spraying operations, since the concentration of the fungicide in air often exceeded the regulatory value. Hazards and controls for the spraying operation were identified in JHAs. Air monitoring in the 1980s reportedly demonstrated that none of the spray team would inhale air containing fungicidal concentrations over the regulatory limits.

During team interviews, some former carpenters, having previously seen the fungicide spray team in their air-supplied neoprene suits, expressed concern that their carpentry work activities on and in the dry cooling towers could have resulted in an overexposure to fungicides. Carpentry work was performed without PPE. Although a JHA was developed in 1981 for cooling tower inspection, no hazard analysis was performed for carpentry work, nor was there a requirement for chemical protective clothing or air monitoring. Respirators were not required until the mid- to late 1980s. Although the carpenter's exposure to dust laden with fungicides may have been minimal, there was no evaluation of the residual effects of these fungicides and no basis for determining protective clothing requirements.

Industrial Hazards

- *Physical Hazards*
- *Dust, Noise, and Asbestos*
- *Beryllium*

Since the 1950s there has been a conscientious effort by line management to identify and quantify industrial worker hazards at the Paducah Plant, commensurate with the science and understanding of those hazards for that period in time. Retrospectively, this does not imply that with today's knowledge, today's health and safety professionals would perform the same activities or arrive at the same conclusions as the health and safety professionals in the 1950s concerning the identification and quantification of Plant hazards during that period. For example, asbestos has been a significant hazard at the Plant since construction. However, asbestos hazards were not recognized, and efforts to sample and quantify airborne levels of asbestos were not initiated at the Paducah Plant until the 1970s. An OSHA asbestos standard was published in 1971. Routine monitoring of asbestos did not occur until the 1980s. Similarly, some other industrial hazards (e.g., beryllium and PCBs) were not well recognized in industry during the early decades of the Plant's history. Throughout the decades, identification of a hazard often resulted in changes in PGDP facilities, processes, or procedures to reduce or eliminate the hazard.

Physical Hazards. Work activities at the Plant involved a wide variety of physical hazards, including electrical work, working at elevated heights, material handling, welding, vehicle operations, and machining of parts. The Paducah Plant Safety Department was issuing safety procedures, standards, bulletins, and manuals as early as mid-1953. These early publications focused on a variety of physical hazards and issues such as housekeeping, fall protection, floor markings, signs on safety showers, vehicle accidents, and fire protection.

Dust, Noise, and Asbestos. Some hazard identification activities at the Paducah Plant were state-of-the-art for their time. Quarterly Health Physics and Hygiene reports from the 1950s, for example, identify hazards associated with airborne chemical contaminants, dust, and noise. Research in establishing the efficiencies of new types of respirators was evident in the mid-1950s, although the practice of exposing human subjects to gaseous clouds of HF in order to quantify a respirator's efficiency would not be condoned today. During 1954 and 1955, dust hazards were investigated throughout the Plant. Equipment was borrowed from Oak Ridge to help quantify particle size distribution as an aid in selecting respiratory protection. During 1957, a Plant-wide noise exposure evaluation resulted in recommendations for hearing protection and noise-suppression modifications to the Plant. In 1967, a paper on the "Paducah Plant Hearing Conservation Program" was presented at the annual AEC conference.

Asbestos was not recognized as a hazard at Paducah until the 1970s or later. Asbestos had been widely used for construction, welding, and insulation since the early 1950s due to its resistance to heat, flames, and corrosive chemicals. Asbestos fibers are carried into the body as airborne particles, and these fibers can become embedded in the tissues of the lung and digestive system. Once the fibers become trapped in the lung's alveoli (air sacs), they cannot be removed. Years of exposure to asbestos causes a number of disabling and fatal diseases, including asbestosis, an emphysema–like condition; lung cancer; mesothelioma, a cancerous tumor that spreads rapidly in the cells of membranes covering the lungs and body organs; and gastrointestinal cancer, which is caused by ingesting asbestos-contaminated food. During the fourth quarter of 1973, some of the first air samples for asbestos were taken and sent to ORNL for analysis. The PGDP asbestos program began in 1986.

Beryllium. Beryllium is a silver-gray metallic element used as a pure metal, as beryllium-copper and other alloys, and as beryllium oxide. Beryllium is useful in weapons production due to its strength, light weight, relatively high melting point, and machinability. The severity of the health hazards that can result from even minimal contact with beryllium are only now beginning to be fully understood. Beryllium can enter the body through inhalation, skin absorption, skin wounds, and ingestion. The most serious health effects come from inhaling airborne insoluble particles that deposit in the lungs. Chronic beryllium disease, which occurs in one to six percent of exposed workers, has a latency period of up to 20 years and no known cure.

There is no clear evidence of beryllium machining at PGDP during this period. However, as part of the work for others program, machining or cleaning of beryllium-copper components may have been conducted in the 1960s; beryllium was one of the substances in industrial hygiene air samples during this period. For example, a 1968 internal memo indicated that a heat-treat furnace contaminated by beryllium at another AEC installation was cleaned in C-710 without personnel exposure. In general, there was no evidence of airborne beryllium or overexposures.

3.1.2 Programs and Controls

- *Hazard Identification and Analysis, and Safety Training Programs*
- *Hazard Communication Program*
- *External Exposure Monitoring Programs*
- *Bioassay – Urinalysis Programs*
- *Bioassay – In Vivo Radiation Monitoring*
- *Air Sampling*
- *Contamination Control*
- *Personal Protective Equipment*
- *Respiratory Protection*
- *Medical Programs*

Health and safety programs at PGDP were established at the commencement of Plant operations and continue to the present day. Health physics, industrial hygiene, and medical functions were integrated in the Health Physics and Hygiene Department for the first three decades of Plant history, and under the direction of the Plant Medical Director, this integrated several safety disciplines with a focus on worker health. From the commencement of operations until the Tiger Team evaluation in 1990, both health physics and industrial hygiene were minimally staffed, especially in comparison with the number of safety professionals that would be required today for the types of hazards and work activities present. The Health Physics Section from the commencement of operations until 1990 ranged in size from as few as two to six employees. The Industrial Hygiene Section typically consisted of one or two industrial hygienists and a technician. Furthermore, in the early decades, health and safety professionals had limited authority and resources to ensure that line management would implement recommended hazard controls. The primary responsibility for protecting personnel against hazards associated with radioactive materials was placed on line supervision to the same extent that they were responsible for operation and production.

During the first three decades, the Health Physics and Hygiene Department provided workers and line management with the following basic programs and services:

- Monitoring exposures to determine the effectiveness of the health physics program
- Auditing and maintaining records of exposures (radiological, noise, chemicals) and radiation data collected throughout the Plant
- Furnishing line supervisors with advice, information, and training aid on chemical, radiological, or uranium toxicity health hazards
- Assisting in investigations of personnel exposures
- Providing film badge services
- Maintaining the bioassay and respiratory protection program for both chemical and radiological exposures

- Performing chemical and radiological environmental monitoring for the Plant
- Recommending radiological and chemical Plant guidelines for controlling exposures
- Conducting air sampling for airborne chemicals and radioactive material.

C-400 Building

As early as the 1950s, PGDP set forth in policy and Plant procedures the expectations for the protection of personnel from the hazards inherent in handling radioactive materials. The policy states that "every effort is made to prevent personnel exposure from exceeding the Radiation Protection Guideline established by the Federal Radiation Council, the provisions of the AEC Manual Chapters" (subsequently ERDA and DOE), "or those established by the National Committee on Radiation Protection and Measurements; the maintenance of radiation doses as far below these standards as is practical is also encouraged."

The most significant safety and health programs implemented at the PGDP from the commencement of Plant operations until 1990 are summarized below.

Hazard Identification and Analysis, and Safety Training Programs

Several hazard identification and control activities that were initiated in the 1950s, such as safety procedures and safety committees, continued throughout the Plant's history. The Paducah Plant Safety Department, for example, was issuing safety procedures, standards, bulletins, and manuals as early as mid-1953. These early publications focused on a variety of physical hazards and issues such as housekeeping, fall protection, floor markings, signs on safety showers, vehicle accidents and fire protection. Safety Bulletin No. 4, for example, which was published in June 1953, provided instructions for testing scaffold planks.

The JHA process, which formally evolved in the early 1960s, became the dominant hazard identification process at Paducah and has retained its importance to the present. A precursor to the JHA process was a handbook developed by the Plant Safety Committee in 1959 entitled "Your Guide to Working Safely," which included a chapter on "Safe Practices and Job Methods." During the fourth quarter of 1965, a significant effort to revise the existing JHAs and prepare new JHAs was recorded in a quarterly Plant report. New employees in the late 1970s reported that their first work activity was to read several three-inch binders of JHAs to familiarize them with their work activities, the associated hazards, and the required controls. Industrial hygiene-related procedures on chemicals and respiratory protection, however, did not evolve until the 1980s.

Safety meetings also evolved in mid-1953 and have continued to the present to provide a mechanism for hazard identification, with an emphasis on worker involvement. For example, a safety bulletin was issued during the first quarter of May 1953 entitled "Suggestions for the Preparation and Conduct of Safety Meetings." In 1956, training conducted during safety meetings focused on "Toxic Effects of TCE." In 1957, workers were informed of the hazards of heat stress. One training vehicle that was popular in the 1950s and 1960s was the use or production of safety movies. One Paducah-generated movie on vehicle safety, entitled "Dancing Dolls," was submitted to the National Safety Council in 1958 for award consideration. During an Operations Department Safety Meeting in 1957, a program was initiated to display a large yellow flag each month in the area of the Plant that had the highest injury rate. In 1958, refresher training was provided to supervisors in "techniques for conducting more effective safety meetings." By 1971, safety meetings had become more formal, and all supervisors were required to attend. During the fourth quarter of 1972, a Four-Plant Industrial Hygiene Committee was appointed, with the initial meeting held at Y-12 on October 11, 1972.

Hazard Communication Program

From the outset, radiation and chemical hazards associated with PGDP activities and operations were known; this information was communicated to employees with varying effectiveness. Delays in initial Plant startup gave the workforce the opportunity for relatively extensive hazards training, as evidenced by classroom lecture material presented by the Health Physics Department to all operator and maintenance trainees during 1951 to 1953. During this period other Plant employees, including fire, guard, janitorial, warehouse, and property clerk personnel, received similar instruction, albeit in a condensed format. Paducah community emergency squad personnel also were provided training.

While the aforementioned delays in initiating operations in the early 1950s may have given supervisors more opportunity to ensure that hazards were effectively communicated to workers (relative to subsequent years), there is evidence suggesting that the early programs may not have been comprehensive or highly effective. For example, a review of grievances filed by union workers during the 1950s provides evidence that not all workers had a clear understanding of the need to wear anti-contamination clothing. Contributing to this situation was the discretionary application of Carbide's policy on anti-contamination clothing and a non-conservative approach to the provision of company clothes. Once Plant operations were under way, Carbide management sought ways to acquaint newly acquired personnel with known hazards without impacting production. An April 1958 letter from Carbide management advised all Plant supervisors that "radiation presents a hazard and…must be considered with the same degree of importance as any other hazardous condition." The letter continues by stating that "it is necessary to know the precautionary measures…to reduce the hazards [so that] no unsafe condition will exist."

Efforts to streamline and condense the classroom lectures of earlier years included a series of four one-hour lecture sessions presented by the Paducah Plant Physics Committee to PGDP employees in June and July 1958. The subject material included radiation theory, sources of radiation and methods of detection, non-penetrating radiation, and penetrating radiation. This lecture material was subsequently formalized in the 1959 *Health Physics Training Manual* and was used later to make a movie entitled *Uranium and Us,* which was shown to all PGDP employees for orientation in lieu of extensive classroom training.

The orientation training provided to workers in the late 1950s and 1960s addressed basic atomic theory, protection of personnel from radiation, and critical reaction. Once on the job, the worker was responsible for following more detailed instructions, such as those contained in the *Operator Training Manual* and specific *Standard Practice Procedures* (SPPs). Basic radioactive material control SPPs were identified in the Paducah Plant health physics program. Mentoring (that is, on-the-job training from experienced workers and supervisors), safety meetings, suggestion programs, and emergency squad training supplemented worker orientation training.

The communication of Plant hazard information to the initial operating workforce in the early to mid-1950s and PGDP workers in subsequent years was not always rigorous or consistent. For example, operations and maintenance personnel during the early 1950s received approximately ten hours of formal health physics training, followed by a written examination. This training was tailored to individuals by job classification (for example, maintenance, operations, and instrumentation and electrical) and by Plant location (for example, the feed plant). By the mid-1950s, after initial Plant startup, comprehensive safety meetings conducted by the Health Physics and Hygiene Department began to supplant the formal classroom training of the early years, although the meeting agenda was similar, addressing radiation, chemical, and other Plant hazards.

Throughout the 1960s, there is evidence that classroom training continued to be provided to employees, albeit still tailored to specific job activities. The level of rigor, however, appears to have declined substantially, since fewer than half as many hours were devoted to hazard communication as in the early 1950s. By the end of the 1960s, there is evidence that Carbide managers were addressing retraining of the workforce to review Plant hazards.

Increased production in response to demand, and the corresponding expansion of the workforce from 1,700 in 1954 to 2,500 by 1978, decreased the time and resources available for training. Accordingly, on-the-job training began to emerge as a principal means by which workers were advised and kept apprised of Plant hazards. Review of formal programs to communicate hazards in the 1970s suggests further degradation in the level of attention to this subject. For example, a ten-week program scheduled to begin on April 7, 1970, to "acquaint technical and supervisory employees with the…Paducah Plant" devoted only 2 1/2 hours to health physics, safety, job hazard analysis, and accident prevention. Additional evidence suggests that this trend may have continued, because even fewer hours were spent on communicating Plant hazards in a 1972 supervisory training and orientation program.

Documentation and records attesting to hazard communication activities at PGDP during the 1980s were not discovered during this investigation. Recollections of past and current employees indicate that some orientation was provided. However, there does not appear to be anything presented to employees that resembles the intensive classroom training of earlier years, as on-the-job training continued to emerge as the principal mechanism for communicating Plant hazards to workers.

There is sufficient evidence that formally prepared written material on Plant hazards has existed. For example, the Paducah Plant health physics program, the *Health Physics Training Manual*, and a variety of SPPs reflect Plant hazards in terms of the precautions workers must exercise to protect themselves. There is no evidence of the extent to which this information was either made available or required reading, nor is there any indication of supervisors' diligence in ensuring that Plant health and safety hazards were being communicated to workers.

External Exposure Monitoring Programs

External radiation exposures at PGDP from the 1950s to 1990 were monitored by both the Health Physics and Hygiene Department and line management. The Health Physics and Hygiene Department was responsible for performing beta-gamma radiation monitoring of the general work areas, equipment surfaces, material shipments, and personnel on a routine and spot basis and reporting findings to appropriate supervision with any necessary recommendations. The responsibility for performing routine radiation detection surveys lay with the line division concerned with the work being performed. Each division was responsible for identifying equipment having significant radiation exposure potential and establishing work time limits.

Personnel exposures were primarily monitored by the use of film badges. Health Physics and Hygiene program documentation indicates that after July 1, 1960, film badges were assigned to all employees, and were supplied to all individuals who visited the Plant from other locations and who might have been exposed to as much as one-tenth the RPG. Before July 1960, only selected workers were included in the film badge service based on their work activities. For example, in 1956 and 1958, there were 350 and 450 employees in the film badge service, respectively. Before 1960, the basic film badge use period appeared to be one week; in the early 1960s, the period was extended to one calendar quarter. However, for employees whose work involved significant exposure and who might have exceeded the quarterly RPG, badges were read and exchanged monthly. Review of documentation indicated that the employees on the monthly exchange cycle were primarily involved in chemical processing, maintenance of chemical processing facilities, and uranium metal production.

Review of documentation indicated that in general, the low specific activity and the self-shielding properties of uranium limited dose rates at PGDP. However, as stated in Health Physics quarterly reports, certain operations were known to result in "concentrations of material having higher specific activity and having created conditions that, if undetected, could result in exposures above permissible limits." Routine whole-body beta exposures over PGDP investigation levels existed primarily at areas where uranium daughter products and transuranics tended to concentrate, including the feed plant fluorination towers, converter disassembly areas in C-400 and C-720, the cylinder wash facility in C-400, the C-340 metals plant, and the neptunium and uranium recovery process raffinates. Interviews with Health Physics and Hygiene Department staff also indicated that exposures to external radiation were managed to assure that no one went above their lifetime limit (5N-18 rem, where N is a worker's age in years). It was common to rotate workers through areas of high external exposure concern, such as the ash receiver area, to administratively control individual exposures.

Interviews and documents indicated that in the early 1950s a decision was made that extremity monitoring was not required because it was felt that these doses were not likely to exceed 2.5 times the whole-body exposure. Whole-body exposures to operators and the dose rates in the ash receiver area were large enough that they could exceed 10 percent of the extremity limit and, therefore, would necessitate extremity monitoring. Shell and crucible cleaning operations in the metals plant required time-consuming wire brushing. In this activity, an individual would reach into a mold containing oxides rich in uranium daughter products (primarily beta emitters) and physically clean off the materials from the walls and bottom. The individual's film badge, worn on the torso, would typically be shielded from the majority of the beta activity by the crucible itself. However, since the whole body exposures to operators and the dose rates from these shells and crucibles are large enough that they could exceed 10 percent of the extremity limit, this practice would also have necessitated extremity monitoring. However, Health Physics and Hygiene Department summary reports provided no extremity monitoring data. Two documented, known beta overexposures (skin of the whole body quarterly limit) occurred at the C-400 cylinder wash facility during the first quarter of 1968. However, the investigation of this event was inadequate and did not address or determine extremity dose.

Bioassay – Urinalysis Programs

Individual employees were required to submit urine specimens for uranium analysis at a frequency thought to be commensurate with exposure potential, as well as for periodic physicals. Additionally, special urinalyses were scheduled for those working on special jobs, or when some special investigative information was required. The frequency of routine urine samples for uranium varied from a maximum frequency of four weeks for all personnel working in chemical operations and metal production (primarily C-310, C-315, C-340, C-400 and C-410) to a minimum frequency of 12 months for those working in locations deemed to have little likelihood of exposure. The Health Physics and Hygiene Department routinely issued a master schedule to line management showing when specific samples should be taken from certain groups of employees. This schedule typically covered three calendar months. Action points for uranium levels in urine were established, setting forth recall-sample frequencies, supervisor notification, and investigation reports. These action points ranged in levels from just above detection capability to greater than RPGs. The actions that were taken were commensurate with the result, typically ranging from requiring recall samples, workplace investigation, workplace restriction, estimate of body burden, and internal dose and/or confirmatory in vivo radiation monitoring (e.g., lung counting).

Interviewees employed during the 1952 to 1990 timeframe recalled numerous instances of being administratively removed from work because their samples came up "hot." These individuals received no further explanation that they could recall. However, the requirement to submit additional samples until they were no longer "hot" is consistent with the recall sampling and exposure determination program. Interviews with both former production workers and Health Physics and Hygiene Department staff members indicated the reliance on supervisors to notify workers for recall, and the movement of some workers throughout the Plant made bioassay timing sometimes difficult. In addition to routine sample submission, the Health Physics and Hygiene Department attempted to obtain samples from any individuals involved in releases for sample collection, but records indicated that they were not always successful.

Employees who were administratively removed from work because of exposures were reassigned to areas with less potential for intake, although typically still in areas where uranium work was conducted. The urinary uranium excretion rates were followed for these individuals until the urinalysis results were understood from a solubility standpoint or until rates decreased to baseline values; the personnel then returned to their regular work activity. Biological retention times for these types of exposures are closely related to the solubility class of the compound. Although the health physics group actively tried to gain insight into solubility class and particle size, much of this information was not well understood during the early 1950s and 1960s.

Interviews and much of the sample analysis data revealed that intakes were assumed to be from soluble compounds. This assumption may not have been true for some aerosols generated in the feed plant and during operations where metalworking (e.g., grinding, buffing, and welding) may have resulted in a range of particle sizes of insoluble material. The solubility information would have been important in determining the appropriate routine sample collection frequencies and for computing dose based on uranium concentration in urine. The Health Physics and Hygiene Department maintained in a response to a 1969 AEC-sponsored study on particle size determination that "While we have done very little particle sizing work over the years, we feel that our air-sampling technique and our bioassay program in combination have provided our employees with excellent health protection at relatively low cost to the AEC and the tax payers."

The documents reviewed indicated that urine samples were also collected and analyzed for transuranics, including neptunium and plutonium, and fission products such as technetium. These samples were typically collected following work on systems thought to have built up a concentration of these materials or associated with recovery of these materials. Samples were typically transferred to Oak Ridge for analysis. Interviews referenced some limited onsite laboratory capability for analyzing neptunium samples and fecal samples for plutonium. Review of Health Physics and Hygiene monthly reports for the early 1960s indicated that urinary excretion rates for neptunium had been steadily increasing.

Feed Plant

While the Health Physics and Hygiene Department correspondence indicated historical difficulty in relating results from air samplers to bioassay data, PGDP attempted to gain additional knowledge pertaining to this relationship. A review of the Health Physics Steering Committee files indicated that during meetings in March and May 1958, the Alpha Subcommittee proposed exposing volunteers to known concentrations in air of UO_3, UO_2F_2, and UF_4 to gain an understanding of excretion rates and urinalysis compared to air sample results. Interviews conducted with Health Physics and Hygiene staff employed during this timeframe confirmed that an intentional intake of a known quantity of UO_2F_2 in air was conducted by volunteer health physics staff members. Their excretion of urinary uranium was then tracked and compared to known air sampling data. The results of this experiment could not be found. In another attempt to gain insight into the relationship between ingestion and excretion, a senior health physics staff member drank a known quantity of a uranium-bearing solution in order to understand the excreted fraction. This data was never published.

In 1957, the Health Protection Study Committee at OR issued a report entitled "Health Protection at Paducah and Portsmouth." The committee's summary noted that "It seemed to the committee that undue emphasis is being placed at Paducah on the technique of bio-assay for evaluating exposures to uranium." The report goes on to compare and contrast practices at the two plants and makes recommendations for continuous improvement. Given the size of the air sampling and bioassay programs at Paducah and the relatively few health physics staff, it appears that this greater reliance on the urinalysis program continued from the 1950s through 1990.

Bioassay - In Vivo Radiation Monitoring

In vivo radiation monitoring via lung counting for PGDP workers was conducted initially at fixed facilities at Fernald and Y-12 in Oak Ridge and later at PGDP using a mobile system from Oak Ridge. Data indicated monitoring for uranium, neptunium, and technetium, and generally indicated no significant accumulation of radioactive material in the lungs in excess of RPGs. However, a review of the PGDP quarterly report for July-September 30, 1966, Health Physics and Hygiene summary, indicated that a PGDP maintenance mechanic who had been excreting an elevated level of uranium (approximately 50 micrograms per day) since March was checked in the Y-12 in vivo radiation monitor, and his lung burden was below the detection level in effect at this time. *Radiation Protection Criteria and Standards, Their Basis and Uses at AEC Facilities Operated by Union Carbide Corporation* stated that "an excretion rate of approximately 50 micrograms per day may be considered indicative of a significant internal body deposition of normal uranium." This discrepancy calls into question the accuracy and detection sensitivity related to early in vivo radiation monitoring conducted at, or for, PGDP.

In vivo monitoring was often conducted following discovery of elevated levels of material in air or urine samples. An example of this practice resulted from air samples collected during the first quarter of 1979 for the C-400 converter bundle salvage operations. In vivo results indicated that several personnel had elevated lung deposits of uranium. The Health Physics and Hygiene Department concluded that "When urinalysis, air samples and in vivo was considered jointly the assumption is that concentration was due to insoluble uranium and soluble neptunium." Plutonium was detected in some air samples in significant concentrations during this operation, according to the survey document.

PGDP documents addressing neptunium measurements made during the 1960s state that "good sensitivity was obtainable" for the Y-12 system, although the data indicated that no detectable deposits of neptunium were found in employees who were monitored by this system. Subsequent measurements were made between 1968 and 1974 using the mobile IVRML at the PGDP. However, the investigation team believes that the accuracy of these results is questionable because the IVRML was not routinely calibrated for neptunium, nor were neptunium results recorded. During the mid-1970s and 1980s, measurements were also made for neptunium. Records from this period indicated that any retention of uranium or transuranics was determined by PGDP to be well below the Maximum Permissible Lung Burden.

Air Sampling

From 1952 to 1990, the PGDP used a network of stationary air samplers at various production and non-production areas throughout the Plant. Portable and breathing zone samplers supplemented this network. Much of the data indicated frequent air sampling results in excess of PGDP RCG levels. Review of Health Physics and Hygiene monthly summary reports between 1955 and 1968 indicated that it was common to have air samples collected by both stationary and portable air samplers that exceeded MAC values. These excursions typically were related to a process upset, equipment failure, or maintenance activity. Logs reviewed indicated many dusty operations or smoky conditions related to activities; however, many health physics reviews noted no apparent determination of the cause(s) of these conditions. Interviews with Health Physics and Hygiene Department staff members employed during this timeframe indicated that stationary air samplers monitored the processes throughout the PGDP to indicate problem areas, but they were not used to attribute dose to individuals.

Several air samples that were collected during the first quarter of 1962 in conjunction with converter disassembly work or maintenance were analyzed for the presence of neptunium. The total alpha activity from neptunium in sample results ranged from non-detectable to greater than 90 percent. A review of these evolutions also showed examples of airborne contamination ranging from non-detectable to more than 100 times the PGDP MPC for neptunium. Health Physics and Hygiene Department summaries throughout the 1960s referenced neptunium contamination of cascade equipment as continuing to present a difficult exposure control problem. Health Physics and Hygiene Department surveys of CUP work in the C-720-C Converter Shop in 1980 indicated that Plant guides for airborne alpha activity were exceeded for uranium by a factor of 1,680, neptunium-237 by a factor of 2,121, plutonium-239 by a factor of 2,483, and thorium-230 by a factor of 55. Assuming the PGDP stated factor for respiratory protection afforded by a respirator ("conservatively is 90% effective"), levels even one-tenth as great would be deemed significant. The specific operations identified as generating these high airborne concentrations—the use of an oxyacetylene torch to cut through jack screws from inside the converter and use of compressed air blow-through testing—were both subsequently abandoned.

In summary, there is ample evidence that airborne radioactive contamination and worker exposures were not kept as low as reasonably achievable (ALARA) from startup into the 1980s. Workers received much greater exposures than if the stated AEC/PGDP ALARA policy had been fully implemented and actions had been taken to prevent and quickly moderate high airborne activity in work areas.

Contamination Control

A review of Plant health physics records indicates that many radiation and contamination surveys were conducted as far back as the 1950s. While health physics personnel generally were aware that contamination control practices were desirable, these practices were neither rigorously enforced nor mandatory. Radioactive contamination in the workplace was considered ancillary to the process operations and was considered to be of significant concern only if it gave rise to high dose rates or contributed (by way of resuspension) to high airborne concentrations of radioactive material that could be inhaled. In June 1955, a health physics memo noted that contamination levels in C-410 were higher than at any previous time. It stated that excessive amounts of powder were present and the settling of UF_4 on the west mezzanine floor amounted to a green film that was noticeable even after the floor had been swept. Similar conditions and findings were noted in various health physics inspection reports and surveys through the 1960s and 1970s as well as numerous prior worker accounts of the work environment. The recurring nature of these findings from health physics inspections indicates that corrective actions were not taken to minimize these conditions or were ineffective.

C-100 Administration Building

Several other memos and reports in the 1950s and early 1960s dealt with the notion that ingestion of uranium compounds might not be particularly harmful, based in part on the findings from animal studies conducted at the University of Rochester. While not confirmed, it is possible that this may have been the origin of the often repeated comments during interviews that workers had been told the material they worked with was safe enough to eat. The animal study information was used in part to justify the concept that anti-contamination clothing (coveralls) was not needed for all personnel. The Health Physics and Hygiene Department concluded that the main mode of exposure from contamination on the clothing would be ingestion rather than resuspension/inhalation, and the hazard would be essentially nonexistent for low levels of contamination on personal clothing. The criteria for issuance of company clothing resulted in numerous union safety grievances throughout the 1950 to 1980 time period. There appears to have been no concerted effort by management to ensure that lunchrooms were free of radioactive contamination, and as recently as the late 1980s, many workers were allowed to smoke and eat lunch at their contaminated work locations. While designated lunchrooms were likely to be cleaner than process areas, up until the late 1980s to early 1990s, there were no contamination control zones that would have minimized or eliminated the spread of contamination to these areas.

Contamination control practices were lax at Paducah from the beginning of operations until the mid-1980s, when more stringent contamination control and radiological release criteria were promulgated by both NRC and DOE. This is evidenced not only by the aforementioned health physics inspection reports and worker accounts but also by the legacy of posted contamination areas that remain within the various Plant buildings and grounds. In the late 1980s, the Health Physics and Hygiene Department undertook an effort to survey some Plant locations considered to be non-radiological areas. Findings included contamination in a variety of locations, including the C-100 "Roxie theatre," where personnel would gather for briefings and meetings, as well as various "non-radiological" lunchrooms throughout the site. In one survey evolution, 83 percent of the 150 anchored seats in the Roxie theatre were found to be contaminated, and 47 percent of the lunchrooms surveyed were found to have contamination above the limits for non-radiological areas.

While most labor personnel who were issued company clothes showered and changed clothing before leaving the site, the effect of the lax contamination control practices of prior decades makes clear the probability that radiological contamination was not confined to the work spaces, but was likely taken outside the site boundaries by workers wearing personal clothes on the job. No records of formal radiological monitoring for personnel and equipment leaving the site were noted until the 1986 timeframe.

Personal Protective Equipment

The use of PPE, and particularly respiratory protection equipment and coveralls, was inconsistent at PGDP. As early as 1952, the Health Physics and Hygiene Department recognized the potential hazards associated with personnel contamination and instituted measures to attempt to control potential exposures, including regular work area radiological surveys to determine the levels of personnel and clothing contamination. These surveys clearly indicated significant levels of radiological contaminants on hands, clothing, and shoes.

In several Plant areas, frisking devices were installed to allow personnel to self-monitor for radiological contaminants after hand washing before lunch and at the end of shift. Several thousand survey records for the period 1952 to 1956 indicate that significantly less than 1 percent of the personnel performing self-monitoring activities identified contamination on their hands. No routine survey program was established for clothing or shoes. These survey data are inconsistent with the results of numerous Health Physics and Hygiene lunchtime surveys of personnel and clothing that identified personnel with enough hand and clothing contamination to make ingestion of radioactive material a concern. Nonetheless, on January 1, 1957, the Health Physics and Hygiene Department issued a letter to all division superintendents stating that workers did not need to wash their hands before eating to avoid concerns with radioactive contamination. Shortly after this letter, the use of hand counters was discontinued at the Plant until the 1980s.

In January 1957, the Health Physics and Hygiene Department issued a memorandum to Paducah management entitled "Hand Contamination," which evaluated entry pathways for uranium into the body. The conclusions presented in the memorandum were based upon studies at AEC and research facilities. For inhalation of uranium, the memo concluded that "smoking with contaminated hands is not a significant factor in uranium exposure." For ingestion, the memo stated that "Animal feeding experiments showed that insoluble compounds of uranium may be ingested in relatively large amounts without hazard." Similar conclusions were associated with injection of uranium into the skin of the hand. In 1958, Health Physics and Hygiene management recognized that major portions of the beta radiation exposure to workers resulted from contaminated coveralls. The Health Physics staff estimated exposures and added that to personnel exposure records. Typical annual additional skin doses due to contaminated coveralls were recorded in the 500 to 800 mrad range.

There is evidence of some management effort to minimize the use of protective clothing at the site, and the Health Physics and Hygiene Department was actively involved with contamination control issues associated with the use of personal clothing in process areas. Following a 1956 review of the C-720 Electrical Shop, Health Physics and Hygiene stated that "Nothing was found which could be considered as detrimental to the health of the men working in this shop or to their families as a result of contamination being carried home on shoes or other clothing." In July 1957, management directed that personal clothing would be used on all work in the C-720 Control Valve Shop. However, evidence suggests that Paducah personnel routinely exceeded personal clothing contamination limits without corrective actions being taken by management. Health Physics surveys in the C-720 Control Valve Shop measured personal clothing contamination levels up to 2.5 mrad/hour and 1,250 dpm alpha. Similar measurements were identified in October 1957, with the stipulation that the use of personal clothing was approved as long as beta doses did not exceed 600 mrad/week. This threshold was quite high, considering that an exposure of 600 mrad per week in a year's time would exceed the maximum allowable annual beta skin exposure of 30 rem. In neither case was consideration given to the possible contamination and exposure to non–Plant workers associated with home laundering of the clothing.

In 1967, Health Physics and Hygiene management presented a position paper to all Paducah Plant supervisors, discussing use of contamination clothing. Although the paper acknowledged applications where PPE should be utilized to maximize skin protection, the paper concluded that contamination clothing issuance was not based on past practice, but on whether or not clothing contamination levels of 4,000 cpm alpha were expected during the work to be performed. If contamination levels were not expected to exceed 4,000 cpm alpha, personal clothing was to be utilized. The paper also highlighted supervision's responsibility to determine when contamination clothing should be issued and offered the Health Physics and Hygiene Department's support in conducting surveys and providing supervisors with facts and advice. Interviews during the investigation indicated that supervisors and foremen were never issued company-type clothing, even though in many cases those personnel were exposed to the same radiological hazards as the workers.

Respiratory Protection

The site's Health Physics and Hygiene Department considered personnel exposures to low-enriched uranium compounds to constitute a chemical rather than radiological exposure. Not only were the constituents of uranium compounds within the enrichment cycle hazardous (e.g., fluoride and acid compounds), but heavy metal poisoning could result from exposures to significant quantities of low-enriched uranium. Consequently, respiratory protection programs of the time were instituted to minimize personnel exposures to these contaminants. In general, the respiratory protection program utilized two basic types of respiratory protection equipment, the MSA Dustfoe and the Army assault mask, to minimize personnel exposures to dust-type and chemical contaminants, respectively.

As early as 1953, Paducah management was aware that feed made from recycled reactor fuel processed through the enrichment cascade contained trace quantities of plutonium. Evidence indicates recognition of the potential for personnel exposures to these contaminants. However, at least initially the respiratory protection program and health physics surveys and monitoring did not fully consider the presence of those contaminants. It was not until 1957 that the Health Physics and Hygiene Department discovered, during surveys, that neptunium-237 had also entered the process stream from the reactor return feed materials.

During this period, the Health Physics and Hygiene Department, as well as designated Operations personnel, routinely collected air samples throughout the site. Sample records indicated that airborne contaminants, noted as alpha contaminants, exceeded the MAC. In many cases, after the fact, Health Physics and Hygiene personnel routinely recommended the use of respiratory protection devices for specific tasks with identified high airborne radioactive material concentrations. However, the evidence suggests that although line management acknowledged receipt of those recommendations, they were not always implemented.

In September 1953, urine bioassays for personnel involved in ash receiver handling operations identified two workers with positive results for plutonium, suggesting that personnel did not routinely use respiratory protection equipment during these activities. As a result of this determination, the site's Health Physics and Hygiene Department recommended suspending the practice of transferring ash receivers to drums as a means to reduce potential airborne plutonium levels.

In 1957, radiochemical analysis of impurities from wet chemistry processes at the site revealed the presence of both plutonium and neptunium. Further study concluded that the contaminant was confined to the chemical processing areas of the Plant. However, during Health Physics surveys in the Weld Shop in 1957, unusually high alpha contamination levels were detected on large diameter process piping. Records indicate that no visible uranium was present on the work piece, even though high smearable alpha contamination was detected. Radiochemical analysis of swipe samples indicated that 50 percent or more of the alpha activity on the work piece was due to neptunium-237. This finding resulted in recognition that the entire cascade was contaminated with neptunium, and studies were conducted to determine which jobs presented the highest potential for exposure.

Many jobs were assessed for potential neptunium exposures; Health Physics and Hygiene concluded that the disassembly of converters presented the highest exposure potential. Although the record indicates that dust respirators were used during converter work, elevated air sample results clearly indicated that airborne neptunium contamination presented a serious personnel exposure problem. Additional control measures were evaluated and implemented, including the use of ventilation systems and wetting of surfaces to reduce dust dispersion. When equipment size or configuration precluded the use of other control measures, records indicate that the use of air-supplied hoods was recommended.

It is clear that the Health Physics and Hygiene Department actively promoted the use of respiratory protection devices in areas with high potential for airborne and/or chemical contaminants. Records indicate that the Health Physics and Hygiene Department routinely interacted with operations management and workers to advise on the use of respiratory protection equipment and provide counsel on the types of work that would normally require respiratory protection. However, archived records indicate that despite the Health Physics and Hygiene Department's concern with personnel protection, that group did not have the authority to direct the use of respiratory protection. Consequently, records also indicate that respiratory protection was not always utilized when high levels of airborne contaminants were present. For example, a Health Physics and Hygiene Department quarterly report for the first quarter of 1959 reported that continuous air samples collected near the neptunium recovery operation in C-710 averaged slightly above the MAC assumed for neptunium. Later analysis indicated that 29 percent of the alpha activity was attributable to neptunium. There is no indication that respiratory protection was used during these activities. Urine samples collected and sent to ORNL for analysis tested positive for neptunium.

It was also noted that work was routinely conducted without the benefit of respirators on open cascade components in process buildings, maintenance and refurbishment work, and waste handling activities, which were known to contain transuranic compounds. Records and interviews also indicated that respiratory protection was not always used during UF_6 releases in process areas, and it was common for operators or Operations supervisors to enter the area of an active UF_6 release without respiratory protection or other PPE in order to stop the release.

It is unclear why the discrepancy between Health Physics and Hygiene initiatives and actual work practices existed, although the Twenty-first Semiannual Report of the AEC, January 1957, page 176, may shed light on this inconsistency. The AEC, in noting that certain patterns of administration were common among the contractors, stated in part that "The role of the health physicists, where actual enforcement of radiation safety on the job is concerned, is cautionary and advisory. The supervisor in charge of a certain piece or area of work is the man who is answerable to management for the workers' protection, and for safe operations in general."

The Health Physics and Hygiene report for January 1962 outlines that urinary excretion rates had steadily increased over the past several years, to the point that some personnel were now excreting as much as 3 dpm/24 hour specimen. By today's standards, the dose represented by this excretion rate would be well in excess of regulatory limits (i.e., the team calculated a Np-237 excretion rate of 2 dpm = 2,000 rem to the bone). This report also notes that the time-weighted average airborne neptunium alpha activity in the breathing zone of personnel disassembling converters from C-337 had increased and was 237 dpm/m^3, with 90 percent of the alpha activity in the deposited dust on the equipment coming from neptunium. Controls included additional vacuuming and the use of air-supplied hoods instead of dust masks.

There is evidence that as late as 1973, inconsistencies in the use of respiratory protective equipment remained. The site attempted to justify these inconsistencies by noting that the guidance to employees allowed workers to choose whether to use a respirator, and what type, based on their perception of odor or visible fumes in the work area. It is evident that respirator use during this period remained largely voluntary, since the guidance only recommended that personnel leave the area of air contamination when necessary to obtain proper respiratory protection for the contaminant encountered. It is interesting to note that in 1973, uranium compounds were the only radiological hazard mentioned in the respiratory protection guidance, even though during the years 1969, 1970, 1972, and 1973, the highest percentage of reactor tails (with their attendant transuranics) were fed to the cascade.

At least two respiratory protection experiments were conducted at Paducah involving Plant personnel; the record is unclear as to whether the personnel involved in the experiments were volunteers or informed that they were participants. A March 1, 1956, memorandum, "Field Tests of Respirator Efficiency," documented the results of experiments at Paducah, involving the exposure of eight subjects to UO_2F_2 fumes to test the filter efficiencies of various respiratory protection systems. In this experiment, two subjects wore a combination dust and acid gas respirator and were exposed for one hour to UO_2F_2 fumes generated by hydrolysis of UF_6 in the dismantling booth in C-400. Three additional subjects wore the MSA "All Dust" respirator and were exposed to UO_2F_2 smoke for one-half hour. An additional three subjects wore the assault mask and were exposed to higher concentrations of UO_2F_2, sufficient to limit visibility to 10 to15 feet. All eight test subjects submitted urine samples, which were subsequently analyzed to determine respirator efficiencies. This memorandum also appears to indicate that these were not the first experiments undertaken at Paducah, although records of previous tests were not discovered during this investigation.

A November 1, 1956, memorandum entitled "Test of Dustfoe 66 Respirator" documented the results of an experiment at Paducah. This involved the exposure of six subjects, previously known to have insignificant uranium excretion, to a typical UO_2F_2 release while wearing Dustfoe 66 respirators. This experiment was conducted to determine the efficiency of the respirator filter and involved a measurement of the total uranium excreted by each test subject for the 24 hours after the test. References cited in the experiments noted above indicate that a variety of other urinary uranium excretion experiments were conducted on human subjects at a variety of facilities, some within the Oak Ridge complex.

Respiratory protection issues have continued throughout the Plant's history, as evidenced by concerns raised in DOE's technical safety appraisal of the Plant in April 1987. This report noted that implementation of the radiation protection and contamination control programs was designated as a line management function with the support of the Health Physics and Hygiene Department. The report went on to state that "Line management is not qualified either by virtue of training or expertise to specify radiation protection and contamination control requirements" and that "They [line management] recognize they are responsible but appear to regard radiation protection as not being a significant safety concern." Other sections of the report noted inconsistencies in industrial hygiene program implementation, including the absence of baseline surveys, monitoring, and respirator control and maintenance.

Medical Programs

A formal medical program to monitor and treat workers has been in place since the initial construction phase of the Paducah Plant. Union Carbide Corporation, AEC, ERDA, and ultimately DOE have had documents in place that reflected the basic concepts of occupational medicine during their periods of authority. Provisions have always been in place for medical personnel to respond to emergencies, conduct examinations, treat illnesses and injuries, and monitor both work-related and personal health issues. Until the 1980s, the Plant Medical Director had management responsibility for the medical, industrial hygiene, and health physics programs at the Plant. This management relationship greatly contributed to the physician's knowledge of workplace hazards, workplace concerns, and health effects at the work site.

Mandatory and voluntary examination programs were provided to all employees working at the Plant. Pre-employment examinations, termination examinations, and examinations for some job classifications were conducted on a regular, non-voluntary basis. Other employees were offered voluntary examinations depending on age or special needs. Examinations were comprehensive and included standard components such as history and physical, hearing test, laboratory studies (blood and urine), chest x-ray, cardiogram, and eye examination. Later on, more sophisticated studies, such as pulmonary function, comprehensive blood chemistry studies, and glaucoma testing, were added to the protocols. Along with the promulgation of industrial standards and regulations, medical surveillance requirements for regulated substances (such as asbestos) and medical approval for persons working in potentially hazardous situations requiring respirator use were incorporated into the medical program.

Employee medical records have been retained locally for most former and current PGDP employees. Some exceptions include employees who may have been transferred to other Federal facilities or a few records that may have been misplaced or lost. The medical records contain the results of all physical examinations, personal and occupational treatments rendered by the medical staff, major medical insurance records, and all work-related incidents or accidents that required medical intervention. Of special interest are the incident/accident reports, especially from the 1950s and 1960s, that chronicle the nature and extent of worker exposures to process gas, HF acid, and welding injuries.

It was evident from interviews and the review of official PGDP publications, such as the AEC quarterly report, that medical personnel were aware of and concerned about the long-term effects of exposures to chemicals and radiation; however, physical examination results did not appear to discuss or target those concerns. Quarterly reports document that no major long-term health effects from these exposures have appeared in the Plant population. Similarly, very little exposure information was included in any individual medical record, but interviews with former medical personnel indicate that exposure information was available if needed by the physician.

Several former workers noted during interviews that in the 1950s and 1960s, some employees working in or near hazardous operations did not receive the required medical examinations. For example, machine shop employees working in C-720, adjacent to the compressor maintenance shop, reported that although they may have been routinely exposed to process gas and contaminated dust, they were not required to have protective equipment or participate in mandatory medical examination programs. This failure to recognize and monitor some obvious worker exposure groups was not explained by either the former workers themselves or documents available to the team.

Personal medical care for employees has always been important in the PGDP medical program. Many employees utilized the medical care available at the Plant to supplement the available resources in the community. It appeared that keeping workers healthy and productive at work was an important consideration for the medical staff, resulting in many personal visits to the dispensary for advice, medications, and treatment. It was also obvious from interviews that some employees considered routine exposures to gases and chemicals insignificant and simply part of their normal work routine. Therefore, they did not report minor skin irritations, congestion, nosebleeds, eye irritation, and other indicators of possible long-term health effects.

Identification of physical hazards received greater focus in the Plant's early history than did identification of hazards that resulted in an exposure. However, there were a few exceptions, such as noise, uranium, fluorides, and dust. Recording and trending of injury data, which began in the second quarter of 1953, continue today. Early recorded statistics included man-hours worked, number of minor and disabling physical injuries (e.g., cuts and burns), and man-days lost. The rates of both frequency and severity of injuries were calculated from the beginning of the Plant's history. (Illness statistics were not compiled until after the 1970s.) In the 1950s, the Health Physics and Hygiene Department quarterly reports typically identified 40 to 60 workers per quarter seeking medical attention as a result of accidental releases of uranium, hydrogen fluoride, and fluorine. In the second quarter of 1955, accidental releases of toxic material within the Plant were considered "minor" since "only 12 men reported to the dispensary for medical attention." The 1961 Paducah Operations Training Manual compared injury rates at Paducah to injury rates at common industrial sites (e.g., coal mining and lumber jacking). Although Paducah's disabling injury rate compared favorably, such was not the case for Paducah's injury severity rate.

3.2 Operations and Maintenance

Operations and maintenance activities are described below, as well as the effectiveness of controls to protect workers, the public, and the environment from hazards. In addition, Appendix B summarizes the principal hazardous activities conducted at PGDP during the period 1952 to 1990 and provides an assessment of the hazards presented by these activities, the controls used to mitigate the hazards, and the effectiveness of the controls.

- *Feed Plant Operations*
- *Cascade Operations*
- *UF_4 and Metal Production*
- *Recovery Operations*
- *Smelting*
- *Maintenance*
- *Summary*

3.2.1 Feed Plant Operations

In order to enrich the uranium in the cascades, the feed product has to be in the form of UF_6. PGDP currently receives UF_6 directly from various customers. Before 1976, however, much of the uranium was received from the various ore processing refineries and reactor uranium recovery facilities (Savannah River and Hanford) in the form of UO_3, also commonly known as "yellow powder" or "yellowcake." This material was then converted to UF_6 by a three-step reaction process in the C-410/-420 feed plant, which operated from July 1953 through June 1964 and from July 1968 through June 1977. In the first step, the UO_3 was reduced to uranium dioxide (UO_2) by reacting with hydrogen (H_2). The UO_2 was then reacted with HF to produce UF_4, also commonly known as "green salt." The UF_4 was finally converted to UF_6 with fluorine (F_2).

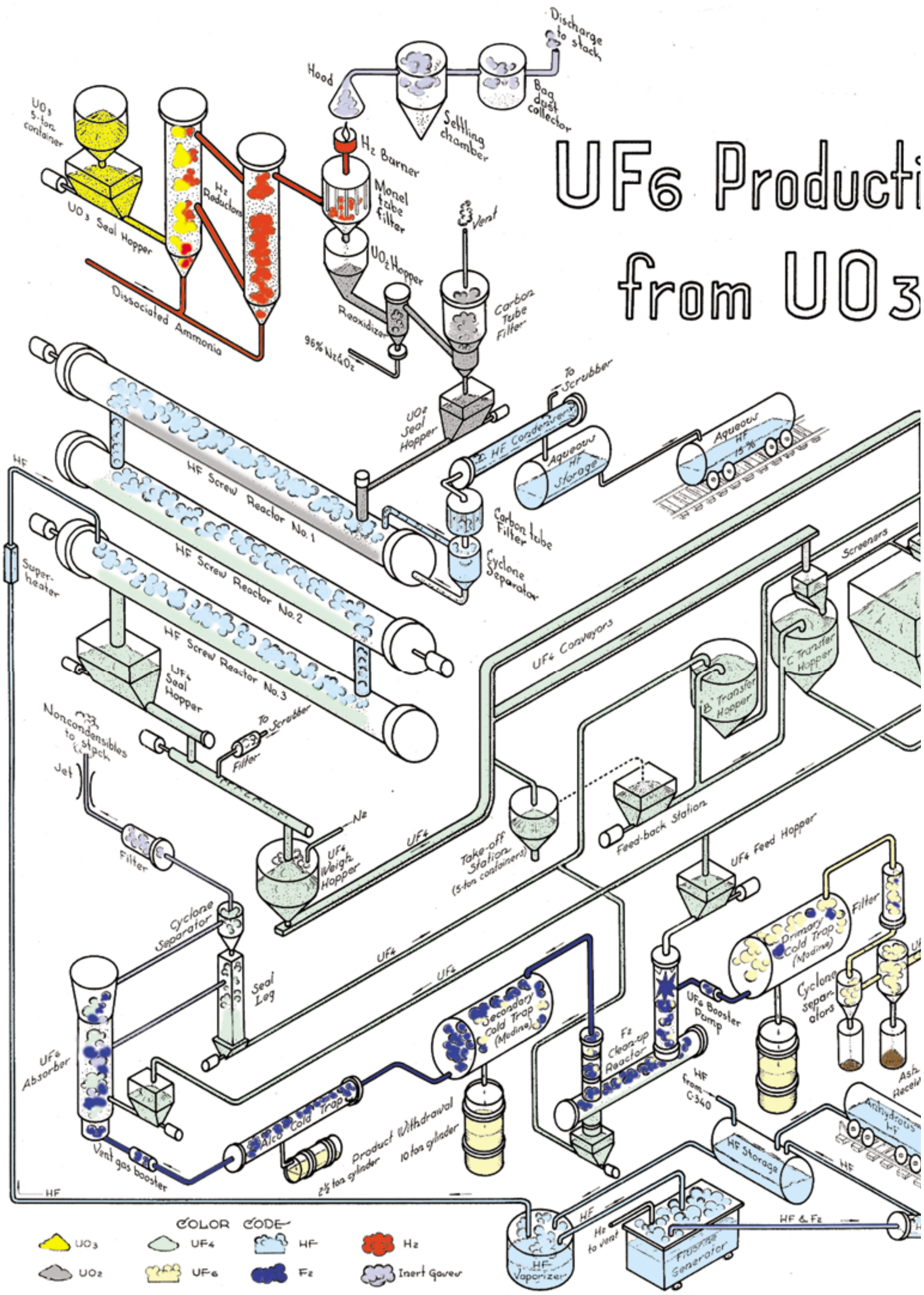
Operating procedures and personnel interviews indicate that the operating and maintenance practices in the feed plant were generally consistent with accepted industrial practices at the time, although the work environment was harsh. From the feed plant startup in 1953 until 1956, there were three lines for processing UO_3 to UF_6 located in C-410. In each line, the first two steps of feed production (green salt production) were conducted on vibrating tray reactors (shaker trays): a 15-foot-long tray for UO_2 production and two 40-foot long trays for UF_4 production. Each line contained a fluorination tower for converting green salt to UF_6 gas. Unexpected harmonic stresses on the trays resulted in frequent failures of the trays and bellows, with subsequent spills and leaks of uranium powders and gases, thereby contributing to the harsh working environment. These failures, combined with increased demand for feed, resulted in the addition of five more fluorination towers and the C-420 green salt feed plant, which replaced the shaker trays with screw reactor and fluid bed technologies. These technologies also had their share of problems. Room temperatures in the feed plant were usually in excess of 100 degrees Fahrenheit, noise levels were high, and leaks in all systems were common throughout the life of the plant.

Exposure to uranium powder dusts was prevalent in both operations and maintenance activities. For example, plugging of conveyers, hoppers, and screws with UO_3 or UF_4 routinely required physical agitation with sledgehammers or metal rods. In many cases, shear pins or chains on the associated drive mechanisms broke, requiring operations personnel to clean the product out of the jammed equipment and maintenance personnel to disassemble and repair the equipment.

The concentrations of uranium daughter products, transuranics, or fission product impurities in the incoming bulk reactor recycle uranium were quite low. However, in certain areas of the feed plant, these materials tended to concentrate to appreciable levels. These areas included the plant dust collection systems, the fluorination towers, and the ash receivers downstream of the fluorination towers. Vacuum and ventilation system bag rooms exposed workers to fine particle dust containing appreciable concentrations of the impurities. The impurities plated out on the inside of the fluorination towers, making them radiation areas and creating intense beta radiation fields when opened for maintenance or unplugging operations. The ash resulting from the fluorination of the UF_4 contained the most radioactive impurities and was sometimes in the form of small

CHEMICAL REACTIONS FOR CONVERSION OF URANIUM TRIOXIDE TO URANIUM HEXAFLUORIDE

- UO_3 (yellowcake) + H_2 (gas) $\longrightarrow$ UO_2 (black powder) + H_2O (steam) (1050°F)
- UO_2 + 4HF (gas) $\longrightarrow$ UF_4 (green salt) + $2H_2O$ (steam) (500 – 1200°F)
- UF_4 + F_2 (gas) $\longrightarrow$ UF_6 (gas) (2000°F)


UF6 Producti
from UO3
Discharge to stack
Hood
Bag dust collector
Settling chamber
H2 Burner
Monel tube filter
UO3 5-ton container
UO3 Seal Hopper
H2 Reductors
Dissociated Ammonia
UO2 Hopper
Reoxidizer
95% N2 & O2
Vent
Carbon Tube Filter
UO2 Seal Hopper
To Scrubber
HF Condenser
Aqueous HF Storage
Aqueous HF 15%
HF Screw Reactor No. 1
HF Screw Reactor No. 2
HF Screw Reactor No. 3
Carbon tube Filter
Cyclone Separator
Super-heater
HF
UF4 Seal Hopper
Noncondensibles to stack
Jet
Filter
To Scrubber
N2
UF4 Weigh Hopper
UF4 Conveyors
Screeners
B Transfer Hopper
C Transfer Hopper
Take-off Station (5-ton containers)
Feed-back Station
UF4 Feed Hopper
Cyclone Separator
Seal Leg
UF4
UF6 Absorber
Secondary Cold Trap (Modine)
F2 Clean-up Reactor
UF6 Booster Pump
Primary Cold Trap (Modine)
Filter
Cyclone separators
HF from C-340
Alco Cold Trap
Product Withdrawal
10 ton cylinder
2½ ton cylinder
Vent gas booster
HF Storage
Anhydrous HF
HF Vaporizer
H2 to vent
Fluorine Generator
HF & F2
COLOR CODE
UO3
UO2
UF4
UF6
HF
F2
H2
Inert Gases

particulates. As a result, the ash receivers provided one of the highest potentials for exposures to workers. Ash receivers were hot and fuming, and at least one full ash receiver usually needed changing out each shift. In addition, plugging of towers with ash frequently required physically challenging manual cleanout, putting workers in close proximity to the towers and the ash plugs for long periods of time. Review of procedures and training records indicates that respirators were typically required for most of this work. However, information from interviews indicated that compliance with these requirements was not always consistent, and compliance with respiratory protection requirements appeared to decline after the feed plant restarted in 1968. In particular, respirator fit problems increased, and the use of respirators tended to decrease during work involving strenuous physical exertion such as clearing plugs in towers, changing out ash receivers, and bag house maintenance. At times, the pressure of the feed production schedule also had a negative effect on respirator use.

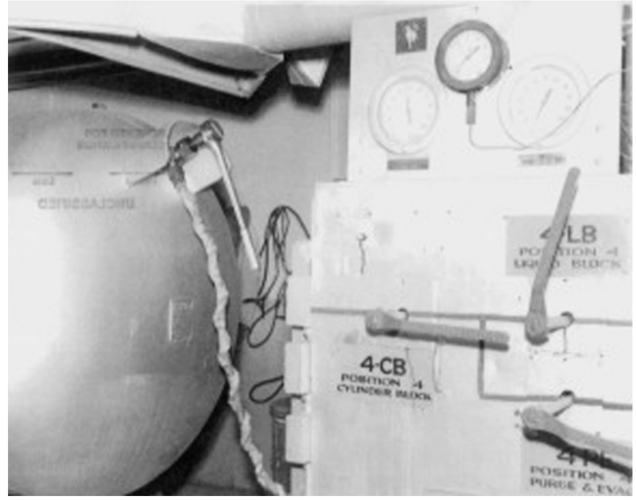
3.2.2 Cascade Operations

- *Product Feed and Withdrawal*
- *Puffs*
- *Jetting and Midnight Negatives*

Product Feed/Withdrawal

The cascades generally operated below atmospheric pressure, and therefore, any leakage consisted of air flowing into the process. The cylinder feed system and the product withdrawal system operated above atmospheric pressure. Any leakage in these areas resulted in process gas venting into and contaminating the surrounding atmosphere. In addition, the "heels" in empty cylinders brought to the withdrawal areas or removed from the feed areas were a source of penetrating radiation for the workers. Cylinder heels are composed of non-volatile corrosion products, uranium salts and oxides, and residual transuranic and uranium daughter product compounds when UF_6 is fed to the cascade. Without the self-shielding effects of the uranium in a full cylinder, the empty cylinders produced appreciable gamma fields. Since cylinders were re-used for five-year periods between cleaning and testing, heels in some cylinders accumulated significant radiation sources.

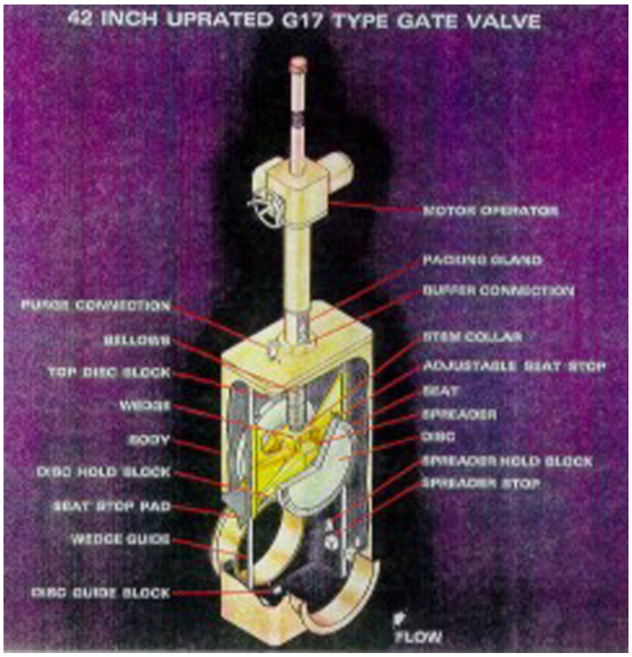
During the 1950s, UF_6 gas was pressurized for feeding to the cascade by heating the cylinders in warm water baths; the water baths had minimal engineered safety features. In November 1960, a cylinder was valved into the cascade before the water bath was fully heated, resulting in backflow into the cylinder from the cascade and an overfill condition. When the inappropriate valving was discovered, the cylinder isolation valve was closed. As the water bath continued to heat the cylinder, the cylinder overpressurized, rupturing the cylinder and releasing approximately 6,800 pounds of uranium.



Cylinder Filling Operation

In the early 1960s, the water baths were replaced with autoclaves, principally located in Buildings C-333A and C-337A, with each building containing several autoclave feed stations. Each autoclave served as a containment boundary in case a leak developed and was equipped with appropriate alarms, indicators, valves, and a remote cylinder valve closure device. Prior to connection to the cascade, each UF_6 cylinder was inspected for damage and confirmed to be safe for use. If a cylinder was found to be defective, it was tagged and moved aside for special handling. Following inspection, a heat traced copper pipe (pigtail) was attached to the cylinder valve and to a corresponding connection within the autoclave, the cylinder valve was opened, the autoclave was closed, and the various alarms were tested. Once the connection integrity and feed path clearance were confirmed, steam heat was initiated to vaporize the UF_6 and began feeding it to its corresponding assay point in the cascade. A UF_6 release within an autoclave would actuate an automatic emergency shutdown and autoclave isolation to protect workers and the environment.

Enriched and depleted UF_6 gas was withdrawn in Buildings C-310 and 315, respectively. Product (enriched UF_6) and tails (depleted UF_6) were withdrawn from the cascade by pumps that discharged through a condenser, piping, and cylinder pigtails to the intended receiving UF_6 cylinder. Product cylinders were not supposed to be filled to more than 95 percent (liquid) of capacity. Those that were overfilled were tagged and subject to special handling to resolve the overfilled condition. UF_6 cylinders still containing liquid could not be transported around the site without special consideration. Before solid UF_6 cylinders were moved to storage, they were "burped" of light gases through sodium fluoride (NaF) traps.



Gate Valve

One ex-operations supervisor reported that operators turned up "hot" in the product withdrawal area more than any other area of the cascade. Portions of the product withdrawal system operated at approximately 30 psig. As a result, small leaks in this area released enriched process gas into the room atmosphere and provided a higher potential for an intake. Air monitor sampling indicated moderately high activity readings for the withdrawal room from initial operations up through the early 1960s. Subsequent increased attention to repairing leaks and improving the ventilation systems led to low activity readings in the room by 1964. Other than a few specific high readings due to leaks, general area air monitoring samples remained low.

Accidental UF_6 releases during the connection and disconnection of cylinders was one of the leading causes of individuals reporting to the dispensary for medical attention in 1953, according to a PGDP quarterly report. It was reported that UF_6 releases often occurred when burping recently-filled UF_6 cylinders. Workers generally wore full-face respirators during this activity and received monthly bioassays. Interviewees recalled at least one instance of a worker attempting to move a product cylinder that was still connected to its pigtail, resulting in a major UF_6 release. Workers reportedly received skin burns while attempting to isolate the release. Interlocks were subsequently added to prevent a recurrence.

Puffs

Puffs are minor releases of UF_6 from process gas equipment and were a common occurrence, despite efforts to minimize the amount of material available for release. Frequently, solid UF_6 deposits became isolated from the process gas stream in closed-end volumes, such as instrument lines, that developed blockage. One instrument mechanic estimated that puffs occurred weekly in the late 1970s. He described frequent puffs on opening process gas systems, despite work permits indicating that the systems contained no UF_6 ("UF_6 negatives"). In some cases, this may be explained by UF_6 freeze-out blockage of sample lines. He described the classic white cloud release, losing his breath, backing away to let normal exhaust ventilation disperse the cloud, and returning to work without special monitoring or cleanup.

An incident was reported in the C-310 product withdrawal building where an instrument heater control malfunctioned, melted tubing solder, and initiated a significant release that filled C-310 and was working its way across the bridge to C-331. Mechanics were reportedly sent without PPE to shut doors in the bridge. The original instrument line leak was secured by crimping the line by another worker outfitted in a Gra-Lite suit. Reportedly there was no special monitoring of the involved individuals, and work resumed after the cloud dispersed.

Operators in the late 1970s and early 1980s reportedly did not typically wear respirators while sampling cascade process gas, despite frequent whiffs and puffs of UF_6. Puffs were frequently experienced in product feed and withdrawal areas when UF_6 cylinder pigtails were disconnected. One interviewee recounted pressurizing offline cascade equipment with UF_6 to "smoke" the cell and detect leaks. He did not recall respirators being worn for this activity. Workers interviewed recall respirators being available, but not being required to wear them; workers' experience helped them determine when a job might produce a puff and, therefore, whether a respirator should be worn.

Jetting/Midnight Negatives

Jetting is the process of purging isolated process gas system equipment of UF_6 and HF by introducing dry air or nitrogen and removing the resulting gaseous mixture with the process building purge jets. Each jet took a suction on its process building evacuation header, which consisted of a two-stage Venturi supplied with 100-pound air, and discharged the resulting gaseous mixture to the environment from an unmonitored open pipe on the process building roof. The jets were intended to evacuate atmospheric air from isolated process gas system equipment in preparation for startup and the introduction of UF_6, and for performing HF sweeps of isolated process gas system equipment once the UF_6 concentration had been reduced below 10 ppm (UF_6 negative) in preparation for opening the process gas system for maintenance, inspection, or parts retrieval. Assuming that the jets were only used as prescribed after a satisfactory UF_6 negative was achieved, less than one-fifth pound of UF_6 was available for release to the environment from a single cascade cell each time. The number and frequency of these authorized releases were not determined.

"Midnight negatives" refers to using the jets at night to accelerate the attainment of an adequate UF_6 negative to support a planned opening of isolated process gas equipment. Depending on the pressure, temperature, and concentration of UF_6 in a cascade cell when jetting was initiated, and assuming that the concentration had been reduced by at least one-tenth through purging and evacuation pumps, up to several thousand pounds of UF_6 could still have been available for release to the environment from a single cascade cell. As with normal jetting, the UF_6 gas would hydrolyze with moist air to form UO_2F_2 powder and HF gas. The number and frequency of these inappropriate releases were not determined during this investigation.

Some current and former operators were aware of rumors about or participated in midnight negatives. As related to the team, an operator would be sent to the roof in the middle of the night with a "half-mile lantern" to report when the plume of white "smoke" stopped issuing from the jet exhaust, thereby signifying a satisfactory UF_6 negative.

Procedures available for team review from the 1970s and 1980s do not address the use of jets to obtain UF_6 negatives. Where discussed in the procedures, the use of jetting was limited to static or sweep purging of isolated process gas equipment after a satisfactory UF_6 negative had been achieved and confirmed by sampling. Procedures from the late 1980s and 1990s do not address jetting at all, relying instead on evacuated surge drums and wet air pumps to perform HF static and sweeping purges, with essentially no release of UF_6 to the environment.

In the mid-1980s, several Paducah process improvement projects focused on ways to reduce cascade vent emissions. Chief among their recommendations for reducing UF_6 emissions to the environment was discontinuing using process building air jets for evacuating cascade cells. Although using the jets was not banned as late as April 1986, efforts were under way to demonstrate and establish alternatives and to revise procedures to avoid jet use. However, as late as September 1988, the procedure for "Startup of the Cascade" still stated that the building purge jets could be used for evacuating air.

No interviewee remembered the jets being used after the mid-1980s, and many believed it was no longer physically possible to use the jets. Upon inspection, it was discovered that the jet isolation valves could still be opened by inappropriate manual operation. Even without such manipulation, the purge jet piping presents a potential unmonitored path for release of UF_6 through leaks or inadvertent valve manipulation. USEC promptly issued two assessment and tracking reports, established additional administrative controls, and recommended cutting and capping the lines to the jets after assuring no nuclear criticality safety concerns. Although the flat and expansive roof of each process building is treated as a contamination control area, no special posting was observed in the vicinity of the jet exhausts that would indicate higher contamination levels, suggesting that the process building purge jets have not been used in a long time.

3.2.3 UF_4 and Metal Production

Along with the enriched uranium produced at Paducah, the Plant also produced uranium metal. These operations were conducted, upon completion of construction in 1957, in a small complex of buildings on the eastern side of the Plant known as C-340. In June 1962, operations were significantly scaled back. A second campaign began in 1967 and continued until 1977. From 1978 to 1982, the building served as a shipping point for UF_4 green salt. This area of the Plant was one of the least desirable job assignments for workers. The work was hot and dirty, high levels of airborne uranium were often present, and HF was frequently released in small quantities from various points. In 1962, a worker was killed in C-340 and another seriously injured from burns received during a furnace accident. Another worker was severely injured by anhydrous HF during a maintenance operation on an HF transfer line. Although it could not be confirmed by records, at least one operator interviewed believed that the worker died later as a result of his exposure; the investigation team did not find any documentation to support this belief. After 1982, the building was used for utilities maintenance, training classes, security exercises, and prototype valve tests. In 1994, the building was fenced and locked, and it is currently accepted into the decontamination and decommissioning program, but receives only routine surveillance and maintenance. Decontamination and decommissioning will not take place until after shutdown of the gaseous diffusion plant.

Metals production involved several steps, each with its own unique hazards. The first step in the process was powder production. UF_6 process gas reacted with hydrogen in a heated tower to produce UF_4 powder (green salt) and HF. The HF was vented from the tower through a collection system that condensed the HF to a liquid, which was stored in a tank. Periodically, the tank would be pressurized with nitrogen and transferred to Building C-410 for use in feed production. Fluoride releases from production of UF_4 are likely responsible for most of the ecological damage that occurred in the northeast quadrant during early operations at the Plant. C-340 was capable of producing several thousand pounds of HF daily when operating. Even if the Plant recovered 99 percent of the HF produced, as reported by a former building supervisor, a significant amount of HF would have been released.

Army assault masks and respirators were normally available to operators and were required for many of the operations. Entries in operating instructions and reports from workers indicated that these requirements were not always followed or adequately stressed by foremen. Consequently, operators in C-340 were frequently placed on restriction due to the intake of uranium compounds, especially in the powder areas on the fifth and sixth floors of the tower building.

The reaction towers were a primary source of airborne uranium. Operating at pressures above atmospheric, any leak in the system could release fine dust and HF. The building had two vacuum systems (dust collectors), one for general cleaning and one for uranium, with hose ports that could be connected in many locations. These hoses were frequently placed near leak sources to minimize releases, but they were not always effective. To meet production needs, the towers would sometimes be operated with leaks that approached or exceeded the capture capacity of the vacuum system. Very early on, the general cleaning system became contaminated when it was used while the uranium system was shut down for maintenance.

The UF_4 green salt fell out of the bottom of the tower into a series of hoppers and screws used for powder transfer. It could then be placed into drums for sale or storage or sent to the next step. UF_4 was removed from the hoppers at the bottom of the reaction towers. This operation created large amounts of airborne uranium dust. Within four months after startup, respirators were identified as being required for drumming operations.

Metals were produced by reduction of the green salt to uranium metal with magnesium. The first step in the process was preparation of a "bomb" liner. Magnesium fluoride (MgF_2) was placed in a steel shell and "jolted" (mechanically agitated) to pack the refractory and remove any voids. The next phase of the operation involved blending measured quantities of green salt with measured quantities of powdered magnesium metal, and then pouring this mixture into the bomb liner. A refractory cap was then poured, and a lid was bolted to the top of the charged bomb. The charged bomb was then transferred to an induction furnace where it was heated to the point where the magnesium reduction started.

The primary hazard associated with this part of the process was exposure to the airborne uranium dust during weighing, blending, and pouring. Respirators were required very early during the initial production operations. The bombs also presented a significant hazard from burning magnesium and molten uranium metal. A phenomenon described as "burnout" and "lid fires" occurred infrequently when the refractory liner was not correctly prepared. For example, burnouts occurred when the burning magnesium came in contact with the steel shell, melting through the shell and releasing the bomb contents into the furnace. Lid fires were similar, but occurred at the lid rather than the side of the shell. Such an occurrence led to the fatality in March 1962. Burnouts resulted in significant contamination of the furnace refractory and would normally require the entire furnace to be relined. Removing the old refractory lining generated large quantities of dust; personnel repairing the furnaces would not always wear proper respiratory protection and consequently might have been exposed to high levels of uranium oxides from the refractory dust.

After the "bomb" was cooled, it was sent to the breakout area where the lid was removed, the shell was inverted, and the contents were dumped onto a grating, referred to as a "grizzly." The slag material, at this point a hard ceramic material, was broken into smaller pieces by beating it with a hammer. The pieces were dropped through a grating into a jaw crusher and sent to the slag plant. This operation was among the dirtiest jobs in C-340. Operators reported (with confirmation from supervisors) being completely covered with black dust. Respirators were required and generally worn, although the extent of dust and contamination probably exceeded the protection they provided. The metal ingot, referred to as a derby, was freed from the slag and could be "roasted" to oxidize the surface and loosen any remaining slag. Loose oxides that fell from the derbies during roasting were collected, put in drums, and sent to a burial yard. After roasting, the derbies were cleaned by hand in a cleaning booth using power brushes and grinders to remove any remaining slag. While not as dirty a job as the breakout and slag crushing, this job also generated high levels (i.e., periodically above Plant allowable limits) of airborne contamination.

After cleaning, the derbies could be shipped directly or sawed into smaller shapes, depending on customer requirements. Derby sawing generated large amounts of uranium metal "saw dust," which burns readily in air. Consequently, saw dust was collected in drums of oil and kept covered. Despite these measures, uranium metal fires were common (daily or weekly), resulting in high levels of airborne uranium oxides.

The MgF_2 reaction product remaining in the bomb was captured, crushed, ball milled, and then sized to be recycled as refractory. Although primarily a hands-off operation, it generated significant quantities of dust. Over time, the slag became contaminated with significant quantities of uranium oxides (several percent) that could have contributed to worker intakes. Reject slag (too small or too large) was collected in a hopper, then periodically drummed and sent to the northeast corner of the Plant site. It was not clear from either operators or log reviews whether those drums were stored and later removed or dumped and buried.

C-340 was also capable of re-melting the uranium derbies and casting specific shapes; operations were conducted in a furnace with a controlled atmosphere. Graphite crucibles were used to receive the molten uranium. The primary hazard associated with these operations was cleaning the crucibles between pours. Over time, oxides of uranium and beta-emitting uranium decay products would impregnate the crucible. Since crucibles were cleaned by hand, operators would have received radiation dose to their hands, arms, and fingers. No dosimetry was worn by operators that would have measured these extremity exposures.

3.2.4 Recovery Operations

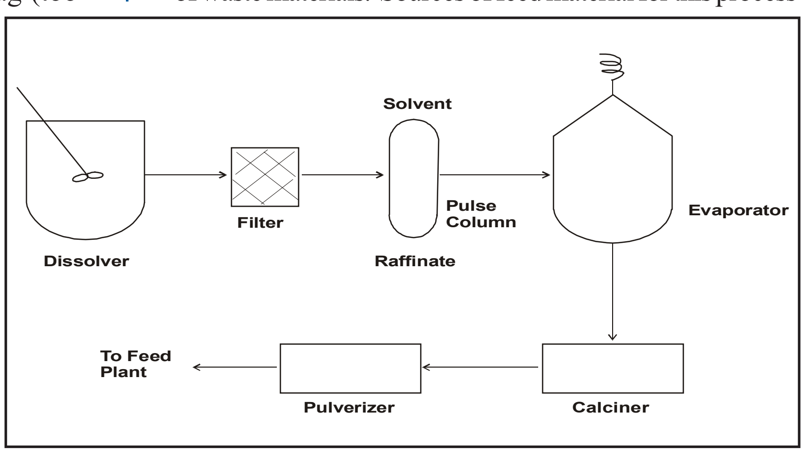
- *Uranium Recovery*
- *Neptunium Recovery*
- *Technetium Recovery*

Throughout PGDP's operational history, uranium has been recovered from waste streams and recycled through the enrichment process to minimize loss of this valuable material. Neptunium and technetium were also recovered during early Plant operations to meet high demands for these materials. Recovery operations reduced the releases of uranium, neptunium, and technetium to the environment but produced high concentrations of radioactive materials in Plant processes that posed significant occupational hazards to Plant workers.

The source of neptunium and technetium at PGDP was feed material from uranium recovered from spent reactor fuel at the Hanford and Savannah River sites. The AEC understood that fission products and transuranics could present health problems to gaseous diffusion workers and set limits on the amount of that could be present in feed materials. The chemical separation processes at Hanford and Savannah River removed most, but not all, of the transuranics and fission products.

Uranium Recovery

Uranium recovery facilities in C-400 were used to chemically separate and recover uranium from a variety of waste materials. Sources of feed material for this process



Uranium Recovery Process

included: fluorination tower ash, sintered metal filters, decontamination solutions, UF_6 scrubber solutions, particulates from ventilation filters and vacuum cleaners, laboratory wastes, and materials from spills. Before the mid-1970s, a complex uranium recovery process in Building C-400 separated uranium from waste and scrap materials, concentrated it, and converted it to an oxide. The process included the following steps: dissolution of feed materials, filtration, solvent extraction in pulse columns, concentration by evaporation, and denitration to an oxide.

The uranium recovery system was not leak-tight, and leaks were common. Operators were instructed to mop spills from process equipment but acknowledged that some spills probably went down the drain. Steps were taken to control operators' exposure to process materials. Routine surveys were conducted to monitor the concentration of radioactivity on surfaces and in the air in C-400, and the health physics staff recommended changes in work practices based on the results of these surveys. Uranium recovery system operators were provided coveralls. Rubber gloves and respirators were available, but their use was not strictly enforced; they were generally worn at the discretion of the operators. The aqueous raffinate from solvent extraction columns that contained neptunium-237, thorium-234, palladium-234, and technetium-99 was discharged to the environment.

In the mid-1970s, the solvent extraction process for uranium recovery was replaced with a simpler precipitation and filtration process. Steps in this new process included: dissolution of feed materials in nitric acid, addition of lime to precipitated uranium, and recovery of precipitated uranium as a filter cake.

The filtrate, containing low concentrations of radionuclides, was discharged to the environment. Sludges and filter cake were buried on site if uranium concentrations were low or sent to Fernald if concentrations were high enough to warrant further recovery.

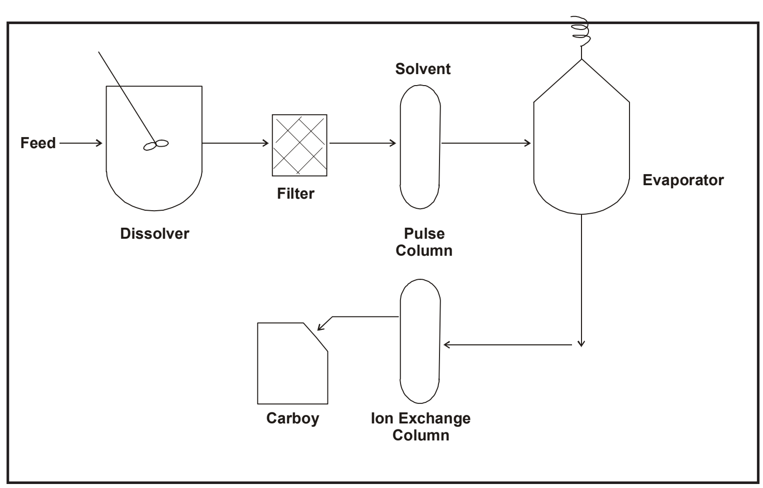
Neptunium Recovery

Soon after neptunium was identified at Paducah in 1957, the AEC placed a high emphasis on its recovery. A neptunium recovery process was developed at ORNL, and began operation at PGDP in November 1958 in Building C-400. The process used a solvent extraction and evaporation method to recover and concentrate neptunium from receiver ash and cylinder heels:

- Receiver ash and solids that settled from cylinder wash water were dissolved in a nitric acid solution.
- Solids suspended in this solution were removed by filtration and discarded as solid waste.
- The filtrate was processed through solvent exchange pulse columns to separate uranium, thorium, and neptunium. (These columns were originally located in Building 710, Room 32, and may have been moved to C-400 sometime after July 1959.)
- Raffinate from these columns was dumped to the building drain if it contained uranium and neptunium concentrations less than 500 ppm and 0.2 mg/L, respectively.
- Uranium and thorium were recovered for future use.
- The neptunium solution was concentrated to about 20 to 25 g/L by evaporation.
- The concentrate was sent to a laboratory in Building 710 for additional separation and concentration in ion exchange columns. The final product was siphoned into glass carboys on the loading dock at C-710.

The highest concentrations of neptunium at PGDP were associated with neptunium recovery processes that operated intermittently from 1958 until the late 1970s. These processes separated and concentrated neptunium from receiver ash, cylinder wash water, and MgF_2 pellets used in technetium traps. One liter of neptunium recovery product contained about one curie of radioactivity. Processing systems were complex, leaks were common, and respirators were not always worn.

The relatively high hazards associated with neptunium were understood at Paducah as early as 1959, and special practices for handling neptunium solutions and neptunium-contaminated equipment were



Neptunium Recovery Process

recommended. Recommendations included: using non-breakable containers; maintaining tight systems; keeping lids on containers; preventing bubbling, frothing, or spraying of solutions; using rubber gloves; washing the gloves before using them in other areas; using respirators (or assault masks) for welding or burning; and performing alpha surveys of all equipment removed from neptunium processing areas.

The limited information available indicates inconsistent implementation of these recommendations. For example, a recovery system operator did not recall using a survey meter. He said that the resin exchange columns were made of glass and that they broke from time to time, discharging their contents to the Building C-400 drain. He was concerned that the system was not sufficiently leak-tight to contain hazardous materials.

Estimates show that 4.289 kg of neptunium were recovered using the above process (3.215 kg from heel washings and 1.074 kg from ash). This process was discontinued in October 1961, after MgF_2 traps were determined to be a more productive method of recovery. The recovered neptunium was shipped from the site. The neptunium recovery system was removed from the Plant in the late 1970s.

The processing of solutions containing neptunium though the solvent extraction and ion exchange system produced raffinate and wash solutions with some neptunium remaining. Solutions with neptunium concentrations greater than 2 mg/L were either reprocessed or stored. Seventeen drums of waste from the neptunium recovery program remain stored on site today. Solutions with a neptunium content less than 2 mg/L were discharged to the environment using building drains. Estimates indicate that approximately 200 grams were discharged in this manner.

A second neptunium recovery process was used briefly after 1961 to recover neptunium from MgF_2 pellets that had been removed from technetium traps in the feed plant and cascades. Although the traps were originally installed to adsorb technetium, they were also quite effective in adsorbing neptunium. The pellets were vacuumed from traps in the feed plant and cascades and transported to Building C-400, where neptunium was removed by a chemical stripping process. Approximately 33 grams of neptunium were recovered by this method before recovery operations were terminated at the site in the mid-1960s.

Neptunium recovery was classified at the time, and only individuals with a need to know were familiar with the details of the program. For security reasons, neptunium was known by the code name "Trace," and most Paducah workers were not aware of its presence at the Plant. Operators and maintenance mechanics interviewed during this investigation could recall no training on the hazards associated with neptunium before the late 1980s, although it is possible that such training was provided. A 1962 training manual for chemical operators stated that "Since neptunium is more active than uranium, greater precautions should be taken to prevent its inhalation and any spills should be cleaned up immediately to prevent the material from becoming airborne. In addition, an ultrafilter chemical respirator, rubber gloves and acid goggles should be worn when transferring solutions."

Technetium Recovery

Technetium-99 is a fission product that was received at Paducah in recycled feed from Hanford and Savannah River Sites. Technetium passed through the Paducah cascade as a volatile compound of fluorine, depositing on internal surfaces of the cascade and contaminating the enriched uranium product. The AEC did not specify a limit for technetium in UF_6 feed but controlled the concentration of technetium indirectly to about ten ppm by limiting gross beta from fission products.

A demand for techtetium-99 in the early 1960s prompted Paducah to begin a campaign to recover 25 kg of this material from various effluent streams. In 1960, a process was begun to recover technetium from UF_6 cylinder wash water and from the raffinate generated during neptunium recovery. Process steps included precipitation and removal of uranium from these solutions by adding sodium hydroxide. The aqueous superannuate was processed through an ion exchange column and elutriated with nitric acid to produce a concentrated solution of technetium that was shipped to ORNL. Although technetium was not a significant radiological hazard during most PGDP operation and maintenance activities, this concentrated form presented a more significant hazard.

Technetium traps were installed in the feed plant and in the cascades in 1961 and 1963, respectively, to reduce contamination of the enriched uranium product. A small amount of technetium was recovered from these traps in the early 1960s. Technetium was leached from the pellets in a dissolver in C-400 and potassium hydroxide was added to precipitate the uranium. The solution was then filtered and processed in the same manner discussed above.

In the mid-1970s, a process was developed and implemented at PGDP to remove technetium from aqueous waste streams for the purpose of environmental protection. Technetium in superannuates following uranium precipitation was removed as an insoluble solid through the use of iron sulfate as a flocculating agent.

3.2.5 Smelting

Three smelters operated in C-746A, including a nickel induction furnace, a reverberatory furnace used to melt clean aluminum, and an aluminum sweating furnace. Little data on smelter operations at the Plant was available to the investigation team because records were stored in contaminated waste drums or were removed by another DOE team investigating scrap metal recovery at the Plant. A 1972 study of radionuclides in scrap indicated the potential for airborne concentrations of uranium during loading of melting pots; however, no uranium fumes were detected during alloy melting or pouring.

3.2.6 Maintenance

Aluminum Pouring Operations

- *Major Component Maintenance*
- *Cylinder Cleaning*
- *Cylinder Valve Replacement*
- *Filter Bag Replacement*
- *Cooling Tower Chemical Treatment and Repair*

Maintenance tasks often presented the most likely opportunities for worker exposure to the unique hazards of the gaseous diffusion process. Process piping penetrations, work with solvents, component disassembly and cleaning, and cylinder valve replacements were commonplace activities. Additionally, much of the work was conducted in open bay shops without controlled ventilation. Consequently, workers in the vicinity of, but not directly involved with, specific maintenance actions could have been exposed to hazardous conditions beyond their control or knowledge.

Major Component Maintenance

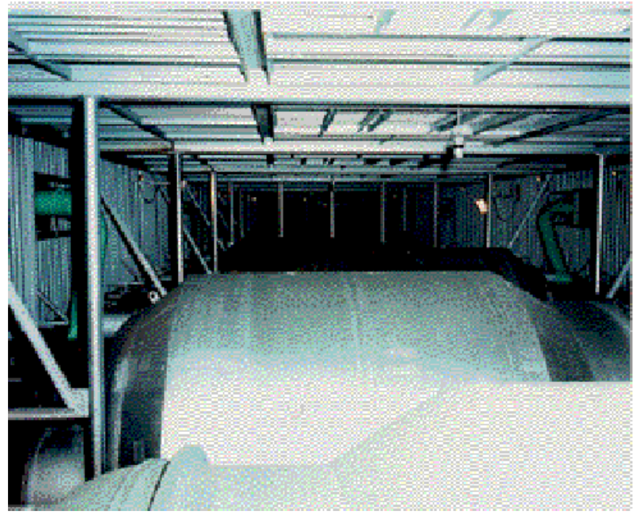
Maintenance on major components in the cascade (compressors, converters, and process block valves) presented some of the most significant opportunities for exposure of maintenance personnel. Work on these components required that they be removed from the system, cleaned, rebuilt or repaired, and then reinstalled. In order to remove these components, process operators isolated and bypassed the cascade cell containing the component, reduced the UF_6 within the cell to less than 10 ppm equivalent at atmospheric pressure (a UF_6 negative), and then purged the cell to minimize HF and UF_6 exposure of workers involved in opening, maintaining, or modifying cell components. Once a satisfactory UF_6 negative and HF purge was accomplished and the pressure of the isolated cell was raised to atmospheric pressure with dry air, the isolated cell was turned over to process maintenance for cell opening and disassembly.

Workers opening a cell and dismantling cell components could be exposed to UF_6, HF, UO_2F_2, and to a lesser extent, transuranics and certain fission products, such as technetium. Maintenance personnel would initially make a small hole or cut in the process gas piping to confirm that cell pressure was at approximately atmospheric pressure. A 1989 procedure for maintenance personnel entitled “Penetration of UF_6 Piping Systems” required all personnel within 15 feet of the opening to be wearing full-face respirators with GMHF-C canisters, and to wait for industrial hygiene/health physics personnel to provide guidance on when they could remove the respirators. One interviewee described times during CIP/CUP when “smoke” (UF_6) released from compressors as they were cut out of the process gas system would obscure visibility. Work would resume once the process building exhaust fans dissipated the cloud. To prevent the potential spread of radioactive contamination, the same maintenance procedure required all openings into components to be covered as soon as practicable after removal from the process gas piping.

Compressors were transported from the process buildings to Buildings C-720 and C-400 for “000” and

"00" sizes, respectively ("000" and "00" are size designations, with "000" being larger). The compressors were then disassembled into major components within pits, the parts transported to Building C-400 for spray washing to remove uranium deposits, the rotor and stator relocated as required for deblading within C-400 and C-410, respectively, and all the reusable washed parts returned to their respective maintenance buildings for modification, refurbishment, degreasing, and reassembly. Once reassembled, the compressor openings were covered for transportation to storage or reinstallation. Converters were transported from the process buildings to Building C-409 for decontamination. The barriers were then taken to Building C-400 for washing, disassembly, and scrap recovery. Following washing in C-400, the converters were modified, refurbished, and reassembled in Building C-720. Prior to removal from the system, block valves were slightly opened (where possible), inspected, cut out of the system, lifted free of process piping, decontaminated, covers installed, and shipped to C-400 for preliminary disassembly and decontamination to the limits allowed in C-720. Once decontaminated, the valve was again covered and transported to C-720 for final repair and reassembly, and staged in the process building for reinstallation.

UF_6 as a gas or solid was sometimes trapped within components and would be released when finally exposed to air. Remaining solids would become airborne, particularly when pneumatic tools were used. Because of the resulting white smoke and pungent odor, these releases were apparent to both the mechanics and the other workers in the area, resulting in some instances of spontaneous evacuation of the area. As one interviewee described it, "smoke out conditions" were commonplace, and workers donned respirators if they couldn't breathe. The job steps most likely to present these inhalation hazards included removal of the stator/rotor stack from the outer compressor shell, removal of the compressor stub shaft, removal and disassembly of shaft seals, compressor rotor deblading, removal of converter internal hardware in C-409, barrier disassembly in C-400, cutting of the valve purge pigtail, opening or removal of the bonnet flange of a stuck-shut valve, and disassembly of the stem gland of a valve with a leaking bellows. Although respirators were specifically recommended for these activities, their use was sporadic, as reported by those interviewed and by industrial hygiene/health physics personnel who occasionally monitored airborne contaminants and made recommendations for worker protection.



Converters

The potential hazards are best illustrated by an early 1970s event recounted by one interviewee. He was involved in removing the top of a 20-inch G-17 valve using air-arcing near the pump shop (at the edge of the C-720 fabrication shop). The valve was tagged, indicating that it had been decontaminated in C-400. However, when the top flange of the valve was lifted with the crane, gray smoke came pouring out and continued to smoke, affecting much of C-720. The crane operator (directly above the valve), who reportedly balked at evacuation because he had seen it happen before, passed out and had to be rescued. Before his evacuation, the interviewee and his supervisor, without any respiratory protection, tried to close the opening by using sledgehammers. Finally, they too had to leave the building without stopping the smoke, due to burning eyes and throats. Three individuals (including the interviewee) exceeded the threshold action levels for uranium on urinalysis. Although the next 24-hour samples were reportedly clear, all urine was collected from the individuals for the next eight weeks. A similar event occurred in C-720 in February 1986, when 100 people were evacuated and 40 were put on urinalysis, with seven on recall. Respirators were not worn for this work, and the JHA did not address the hazards of contaminated valves.

Compressor mechanics were also exposed to TCE during component degreasing. One interviewee indicated that while cleaning compressors, it was common to use TCE bare-handed (to reach into components) without respiratory protection. Rubber gloves were available for handling TCE, but he did not use them. Reportedly, workers did not have masks available for degreasing work, and he would often feel lightheaded from fumes.

During the 1970s and early 1980s, AEC/ERDA/DOE and Union Carbide undertook the most extensive of several campaigns to improve PGDP technology and exchange or replace aging equipment. All of the industrial, radiological, and chemical hazards discussed for normal compressor and converter maintenance were present, with the additional challenge of a demanding, manpower-intensive schedule for completing each task. Dedicated cell change-out teams were established to remove and replace cell components almost continuously. Tools for cell change-out were pre-positioned. Cell housings were opened even as operators worked to establish a UF_6 negative. Modified and refurbished compressors and converters were pre-staged in the process buildings with proper orientation, ready for emplacement once the cells were cleaned out and new saddles and support systems installed. Original cell components were disassembled, cleaned, modified, refurbished, reassembled, conditioned, and pre-positioned for another cell change-out, even as the original cell was being repopulated. Operators were prepared to perform leak checks, pre-operational tests, and cell startup as soon as maintenance approved the release of the various permits establishing their safety envelope. Many workers were hired to support CIP/CUP, but reportedly they did not get the same level of training as older workers; they were told to rely on more experienced workers while learning their jobs, principally through on-the-job training.

Practices to protect personnel from excessive exposure to airborne radioactivity in the shops evolved over time. In 1959, recommendations were made for additional dust control measures to minimize the potential for exposure. These included use of continuous water mist spray during removal of the compressor stack and collection of the resulting wash water, wearing air respirators in the C-720 pit area until lower air counts were obtained, disassembling compressors to three main components and removing them to C-400 for spray decontamination, wetting down compressor spool piece bolts prior to air tool removal, decontaminating compressor mating pipe flanges in the original cell area prior to grinding, and removing slag. Despite ongoing work to improve the local area exhaust in the C-720 converter shop, health physics also recommended thorough wetting of disassembly work while workers continued to wear respirators. In 1962, at least one sample of dust from C-400 compressor deblading showed 90 percent of its radioactivity from transuranics and fission products. Although dust was removed by vacuuming, the rotor was not wetted to control dust as required. Respirator use was noted to be “as required.”

By the mid- to late 1970s, health physics surveys of work practices, fixed and portable continuous airborne activity monitor analysis, and contamination surveys were routinely documented. During this period, the Health Physics and Hygiene Department was aware of the presence and increasing amounts of transuranics and fission products. The Health Physics and Hygiene Department emphasized the importance of respirator use during certain disassembly steps, encouraged the repair and improvement of local air exhaust systems, criticized the use of portable air movers for ventilation, and pushed for better tooling to minimize dust production. The Health Physics and Hygiene Department also noted inadequate respirator use, reportedly prompting correction by work supervisors.

As CIP/CUP progressed in the late 1970s, so did the degree of sophistication of the health physics survey reports. Levels of uranium, neptunium, plutonium, thorium, technetium, and uranium daughter products were routinely reported and discussed, with accompanying recommendations. Contamination surveys just outside the compressor pit area prompted a call for better housekeeping practices. Continuous air samples near the pit and adjacent machine shop indicated no significant spread of airborne radioactivity to the surrounding area. During obviously dirty job steps, respirators were reportedly used; however, respirator use was still observed to be lax during many short-duration tasks. A December 1975 shop memorandum required the use of respirators and local area exhaust for welding, cutting, grinding, buffing, and use of certain power tools on specified components.

In 1976, the Health Physics and Hygiene Department concluded that methods established to that date for control of personnel exposure during compressor maintenance were adequate, but emphasized the importance of maintaining these practices. The practices included respiratory protection using one-quarter or one-half respirators with radioactive aerosols or radionuclide filter cartridges for certain specified jobs; vacuuming loose material, dust deposits, and spilled material; wetting down compressor stacks with water before placing them in the disassembly stand; collecting wash water for delivery to C-400; and decontaminating compressor parts in C-400 after stack disassembly. Despite these recommendations, problems with respirator use continued to be reported (though less often). The Health Physics and Hygiene Department reminded management of the importance of respirator use while disassembling converters in C-409, particularly in light of the high levels of transuranics detected in solid deposits within the converters. Concern was again expressed over the lack of adequate local air exhaust in the C-409 converter shop areas where dust-producing activities were performed.

In 1977, continued attempts to establish adequate local area exhaust and stop the use of the air mover in the compressor pits were at first unsuccessful. The Health Physics and Hygiene Department recommended continued efforts to stop dust generation at the source as an ALARA principle. Further, the Health Physics and Hygiene Department recommended immediate action to provide adequate exhaust ventilation, supported in part by breathing zone air samples exceeding Plant guidelines for uranium, neptunium, and thorium by factors of 40, 22, and 15, respectively. The Health Physics and Hygiene Department also recommended continuing use of the vacuum collector system for loose deposits, keeping compressor components wet during use of pneumatic tools, and providing local air exhaust to all disassembly steps where practical. The Health Physics and Hygiene Department noted that additional local area exhaust was being designed and would be installed as soon as possible in C-409 to support converter disassembly work. The Health Physics and Hygiene Department also recommended the use of water sprays in C-400 to control dust during barrier disassembly. Respirator use was apparently improving during this period, as indicated by interviews and Health Physics and Hygiene Department reports.

In 1978, The Health Physics and Hygiene Department commended the shops for use of low-speed, high-torque wrenches and ventilation uprating by extending the vacuum system to an adapter on the pneumatic wrenches. Collecting the dust at the source of generation was noted to decrease concentrations of uranium by 98 percent and neptunium by 91 percent. However, individuals noted during interviews that this fix did not survive the rigors of compressor maintenance work and was later abandoned. No replacement mitigation equipment was remembered by those interviewed or observed in the C-720 pit by the investigation team.

Health physics surveys of the C-720-C converter shop in 1980 for the CIP/CUP indicated that Plant guides for airborne alpha activity were exceeded for uranium by a factor of 1680, neptunium-237 by a factor of 2121, plutonium-239 by a factor of 2483 and thorium-230 by a factor of 55. Even using conservative protection factors for the respirators used, these exposure levels were significant.

The levels of airborne contaminants resulting from these maintenance activities, supervisors' failure to enforce proper use of respirators, and employees' failure to wear respirators when required contributed to the high proportion of personnel who were on restriction for elevated levels of uranium in their urine and were CIP/CUP workers. For example, a sample of exposure records from the first half of 1978 shows that 20 of 29 urine samples exceeding the PGDP investigation level were from individuals involved in CIP/CUP activities.

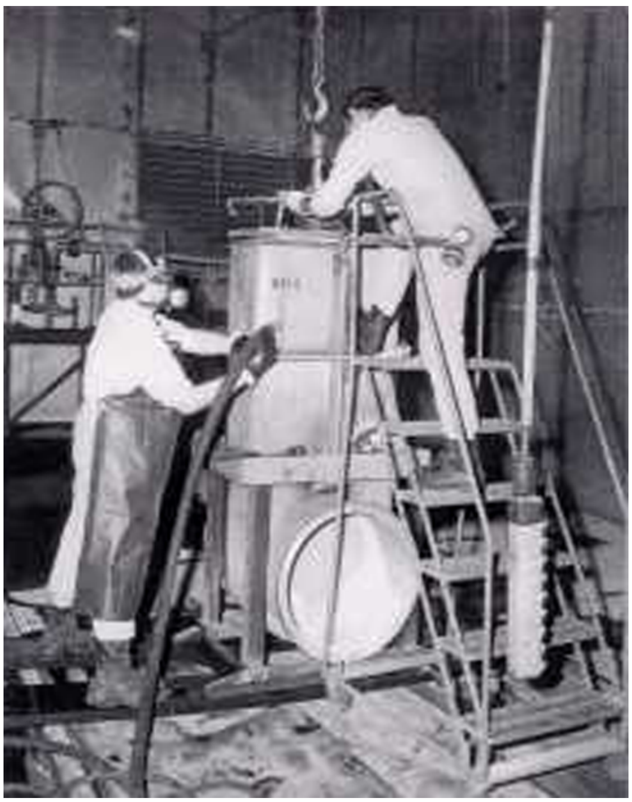
Cylinder Cleaning

With repeated reuse, UF_6 cylinders collected deposits that did not completely volatilize in the autoclave. Periodically these deposits, called "cylinder heels," had to be dissolved and removed, and the cylinder was then cleaned, refurbished as necessary, re-inspected, hydrostatically tested, and weighed for subsequent use. Cylinder heels were composed of corrosion products, uranium salts and oxides, and transuranic and uranium daughter product compounds. With regard to the neptunium contaminants of the process gas, most of the plutonium and technetium was volatilized to the cascade, while most of the neptunium remained behind in the cylinder heels, creating a significant radiological hazard. Cylinder cleaning was performed at Building C-400, where the heels were dissolved and the rinse water was collected in a large pan. Cylinder rinse water was used as the principal source for neptunium and technetium recovery in the late 1950s and early 1960s. Otherwise, liquid effluents were pumped to the tank farm for feed into one of the digesters, while workers shoveled sludge, which collected in the pan, into containers for further processing or disposal. Sludge reportedly was shoveled approximately once a month; workers were limited to 15-minute exposures, and it usually took four workers to complete the task. The Health Physics and Hygiene Department closely monitored worker activities.

Two documented beta overexposures occurred at the C-400 cylinder wash facility in the first quarter of 1968. The estimated exposures were 24 and 36 rem, whereas the quarterly limit for skin of the whole body was 10 rem. The two workers were standing in a metal tray used for collecting cylinder rinse water that was emitting several hundred rads of beta radiation. Interviews and documents indicated that in the early 1950s a decision was made that extremity monitoring was not required because it was felt that these doses were not likely to exceed 2.5 times the whole body exposure. The evaluation for the cylinder wash overexposure incident failed to completely evaluate this event and determine extremity dose.

Cylinder Valve Replacement

Each UF_6 cylinder is equipped with a manual cylinder valve. Occasionally, these valves were identified as defective and would be replaced. According to procedures that existed in the 1970s, any UF_6 cylinder was required to cool at least five days before its valve was replaced. Cylinders known to be above atmospheric pressure after the minimum cooling period would be cold-burped and further cooled, if necessary, with cold water. If pressure above atmospheric could not be relieved, the cylinder would be turned over to Chemical Operations in C-400 for special handling, which involved dedicated tanks used to further cool the cylinders to promote UF_6 solidification and pressure reduction.



Valve Maintenance

Cylinder valves were normally replaced in C-310, C-315, or the tails storage area. Interviewees also described valve replacement during the 1960s in the vicinity of C-400, after icing down cylinders. One interviewee indicated that until the mid-1970s, defective UF_6 cylinder valves were routinely replaced "on the fly" with the mechanic standing upwind and any escaping smoke going the other way. The applicable maintenance procedure in the 1970s and 1980s required respiratory protection to be worn; however, interviews suggest that although gas masks were available, they were not always utilized until a release of HF ("blow-out") occurred. The defective valve was slightly unscrewed to confirm that air would be drawn into the cylinder. Once a vacuum was confirmed, the valve was quickly removed and the replacement valve installed. If positive pressure was evident on the first attempt to change the valve, the original valve would be retightened and another attempt scheduled in not less than 24 hours. If positive pressure was still noted on the second attempt, the valve would again be retightened and the cylinder would be turned over to Chemical Operations in C-400 for special handling. Once the valve was successfully replaced with the proper torque and thread engagement, the defective valve was decontaminated and appropriately dispositioned. The new valve and cylinder combination was then inspected and pressure tested to confirm a successful repair.

In the event of a major UF_6 release from an open or broken cylinder valve, procedures in the 1970s provided guidance that personnel should be immediately evacuated from the area of the release, emergency assistance summoned, and available emergency ventilation maximized. Caution was provided to stay upwind of the release; that personnel required to enter the release area must wear Gra-Lite, Acid Master, or impermeable suits with self-contained air masks; that exposed personnel should report to the dispensary as soon as possible; and that all water in the area should be considered contaminated with HF and neutralized with soda ash. The emergency squad was expected to apply water to the cylinder to promote cooling and knock down the UF_6 cloud, stop the leak with a wooden plug or tape if the valve could not be shut, and (if that didn't work) cover the cylinder with a prefabricated box from C-310, filling the box with dry ice and covering with a tarpaulin. Once the cylinder could be cooled to the point of drawing a vacuum, the defective valve was removed and a replacement valve installed.

A Three-Plant UF_6 Cylinder Handling Committee convened in the mid-1970s and made a number of recommendations that affected PGDP cylinder valve replacement activities. Among the recommendations implemented by 1986 were the sole use of new valves for valve repair or replacement, modification of procedures for valve replacement to drop reference to freeze-down tanks at C-400 (although the tanks existed, onsite supplies of dry ice were insufficient for emergency or contingency use), and revision of site procedures to address the use of updated emergency release securing equipment and new studies indicating that water should not be used on liquid UF_6 releases.

The principal hazards to workers engaged in cylinder valve replacement were both radiological and chemical, involving the potential for inhalation of and exposure to UF_6, HF, and UO_2F_2. One person recounted an event where pressure in a 2-ton cylinder was found to be above atmospheric while he was attempting to clear ice from the cylinder-valve hole threads in preparation for inserting a new valve. He reportedly grabbed an available army assault mask and drove a wooden plug into the hole to stop the release. No exposure data specific to this mid-1960s event was obtained by the team. Another interviewee remembered several instances in the 1960s and 1970s when he and his partner were replacing 14-ton cylinder valves; UF_6 apparently had not completely solidified in the cold bath, and he and his partner were covered in yellow material. Both were wearing respirators and subsequently took showers to remove surface contamination. He believed that they were frisked after each UF_6 cylinder event and that such frisking was a normal follow-up to such an event. These descriptions of cylinder valve leaks while replacing valves were typical of a number of interviews.

Filter Bag Replacement

Filter bag houses existed in several buildings for both ventilation and dust collection. Replacing the bags in these systems was described as very dusty and the dirtiest work that could be assigned. Workers were periodically directed to replace the filter bags when needed because of excessive dust loading. Reportedly, filter bags needed to be changed once or twice a month, but the same individuals did not always get the assignment due to shift work. In the 1950s, workers reportedly secured the evacuation jet, donned army assault masks and a company-provided coat over their company-provided coveralls, draped towels over their heads and around their necks, taped their sleeves up, opened the enclosure, released the hose clamps in sequence, and carefully put the dusty bags in large barrels. Operators then vacuumed the remaining dust from the enclosure, and maintenance installed new filter bags, closed the enclosure, and started the evacuation jets again. The job frequently took half the day and had to be halted for lunch. Although workers were reportedly allowed to change into clean coveralls for lunch or after the job was done, most of those interviewed suggested that they seldom changed. Workers described blowing their noses after changing filters and obtaining a black discharge despite having worn the respirators. In the early 1960s, concern about radiological exposure resulted in reducing workers' times in the area to no more than 15 minutes, significantly less than previously allowed.

Some workers in C-340 and C-420 described changing filter bags without respirators or anti-contamination clothing. Sometimes they reportedly used small paper masks, even though they came out covered in green dust. If procedures existed for changing filter bags, workers did not recall seeing them. Other individuals remember occasional periods between 1968 and 1977 when the C-410 or C-420 bag houses were bypassed straight to the atmosphere whenever they got plugged or needed changing. Hazards to workers included airborne UF_4, uranium oxides, process dust, and alpha and beta contamination. Workers wore dosimetry devices and were subject to monthly bioassays. Respirators occasionally became plugged and were sometimes not used. When filter bag replacement activities were evaluated by health physics, they were found to be dusty and often presenting the potential for elevated external exposure. Air samples reviewed were found to be above the PGDP MPC.

Cooling Tower Chemical Treatment and Repair

The cooling towers were treated annually with fungicides, principally to protect wooden components from fungal attack and deterioration. Inspections in 1958 showed significant internal fungal attack. Several different chemical treatments were tested, some of which involved arsenic and chromate compounds. Additionally, much of the original redwood was replaced with pressure treated lumber. Finally, the commercially available wood preservative/fungicide pentachlorophenol (PCP) was selected.

As originally practiced, fungicide spraying involved operators climbing within the cooling tower structure with ladders, work platforms, safety ropes and guidelines, and finding perches on cooling tower structural members to stand on while directing the spray. The workers wore protective clothing and breathing apparatus. This difficult task was made more hazardous by the risk of slipping and falling. At least one worker fell within the confines of the cooling tower during repair operations. In the early 1980s, a modified in-place fungicide treatment process was developed that did not require any climbing within the cooling tower, thereby significantly improving safety and reducing the difficulty of the job.

Cooling Towers

During interviews, some former workers expressed concern about their activities on and in the dry cooling towers without respirators or special protective clothing, having previously seen the fungicide spray team in their air-supplied neoprene suits. A 1981 JHA for "Routine Cooling Tower Inspection" does not identify any inhalation or skin absorption hazards for cooling tower repairs, but does require that gloves be worn to avoid splinters. The 1987 version of this JHA requires, in addition, the use of a respirator with a GMC-H cartridge due to the possible presence of legionnaire's disease bacteria or asbestos fibers, the latter more likely in older cooling towers where the asbestos fibers have become friable. In neither JHA is there any mention of residual PCP as a potential hazard to individuals climbing on or in the cooling towers. No JHA or monitoring data was identified for carpentry work in the cooling towers.

3.2.7 Operations and Maintenance Summary

It is clear that during operations and maintenance activities at PGDP, many situations allowed workers to be exposed to both radioactive and chemical hazards. While workers were exposed to higher levels of radiation, especially beta radiation, than they were previously made aware of, monitored exposures were tracked and (with documented exceptions) did not exceed the standards of the time. In some situations, workers could have exceeded the standards, and those situations were not adequately monitored; consequently, some workers might have exceeded acceptable doses established for that time, especially to extremities such as hands and feet. Workers' failure to properly use PPE and supervisors' failure to enforce the use of PPE, especially respirators, contributed significantly to these radiation and chemical exposures. Finally, production needs in many aspects of operation and maintenance further contributed to worker radiation and chemical exposures. Examples included operating equipment with leaks, removing equipment without adequately venting the systems or removing deposits, and releasing uranium materials to the air without use of confinement systems.

4.0 Environmental Management Practices

PGDP operations have resulted in the release of a variety of contaminants into the environment through stack and diffuse air emissions; discharges through sewers into lagoons, local ditches, and streams; accidental releases; and past waste disposal practices such as the burial of low-level and hazardous waste.

The primary mission of the Plant involved the enrichment of uranium to support defense and commercial nuclear industries. The uranium used in the Plant was obtained both from commercial industries and from the recycle of reactor tails through separating irradiated fuel and targets. These reactor tails contained trace levels of transuranic and fission products, which were introduced into the enrichment system and the resulting waste materials. Uranium was the largest contributor to environmental contamination. Because uranium was a valued commodity, uranium releases and transfers were minimized from the start of Plant operations in 1952. A variety of chemicals were used directly in the feed production and enrichment processes, or used to in support operations such as cooling water treatment and cleaning.

Requirements relating to the release of chemical and radionuclides into the environment were limited in the early years of Plant operations. AEC established allowable limits for the release of radionuclides into the environment, but Federal and state agencies had few restrictions on discharge and disposal activities until the late 1960s. Releases from U.S. industrial operations during the 1950s and 1960s, including those at Paducah, were significant. Past PGDP operations resulted in a significant environmental degradation in the vicinity of the Plant due to the accumulation and transport of contaminants associated with past disposal and spill sites as well as release and migration of contaminants to local streams and groundwater. DOE submitted a RCRA Part B permit on February 8, 1985; this permit and a RCRA Hazardous and Solid Waste Amendments permit were effective on August 19, 1991. In May 1994, PGDP was listed on the National Priorities under CERCLA, and in February 1998, and DOE, EPA, and the Commonwealth of Kentucky entered into a Federal Facility Agreement for environmental remediation. On February 20, 1992, DOE and EPA entered into the Uranium Enrichment Federal Facility Compliance Agreement that regulating PCB removal and disposal at PGDP. Site remediation of environmental contamination is currently estimated to cost 1 to 2 billion dollars, and it will take more than 20 years to complete.

4.1 Waste Management

- *Solid Waste Disposal*
- *Hazardous Waste Management*
- *Radioactive Waste Management*

Construction and operations at PGDP generated a wide variety of waste and scrap materials beginning in the early 1950s. An integrated waste management program did not

ENVIRONMENTAL MANAGEMENT PRACTICES

- ***Waste Management***
- ***Management and Disposal of Scrap and Surplus Materials***
- ***Liquid Effluents***
- ***Atmospheric Releases of Radioactivity and Fluorine***

begin at the Plant until the early 1980s. Before the establishment of this integrated program, each organization at the Plant disposed of its own waste. The Maintenance Department provided support by operating a number of common disposal sites.

Former and current workers provided information regarding past waste disposal practices at the site. Former workers recounted past disposal practices that involved discarding waste materials at locations around the site. With few exceptions, these locations correspond to past landfills, scrap yards, lagoons, and spill sites that have been identified as SWMUs as part of the current cleanup program. Several other possible disposal locations were identified to site management for their evaluation.

The formation of an integrated program began in response to a December 1978 report by the site Environmental Control Department on disposal of solid waste (including radioactive and hazardous waste). This report stated that the Plant was not meeting current and planned solid waste regulations. In addition to the recommendations for better management of existing facilities and the need for additional facilities, the report recommended that specific individuals be made responsible for operation, maintenance, record-keeping, and planning of solid waste storage and disposal areas. The resulting organization, the MTM Department, implemented the integrated waste management program by gaining control of the waste management facilities and developing waste management procedures for the Plant.

Solid Waste Disposal

During construction of the original Plant, the prime contractor established an inert disposal site for construction rubble north of the Plant. Over time, this site continued to be used for disposing of construction materials. As the Plant became operational and generated hazardous and radioactive waste materials, contaminated materials were introduced into this disposal site, including contaminated roofing material and concrete, asbestos, and chemically treated wood from the cooling towers. On the southwest side of the Plant, a borrow pit was used to dispose of ash from the Plant's coal-fired steam plant, which was subsequently designated as the C-746-K landfill.

Over time, these two sites apparently evolved into landfills not requiring permits according to Commonwealth of Kentucky regulations; the Maintenance Department operated the landfills. The limit established during early site operations for radioactive material in these areas was 2 pounds of uranium per ton; however, no records of sampling were located to demonstrate compliance with this limit. For depleted uranium, the limit would correspond to a volumetric concentration of approximately 333 pCi/g or 670 pCi/g for natural uranium. Records from the 1960s and 1970s indicated that floor sweepings were disposed of at these landfills. Since process materials, including green salt and yellowcake, were routinely present in large quantities on floors and equipment in some buildings, it is clear that these radioactive materials, in much higher concentrations than allowed, were inappropriately sent to these landfills.

Site Posting - 1999

Within the Plant's security fence in the northwest corner, a 30-foot-high ramp and pit arrangement, known as the teepee, was used to burn combustible waste. As an aid to combustion, waste oils were added; however, these oils were not controlled and they were likely contaminated with solvents and PCBs. This operation continued until December 1, 1967, when air control regulations for open burning at disposal sites required termination. At that time, these waste streams were sent to the coal ash disposal site.

Although landfills were on government property and patrolled by Plant security, the public could access these areas. Some members of the public routinely retrieved scrap wood and others used construction items from the inert disposal site, starting during Plant construction and continuing into the 1970s. At the 746-K landfill, for example, redwood with brass bolts from the cooling towers and used wood paneling from Plant offices attracted salvaging from the public and possibly workers. Limited controls had been established on disposal of material from the cascade and other process and operations buildings in order to keep highly contaminated items from going to the landfill. However, when surveillances were conducted at the landfill in later years, such items would occasionally be identified, indicating weaknesses in the implementation of management controls.

Maintenance workers operated these disposal sites during the day, implementing verbal guidance from their supervisors. These workers used bulldozers and other heavy equipment to compact and dress the working areas. Since their equipment did not have closed cabs, the workers were exposed to both unconfined asbestos and ash from the coal-fired steam plant. As the Plant's heavy equipment operators, these workers also hauled construction rubble to both the landfills and the inert disposal areas around the Plant, including parts of what is now the Kentucky Wildlife Area. Concrete rubble and debris, some with radioactive contamination, was sent offsite to areas in the former KOW, a fact that was known due to environmental investigations conducted under the Federal Facility Agreement and predecessor environmental regulations and confirmed by the team through visual inspection and walkover radiological surveys. The limited space available for disposal within the Plant security fence probably affected the decision to discard these materials on the KOW.

In the early 1980s, additional controls were implemented at the landfills. These controls eventually included controlled access to the landfills, waste acceptance criteria, record keeping, and licensing both the landfill and the operators with the Commonwealth of Kentucky. Controls were also applied to waste generators. Segregated dumpsters for both non-hazardous and radioactive wastes were acquired, and procedures and guidance on acceptable disposal practices in the Plant's sanitary landfills were established.

Biodegradation Site - 1999

Hazardous Waste Management

Hazardous waste regulations did not emerge in the United States until the early 1980s. In response to these regulations, the newly created MTM Department began to aggressively address hazardous waste disposal practices by identifying and controlling these practices. As an example, a discontinued attempt to use biodegradation for waste oil treatment left a legacy of drums containing not only used oil but also waste solvents. The practice had involved disking waste oil into the soil along with nutrients to allow microbial biodegradation. Although the practice had ceased, generators continued to bring drums of waste liquids to the site. The MTM Department, as one of its first actions, worked with generators to identify other disposal options and characterize the drums already at the biodegradation site. This approach was repeated for other disposal sites across the Plant.

The existing waste streams in numerous disposal sites were evaluated by the MTM Department to determine the generators, who were then contacted to determine the process that produced the waste. Disposal options were explored that would be in compliance with emerging new requirements under RCRA. In addition, MTM Department personnel began to develop standard practice procedures for waste management, assigning responsibility for implementing pollution control programs to the generators with support from several organizations, including the MTM and Environmental Control Departments. Plant Services was responsible for operating the disposal facilities and recording waste transactions. As an example of tightening controls, the blanket request for disposal used before 1983 was cancelled and a "request for disposal" form was required for each waste pickup.

Concurrent with these activities, the MTM and Environmental Control Departments began working with regulators to obtain permits for storage, treatment, and disposal facilities at the Plant. These facilities ranged from the C-400 gold dissolver precipitation system to the C-410 neutralization pit. As hazardous waste streams were identified and brought under control, storage needs were met by using several existing locations for storing all types of materials and waste. Subsequently, these facilities were permitted under the Commonwealth of Kentucky RCRA authority, with the RCRA Part A permit submitted on February 8, 1985, and the RCRA Part B permit effective on August 19, 1991.

Wastes were characterized only to determine compatible storage requirements; this characterization was not sufficient to ensure long-term storage and satisfy final disposal acceptance criteria. In 1987, for example, 840 ash receivers from the 1977 shutdown of the feed plant that were stored in C-746B, a radioactive waste storage facility, were determined to also be hazardous under RCRA. Therefore, this facility became a non-permitted RCRA storage facility until the ash receivers could be overpacked and moved to a permitted RCRA facility. The limited degree of characterization has resulted in storage problems and a need for very large recharacterization efforts at the Plant, as discussed in the Office of Oversight Phase I investigation report.

Oversight for hazardous waste activities also increased from being a subset of landfill reviews to being focused inspections. In the 1970s, OR conducted annual appraisals of the C-746-K landfill and of water and air pollution control facilities at the Plant. These appraisals increased in scope and duration in the 1980s, with a section specifically focused on hazardous waste management practices. In addition, external regulators began inspecting RCRA facilities and operations in the 1980s. Generally, these appraisals and inspections praised the waste management programs. However, problems were identified, including Notices of Violation in 1985 for not performing detailed chemical and physical analysis, and concerns about contingency planning with local authorities and incomplete contingency plans. A Notice of Violation was issued in 1986 for routine disposal of sludge determined to be hazardous in the C-404 facility, which had not been permitted for hazardous waste. Conversely, the Plant also conducted evaluations to determine whether private disposal sites were adequately operated and capable of disposing of Plant waste in accordance with applicable environmental regulations.

Radioactive Waste Management

Radioactive waste management has been evolving since the 1950s. In April 1953, efforts were initiated to reduce the spread of contamination by using drums designed for disposal in work locations known for generating highly contaminated waste. Operating logs in C-340 from 1958 discuss using a supply of scrap drums from the holding pond for packaging black oxide rather than putting the oxide in dumpsters. Actions to segregate these wastes from the Plant's other waste streams resulted in establishing radioactive disposal sites. Although several small sites were used for special disposal activities, including contaminated aluminum and a modine trap, the Plant had three main radioactive disposal sites:

- C-749 Uranium Burial Ground. Used from 1957 to 1977, this site primarily contained pyrophoric uranium metal in the form of saw dust, shavings, and turnings covered in oil. The total amount of uranium placed in this site is approximately 540,000 pounds.

- C-340 Drum and Contaminated Burial Area. Used from the late 1950s until the mid-1970s, this area received C-340 uranium powder scrap. In the 1950s, 50 to75 drums were emptied into a pit 10 feet by 20 feet, and 7 feet deep. In the 1970s, two more 7-foot-deep pits were used for disposal of contaminated metals and equipment.

- C-404 Solid Radioactive Waste Disposal Area. This was the primary disposal site for radioactive waste at the Plant. This area was constructed as a holding pond for C-400 liquid waste, but in early 1957, it was converted to a solid waste disposal area. The pond was 380 by 140 feet, with 6-foot-high dikes. By 1977, approximately 6,400,000 pounds of uranium had been drummed and placed in the holding area. Waste streams included incinerator ash, contaminated alumina, highly contaminated roofing waste, and gold recovery sludge. This area continued in use into the mid-1980s. Subsequently, this area was determined to contain sludge that was also hazardous, thus requiring closure under RCRA in 1987.

After the formation of the MTM Department, radioactive waste disposal on site rapidly decreased. In 1978 and 1979, the amount of disposal was 330,690 pounds per year; in the 1980s, the average was 18,000 pounds per year. As a result of not burying radioactive waste on site and restrictions for offsite disposal, the site experienced a large buildup of contaminated waste and scrap, as discussed in the Office of Oversight Phase I investigation report.

4.2 Management and Disposal of Scrap and Surplus Materials

Large volumes of scrap metal and surplus materials were generated during construction, maintenance, and facility upgrade activities at PGDP. These materials were either managed as waste for disposal or stored and managed as a commodity for resale. Much of the material was contaminated, and large volumes have been disposed of on site. Additionally, large volumes of scrap metals remain in outside storage pending resolution of policy issues associated with the resale of contaminated materials.

As part of scrap metal activities at the Plant, generators were responsible for requesting disposal containers for contaminated and clean scrap metal and then inspecting these containers to determine proper usage. The Material Services Department established and maintained approved scrap yards, and the Maintenance Services Department collected and transported the containers. In addition, special responsibilities for classified scraps were defined in a standard practice procedure. This procedure, dated July 24, 1969, identified four scrap yards: C-746F for buried classified material; C-746E for contaminated material; an unclassified burial yard; and C-746C for clean material (defined as less than 1000 alpha c/m/100 cm^2 and less than 0.3 mrad/hr beta-gamma). This 1969 procedure also required supervisors to determine whether contamination was sufficient to warrant recovery at the C-400 decontamination and recovery area. If not, the scrap was sent to one of the four disposal yards. Source areas for scrap metal included the C-340 metals plant, the cascades, the C-410 and C-420 feed plant, the C-720 fabrication and maintenance shops, and the laboratories. Part of the scrap was buried directly (classified material); however, as the disposal areas were filled, non-classified material began to accumulate in above-ground piles that still exist. These yards and disposal locations are now identified as SWMUs for investigation and possible cleanup under the current restoration program.

Some of the metal components, equipment, and vehicles at PGDP had significant inherent value, including a large amount of material that was considered scrap as a result of upgrades or replacement of equipment and process piping. Consequently, management wished to sell to interested parties as much of this material as was possible. Based on Plant health physics records, it was clearly understood as far back as the 1950s that "contaminated" material above certain limits could not be sold or released to the public. Therefore, the handling and disposal of scrap materials was subject to the corporate procedures described above. While contamination limits and specific categories changed over the years, scrap was required to generally be categorized into one of four groups: classified scrap, unclassified clean scrap, unclassified contaminated scrap, and unclassified non-metal trash. Dumpster pans were provided for each of these categories wherever significant quantities of scrap were generated. Line supervisors were responsible for ensuring that employees segregated all scrap materials appropriately. Once full, these dumpsters were hauled to a designated location. The material categorized as clean unclassified scrap was taken to the C-746C clean scrap yards for placement and preparation for public sale.

Interviews with former and current health physics workers indicated that they believed materials released to the public were surveyed for radioactive contamination. However, the surveys were primarily cursory, consisting largely of periodic inspections and spot-checking of suspect materials in the clean scrap yards based on process knowledge. Vehicle floorboards and seats were also said to be spot-checked before sale to the public, but the process was informal and was not required by procedure. The Health Physics and Hygiene Department was on the distribution for notices of pubic sales and was aware of their responsibility to survey "suspect" items to be sold. Documentation that proper radiological surveys were performed was not consistently maintained until the late 1980s, when the Health Physics and Hygiene Department began to place more emphasis on maintaining formal records for radiological release of material and equipment from the site.

The likelihood that contaminated items were released to various parties during public sales is highlighted by internal memoranda from the mid-1970s. One memorandum calls attention to the fact that the site was doing a less than adequate job of segregating clean from contaminated scrap and that contaminated scrap was often found in clean scrap locations. In May 1976, a health physics inspection of the C-746C scrap yards identified a number of prohibited contaminated items, most notably a 30-gallon drum of uranium metal shavings. A Scrap Handling Committee was formed in mid-1976 to study PGDP solid waste disposal problems, including the issue of segregating contaminated scrap. Some modifications to scrap handling procedures were made; however, a 1977 memorandum indicated continuing problems in this area, particularly with proper implementation of the procedures. Radiological surveys of several older DOE vehicles still present at the site were conducted during this Office of Oversight investigation. These surveys revealed contamination in areas not likely to be detected in cursory surveys of floorboards and seats, such as in the tailgate of a station wagon and in the motor housing and forks of a forklift.

4.3 Liquid Effluents

Liquid effluents were historically released in a number of ways, including via the sanitary sewage and storm water drainage systems. Eventually, effluent material that was not otherwise held up or recovered through wastewater treatment and recovery systems flowed to one or more of the various site outfalls and ditches and then into either the Big or Little Bayou Creeks, which ultimately discharged to the Ohio River.

In the early 1970s, the Clean Water Act established the NPDES, which administered effluent limitations and water quality requirements for chemical releases. These programs could be administered by the states after Federal authorization. In Kentucky, these were known as KPDES permits. The first one was issued for the recirculating cooling tower blowdown water. Subsequently, a total of 18 outfalls were permitted at the site. Liquid effluent discharge limits for radionuclides were not specifically promulgated by EPA, but were always required and published under the AEC and ERDA regulations and later DOE orders as MPC or RCGs in water. Despite the discharge restrictions, it is clear that over the years, enough radionuclides have been released to create legacy environmental contamination; the existence of legacy contamination has been confirmed through environmental sampling data.

Process and Stormwater Flow Near Outfall K001 - 1999

The most significant liquid radiological effluent source was the C-400 decontamination building. This building contained a variety of systems and processes for isotopic recovery and decontamination of process equipment and scrap metal, as well as the sitewide laundry. Given the nature of operations in this facility, managing the various types and quantities of liquid wastes generated was a significant challenge. These wastes included TCE from degreasing operations, contaminated liquids from cleaning operations, and various contaminated raffinate solutions from uranium, neptunium, and technetium recovery operations. For radionuclides, essentially all isotopes at the site were present in various portions of this facility and in its liquid waste streams, including uranium, neptunium, plutonium, thorium, and technetium.

Uranium recovery operations in this building were used to recover valuable uranium materials and also to reduce the uranium concentration in cleaning liquids to acceptable levels before release. Neptunium and technetium recovery campaigns were also conducted at various times during Plant operations. Liquid effluents from these operations and others that generated contaminated liquids were sampled before being released to drainage systems. If the applicable limits were not met, the material was either put in drums and stored or routed back through the uranium recovery process. Liquids that met the discharge limits were released to the North-South Diversion Ditch and outfalls, depending on the piping sequence. In 1972, Union Carbide reported that from 1956 to 1970, the uranium recovery system discharged a total of 4000 grams of neptunium and 191 grams of plutonium to the environment. A 1977 internal memorandum indicated that the then-current method of estimating uranium discharges significantly underestimated the releases.

A review of past correspondence identified instances where specific decisions were made to discharge waste materials containing uranium, transuranics, and fission products directly into local ditches. In 1963, the AEC authorized a request by the site to release thorium-, neptunium-, and uranium-contaminated raffinate solution being stored in drums to the Ohio River via a diversion ditch. The request stated that the discharge would be controlled to keep the concentration of the materials in the river below permissible limits. The request was granted by the AEC, effectively allowing the point of compliance for liquid effluents to be the Ohio River, rather than local ditches and streams. This decision may have been a misapplication of AEC regulations concerning maximum permissible concentrations of liquid effluents in unrestricted areas. This type of approach has contributed to elevated isotopic concentrations of uranium, thorium, transuranics, and fission products found in ditches and outfalls both on and near the site today.

One of the other large sources of contamination from C-400 was the massive amount of TCE used for degreasing operations. TCE contamination emanating from this building was significant and probably occurred over a number of years. For example, in 1986 while upgrading an unfiltered storm water line leading to Outfall K015, a subcontractor discovered a large volume of TCE during an excavation. It is not known how long this release had been occurring, and the quantity of TCE released was never determined. Normal operations presented numerous possibilities for TCE releases in addition to those that have been documented. For example, TCE releases are likely to have been associated with C-720 compressor pit operations, as evidenced in part by the existence of the southwest TCE plume.

Interviews with past workers confirmed the accepted practice of disposal of TCE down building drains not only in C-400, but also at many other process and support facilities on site. This practice occurred from the early Plant operations through the 1970s. Workers also confirmed that TCE was periodically dumped onto the ground at locations near numerous process and support buildings and during cleaning operations in the switchyards. There was apparently a belief that the material would evaporate quickly and cause no harm to the environment.

The outdoor storage and placement of contaminated waste and scrap that began in the late 1950s (e.g., Drum Mountain and scrap yards) has continuously contributed to the spread of contamination through surface water runoff. Contaminants settled in onsite ditches and streams. As a result, in the late 1980s efforts were undertaken to characterize and plan for remedial measures to address these contaminants. Limited removal and access controls were established in the 1990s. The Phase I Oversight investigation provided additional characterization of the contaminants in streams and ditches in the vicinity of the Plant.

Drum Mountain

From the beginning of PGDP operations, the C-615 sewage treatment plant treated sanitary wastewater (sewage and sink wastes) from process and support buildings. Radiological components of treated water caused the sewage sludge to be contaminated with uranium. Subsequently, this material was unknowingly spread at various locations at the site, creating contamination control problems. In 1977, the C-616 wastewater treatment plant came on line. Major liquid effluent streams that feed into the North-South Diversion Ditch were then routed by a lift station to the 616 facility, resulting in a significant improvement in water quality in local streams.

The major component of liquid process waste during early Plant operations was the recirculating cooling water—approximately 500,000 gallons per day, with a 20 ppm concentration of chromium. An additional 80,000 gallons per day of cooling and scrubber tower water contained soluble fluorides. The cooling water was pumped to Little Bayou. At one time, the Little Bayou was a dead stream in parts and was actually colored yellow by the chromium from the cooling water. In response to changing Federal requirements for pollution control, the use of chromium in cooling water was phased out.

4.4 Atmospheric Releases of Radioactivity and Fluorine/ Fluorides

- *Stack Emissions*
- *Accidental Releases*
- *Diffuse and Fugitive Emissions*
- *Planned Emissions*

Radioactive and fluorine/fluoride air emissions to the atmosphere began with startup in 1952 and have continued to the present from USEC operations regulated by NRC. The air emissions from the site were from process stacks, diffuse and fugitive emission sources, accidental releases, and a limited number of planned releases.

Stack Emissions

The site did not perform stack monitoring until the mid-1970s, so the actual quantities of radionuclides released to the environment from routine operations before that time are unknown. From 1959 to 1974, the air emission reports consisted of ambient air monitoring.

Starting in mid-1960, continuous ambient air samples were taken at four locations at the perimeter fence and were analyzed for alpha and beta activity to provide input for estimation of annual ambient air concentrations. In 1961, four additional ambient continuous air samplers were installed one mile outside the perimeter fence. Since stack emissions were not measured from 1952 to 1974, the Health Physics and Hygiene Department estimated emissions based on Plant operations. Interviews indicated that the estimates were probably within a factor of two but could be off by as much as a factor of five. It was not clear whether accidents that occurred during this period were considered in the emission estimates.

The first environmental report indicating stack emissions of uranium and technetium were prepared in 1976 for the 1975 calendar year. Environmental reports for the years after 1975 also reported annual discharges to the atmosphere based on stack measurements.

The site, using available information, estimated that approximately 60,000 kg of uranium was released to the atmosphere between 1952 and 1990. Of the total, approximately 75 percent was estimated to have been released before 1965. Most of the estimated releases were attributed to the C-410 feed plant and the C-340 metals plant. C-410 was shut down in 1962, reactivated in 1968, and finally shut down in 1977; C-340 was first shut down in 1964, reactivated in 1968, and finally shut down in October 1973. When these plants were shut down, estimated air emissions from the site were greatly decreased. The calculations and methods for these estimates could not be located during this investigation.

The release of fluorides is tied closely to releases of uranium. Airborne releases of UF_6 hydrolyze with the water vapor in air to form HF. Routine releases and leaks of this material have resulted in deep etching of glass windows in a number of process buildings at the site. If the form of the uranium releases were known for the listed estimated uranium emissions, the amounts of fluoride released could be estimated. Since approximately 75 percent of uranium emissions were thought to have been released before 1965, it is probable that significant fluoride emissions occurred during the same period.

From 1959 to 1990, the air emission reports consisted of ambient air monitoring results for fluorides. Starting in mid-1960, the continuous ambient gaseous air samples at the four perimeter fence locations were analyzed for gaseous fluorides to support estimates of annual ambient air concentrations. Then, in 1961, the four additional ambient continuous air samplers one mile outside the perimeter fence were used. However, actual stack monitoring of fluoride emissions did not occur until the mid-1970s. The first environmental reporting of fluorine stack emissions that was found was for 1986 emissions; only limited information was found for stack emissions of fluoride prior to 1986. For the period 1986 through 1990, annual discharges to the atmosphere were reported in annual emission reports based on stack measurements.

Accidental Releases

A number of accidental releases to the atmosphere have occurred at PGDP. This Office of Oversight investigation examined several lists of accidents. One of these lists, associated with UF_6 releases from cylinders, identified 15 accidents that released more than 50 pounds of UF_6. Another listing identified about 300 material releases (most of them accidental) from July 1, 1952, to July 1, 1972. These included releases to the atmosphere and some discharges to water. Sixty-nine (excluding routine stack emissions) were probable airborne releases of more than 10 pounds of uranium each. No evidence could be found that any of the accidental releases were analyzed using a meteorological model for assessing whether there were any significant acute doses to the public.

From 1960 to 1974, heavy reliance was placed on ambient air samples for assessing impact on the public. However, ambient air samples were not always available, and they only measure plumes at ground level. Lofted plumes might not be measured, depending on the meteorological conditions. Plume lofting is expected during accidental releases of UF_6, since the reaction between the UF_6 and water vapor releases heat. The expected plume lofting was observed during two accidental releases on May 20, 1958. An attempt was made to sample the plumes downwind from the Plant. The first plume was observed to intersect the ground, while the second plume remained elevated. In addition, based on the results of a limited set of measurements, the statement was made that established MPCs were not exceeded for this release. This conclusion is probably valid; however, such conclusions are only generally valid for a well designed field test run under ideal conditions where peak concentrations can be observed. During the second set of measurements, the plume was elevated, and only the maximum concentration at the ground near the Plant and under the elevated plume was reported. In this case, the peak concentrations in the plume were probably not observed.

In addition to accidental releases of uranium, a number of accidental releases of HF occurred. For example, an analysis was performed in 1975 to explain high gaseous fluoride readings in the ambient air samples. In this occurrence, system failures in the feed plant were attributed to the high readings. Other accidental or unplanned releases have also occurred. For example, several former and current workers interviewed reported blue flames 10 inches high in the classified landfill after a heavy rain.

Diffuse and Fugitive Emissions

Diffuse and fugitive emissions were generally not calculated for the site from 1952 through 1990. A limited set of data exists for releases during the mid-1950s from some processes, such as uranium metal pickling, smoking ash receivers, and drum dryer exhaust. Workplace air samplers and contamination on roofs and ground in the site area point to the occurrence of unmonitored releases. One example is the C-404 Holding Pond. Uranium-contaminated water was originally piped to the pond, and in 1957 the pond was turned into a solid waste burial area. A ramp was later constructed to reduce dust emissions from the area. After the mid-1960s, the ambient air samplers could have reflected some air concentration contributions to diffuse and fugitive emissions. However, no modeling studies were performed to evaluate how those samples might represent these emissions. Also, only low volume samples were taken. This Oversight investigation found no evidence that the performance of the low volume ambient air sampler network was ever evaluated under a variety of wind and weather conditions. There was no evidence that diffuse and fugitive emissions were substantively included in release inventories and subsequent public dose calculations. Also, even though diffuse emissions of transuranics would have occurred during pulverizing of the feed plant receiver ash, no estimates of these emissions were found.

Diffuse and fugitive emissions of fluorides were not calculated for the site from 1952 through 1990. In addition, the investigation team did not have sufficient information to estimate releases of fluorides using the limited set of data for uranium releases during the mid-1950s. However, as discussed under UF_4 and metal production (see Section 3.2.3), the release of fluoride from the production of UF_4 was the probable cause of ecological damage in the areas around C-340.

Planned Releases

Four planned atmospheric releases of UF_6 occurred at PGDP: two 4.4 kg releases in 1955 and two 0.68 kg releases in 1974. These releases were designed to model plume behavior from a surface release and were followed by an additional series of tests where approximately 160 grams of UF_6 was released at ground level directly into the atmosphere. Finally, six releases occurred in the 1975-1976 timeframe, involving a total of approximately 1 kg of UF_6.

As described in Section 3.2.2, there is some evidence that planned releases occurred when preparing the cascade cells for maintenance. Jetting of the cells, possibly to decrease the concentration of uranium in the cells, was accomplished by releasing UF_6 from vents on the roofs of the process building. The frequency and amounts of the releases are unknown. Because a large quantity of uranium could have been involved, jetting of the cascades could be a major contributor to the annual releases. Interviews with the former health physics manager revealed that contaminants jetted to the atmosphere in cascade buildings were not factored into release estimates.

4.5 Environmental Management Summary

The waste management program at the Plant reacted to external requirements. The waste management program that was implemented during the 1980s eventually was able to correct waste activities that had been inadequately managed for years. However, large volumes of waste materials accumulated on site with inadequate characterization for waste classification and disposal. Controls on waste disposal practices were not stringent or fully implemented in the early years of Plant operations, resulting in the creation of numerous disposal sites at the Plant. Additionally, based on employee interviews and a review of procedures and correspondence, it is clear that radiological waste materials were inappropriately disposed of in old and sanitary landfills used at the Plant before the sanitary landfill was permitted by the Commonwealth of Kentucky. Interviews with current and former workers identified locations where waste was discarded around the site from the very early days of operations. With few exceptions, these locations correspond to past landfills, scrap yards, lagoons, and spill sites that have been identified as SWMUs as part of the current cleanup program under the Federal Facility Agreement.

The Health Physics and Hygiene Department has recognized the need to ensure the proper segregation of clean from contaminated materials prior to their release from the site. However, there were documented problems associated with proper implementation of scrap handling procedures and only a very small number of health physics personnel available to perform radiological surveys. Therefore, it is likely that materials exceeding appropriate radiological release guidelines were sent off site on a routine basis until the late 1980s.

Past liquid effluents have had a significant adverse impact on environmental quality with respect to onsite ditches and streams and groundwater resources in the vicinity of the site. Operations at C-400 produced the most significant radiological effluent, releasing uranium, thorium, and small quantities of fission products and transuranic isotopes in process effluents. Additionally, C-400 operations also released significant amounts of TCE from cleaning operations into the environment, resulting in significant environmental liabilities for the Department. Interviews and documents indicate that from the beginning of Plant operations, Plant personnel made deliberate decisions regarding radioactive effluent releases, with the objective of ensuring acceptable impact on the quality of the Ohio River. Significant efforts were undertaken to improve the quality of area surface waters during the 1970s, consistent with increasing regulatory requirements and an increased sensitivity to environmental protection.

There is evidence that air emissions from 1952 to 1990 exceeded previous estimates. Stack monitoring was not conducted until the mid-1970s; before then, process knowledge was used to estimate potential releases from this pathway. Personnel who performed these estimates acknowledged that these calculations are highly uncertain. It was also acknowledged that other isotopes, such as plutonium and neptunium, could have been released, but based upon the limited quantity, these isotopes were considered to be insignificant contributors to dose. Therefore, these isotopes were not included in published estimates. Process gas releases were common throughout 1952 to 1990, and the potential for these to be vented to the atmosphere was high. The magnitude of these unmonitored releases is unknown. Additionally, unauthorized purging of cascade cell gases through the process of jetting appears likely to have been another significant pathway for unmonitored releases, which have never been estimated or factored into known uncertainties. Given all this, it is apparent that past estimates of public dose have a questionable level of accuracy and conservatism.

5.0 Findings

In the 1950s and 1960s, the workers and management at the PGDP, then the area's largest employer, were performing highly important, technologically challenging, and secret work contributing to the national defense. In the midst of the Cold War, the number one priority at PGDP was the production of enriched uranium. Federal and Commonwealth of Kentucky standards for safety and health were just beginning to evolve. Environmental protection standards were limited, and restrictions on waste disposal and environmental discharges were rudimentary. ES&H practices have evolved and improved over the years of Plant operation as knowledge was gained about hazards and controls and as new Federal regulations required improvements, especially in the 1970s, in activities affecting the environment.

Health and safety programs were established before startup at PGDP and included policies, procedures, training, monitoring, and equipment for protecting personnel from hazards at the Plant. Industrial safety was emphasized, with safety committees, publications and posters, frequent safety meetings, and JHAs developed early on for most work activities. The Health Physics and Hygiene Department performed studies of hazards and health effects and surveys and evaluations of working conditions. They also provided line management with recommendations for engineering and administrative controls for hazards. PPE, such as coveralls, gloves, safety glasses, hearing protection, shoes, and respirators, were provided or made available to workers deemed to need them. A variety of personnel monitoring methods, including film badges, urinalysis, and lung counting, were used to determine their exposure to radiological and some chemical hazards and to monitor responses to significant intakes and exposures.

Although the intention to protect workers from the radiological (including transuranic) hazards was apparent, the implementation of the radiological protection program at PGDP was very inconsistent between 1952 and 1989. Limited health physics staffing, a failure to communicate exposure levels and transuranic hazards to workers, worker failure to follow radiological control measures, a failure to consistently enforce radiological control measures, and a lack of adequate understanding and appreciation of the hazards of uranium and transuranics all contributed to inconsistent implementation. The lack of understanding was illustrated by crude experiments at PDGP designed to measure excretion rates, including voluntary inhalation and ingestion of uranium compounds to cause intakes. Line management was responsible for ensuring personnel protection and compliance, and the Health Physics and Hygiene Department staff were advisors only, having no enforcement role. Rigid "need to know" AEC security requirements, a predominantly military veteran workforce, and job insecurity all contributed to an unquestioning attitude, a lack of understanding of hazards, and the resulting inconsistent compliance with controls. An additional impediment was the physical discomfort of wearing ill-fitting PPE, including early styles of masks and respirators, in the often hot and dirty work environments in many areas of the Plant.

There was a widespread belief that uranium did not present a significant health risk to workers. Consequently, eating, drinking, and smoking in contaminated areas; failure to wash or remove contaminated clothing before entering the cafeteria; and wearing contaminated clothing off site without monitoring all occurred during this period. The Health Physics and Hygiene Department assumed that nearly all uranium ingested or inhaled was soluble and quickly excreted from the body without harm or long-term effects. In fact, aerosols of insoluble uranium compounds were generated in some work areas, such as in the feed plant, and by maintenance activities, such as grinding, buffing, and welding. Many hazard controls were recommended or implemented after significant exposures or as a result of high bioassay or air sample readings rather than in a pre-planned, proactive manner. Although ALARA and its predecessor concepts were stated policy, they were not actual practice.

The presence of transuranics including plutonium and neptunium, with a higher specific activity and exposure potential than uranium, constituted a significant inhalation hazard for workers. This was especially true for workers engaged in activities where the transuranics were more concentrated or where there was airborne exposure, such as feed production, ash handling, neptunium recovery, metals production, reactor tails feeding or product withdrawals, and cascade improvement and modification activities. The need for extremity (hand or foot) monitoring for workers performing activities in or near high radiation fields was not recognized, and overexposures may have gone undetected. The presence of transuranics and the reasons for additional controls were not shared with workers. Exposure history was also not provided to workers unless requested. These practices contributed to inconsistent compliance with PPE recommendations.

Airborne releases of radiological and chemical materials were frequent in the 1950s, significantly decreasing in frequency and quantity after the mid-1960s. In some cases, these releases were not adequately monitored, documented, mitigated, or reported. Until the mid-1970s, uranium and fluorine were released unmonitored from process, feed and metals production, and cleaning (decontamination) building stacks. Intentional and improper cell venting to the atmosphere on the backshifts ("midnight negatives") reportedly occurred. "Puffs" of UF_6, HF, and fluorine resulted in hazards to workers, and accidents resulted in the release of visible clouds of UF_6 gas on and off site, often without adequate monitoring or documentation. Acute and chronic exposures to chemical hazards such as TCE, PCBs, and HF occurred, and the potential risks of such exposures were not fully recognized by workers or the Health Physics and Hygiene Department. Exposures to HF resulting in burns, respiratory distress, and bleeding were frequent in the 1950s and 1960s, and their potential long-term health effects are unknown. The determination of the long-term consequences of potentially unmonitored or chronic exposures to radiation and other hazards was outside the scope and resources of this investigation.

Early waste disposal practices at Paducah were consistent with general industry practices at the time and included burial, dilution, and incineration. By today's standards, there were numerous examples of inadequate control and monitoring of liquid effluents, including radiological and chemical waste streams. Uranium solutions were channeled into the sewage treatment system and later contained in the sewage sludge used for fertilizer on site; contaminated laundry solutions were discharged or dumped into lagoons and into the North-South Diversion Ditch; and acids and chromates were discharged into the Bayou Creeks at such levels that DOE had to purchase the property adjoining Little Bayou Creek. PCBs and TCE were discharged to the ground, and liquid radiological and chemical wastes from process operations were discharged to unlined lagoons, ditches, and creeks. Ongoing monitoring and remediation programs are addressing the impacts of legacy contamination from these historical discharge practices and events.

Unsegregated radiological and chemical materials and waste were dumped or buried both inside and outside the fence on DOE property and were not controlled or documented. For example, contaminated concrete rubble and contaminated roofing materials were dumped outside the fence; contaminated sewage sludge was placed in landfills or on site lawns as fertilizer; and contaminated drums, equipment, and materials were dumped in lagoons, burial holes, or piles. Identification, characterization, and remediation of these legacy waste issues are ongoing programs at the Plant.

To put PGDP conditions and activities into perspective, it must be considered that almost 50 years ago there was a significantly smaller body of knowledge about radiation, chemical, and other industrial hazards and their effects on humans and the environment. Global political conditions were different, and attitudes towards openness, worker protection, and environmental stewardship were less sophisticated. Industries, including the AEC/ERDA/DOE complex, were largely self-regulated; guidance and standards were evolving. Although some PGDP exposures may not have been identified and recorded, and those that were measured are high by today's standards, only two reported exposures were above the governing regulatory limits. Total PGDP exposures were generally comparable to similar activities across AEC/ERDA/DOE, Defense Department facilities, and commercial nuclear plants at that time.

APPENDIX A
TEAM COMPOSITION

To reflect the investigation team's overall mission of determining whether ES&H activities and practices from 1952 to 1990 were consistent with the knowledge, standards and local requirements applicable at the time and to identify any ES&H concerns that had not previously been documented, investigation activities were organized into two groups: management and worker safety, and environmental management. Each group was composed of a group leader and individual members with relevant expertise. Each group developed lines of inquiry that guided the evaluation scope of interest for that group. The specific activities of the investigation team are discussed in Section 1.3.

The team composition and areas of responsibility are shown below.

Senior Manager

S. David Stadler, Ph.D.

Team Leader

Patricia Worthington, Ph.D.

Management and Worker Safety Group

Brad Davy - Group Leader
Marvin Mielke, RN
Bill Cooper, CSP
Bill Miller
David Berkey*
Robert Compton*
Ed Stafford*
Al Gibson*
Joseph Lischinsky, CHMM*
Tim Martin, PE*
Jim Lockridge, PE, CIH, CSP*

Environmental Management Group

Bill Eckroade, REM – Group Leader
Vic Crawford, PE, REM
Arlene Weiner, REM*
Mario Vigliani, CHP*
William Davis*

Communications and Support

Regina Griego
Mary Anne Sirk
Barbara Harshman
Bob McCallum
Larry McCabe

Quality Review Board

S. David Stadler, Ph.D.
Raymond Hardwick
Thomas Staker

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* Technical Advisor

CIH – Certified Industrial Hygienist
CSP – Certified Safety Professional
REM – Registered Environmental Manager
PE – Professional Engineer
RN – Registered Nurse
CHP – Certified Health Physicist
CHMM – Certified Hazardous Materials Manager

APPENDIX B

PRINCIPAL HAZARDOUS ACTIVITY EVALUATION SUMMARY

Table B-1outlines the principal hazardous activities conducted at PGDP between 1952 and 1990. This table provides an assessment of the hazards encountered by these activities, the controls used to mitigate the hazards, and the effectiveness of the controls. Acronyms are defined at the end of the table.

Table B-1. Paducah Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1952-1990

Description	Plant Location	Hazards	Controls	Effectiveness	Time Period
Ash handling (or hot hauling)	C-410, C-746B, C-400	RAD, exposure to UF_6 gas, and inhalation of dust containing uranium and concentrated daughter products, fission products, and transuranics	PPE, worker rotation, film badges or TLD, stay times, bioassay program, ambient air flow	Moderately effective when used correctly	1952-1964, 1968-1976
Baghouse filter cleaning and changes	All	Airborne UF_4, Uranium oxides, process dust, RAD	PPE, film badges or TLD, stay times, bioassay program, ambient air flow	Moderately effective when used correctly	1950s-1990
Building access	C-340	Green salt, black oxides on floors and other surfaces	PPE, housekeeping	Ineffective	1957-1977
Burial of pyrophoric uranium metal in landfills	C-749	Exposure to uranium metal	None	Ineffective	1952-1980s
Carpentry	Cooling Towers	Asbestos, arsenic, fungicides	PPE	Effective when used correctly	1952-1990
Crane operation	C-400, C-410 C-420, C-331 C-33, C-335 C-337, C-340	Process gas, heat stress	PPE	Effective when used correctly	1952-1990
Cylinder heel cleaning	C-400	RAD, exposure to UF_6 gas, and inhalation of concentrated daughter products, fission products, and transuranics	PPE, film badges or TLD, stay times, bioassay program, ambient air flow	Moderately effective when used correctly	1952-1990
Deblading of compressor rotor and stator	C-400	Possible release of UF_6, HF, UO_2F_2, transuranics and uranium daughters to shop area	UF_6 negative procedure, washing, and PPE	Moderately effective when used correctly	1975-1981, During CIP/ CUP

Description	Plant Location	Hazards	Controls	Effectiveness	Time Period
Derby breakout, roasting, cleaning, and sawing	C-340	Uranium metal, black oxides of uranium, unburned Mg, uranium bearing sludge from quench tank	PPE, use of downdraft table for cleaning; later modified for improved ventilation flow and control of dust, fire extinguishers; operators on urinalysis	Effectiveness could not be determined; operators may not have been properly monitored for lung burden of insoluble oxides	1957-1977
Disassembly of stuck shut G-17 cell block valves	C-720	Possible release of UF_6, HF, UO_2F_2, transuranics, and uranium daughters to shop area	PPE, UF_6 negative procedure, disassembly procedure, shop evacuation	Moderately effective when used correctly	1952-1990
Drum crushing	C-746	RAD, UF_4, and inhalation of uranium dust	PPE	Respiratory protection was not used until Health Physics and Hygiene identified serious concerns with airborne radioactive material concentrations in September 1981	1980-1982
Drumming green salt	C-340	Green salt dust	PPE required in 1/8/57 when drumming	Effective when used correctly	1957-1977
Dumping uranium from vacuum collector to drums and returning uranium to process	C-410, C-420	RAD and inhalation of uranium dust	PPE, bioassay program, ambient air flow	Moderately effective when used correctly	1952-1964, 1968-1976
Electrical	All	Process gas, PCBs, solvents, U_3O_8, lead	PPE	Effective when used correctly	1950s-1990
Fabrication	C-720	Lead, solvents	PPE	Effective when used correctly	1950s-1990
Firing reduction vessels (bombs) to make derbies	C-340	Vessel exploded in 1962 due to Mg overload; lid fires, burnouts could release molten uranium	Fire protection system, design of bomb, specifications on mandrels for producing bomb liners, operators on urinalysis	Effective when used correctly	1957-1962, 1968-1977
Flange grinding	C-400, C-340, C-410, C-420	U_3O_8 (yellowcake), HF	PPE	Moderately effective when used correctly	1950s-1990

Description	Plant Location	Hazards	Controls	Effectiveness	Time Period
Groundskeeping	All	RAD, PCBs, asbestos, arsenic, fungicides	No PPE	Ineffective	1952-1970s
Guard patrolling	All buildings	Airborne UF_4, uranium oxides, process dust, RAD, TCE, HF, process gas, lead	PPE, film badge, or TLD	Minimally effective; PPE was generally used only during emergency situations	1950s-1990
HF collection and transfer to C-410	C-340	Anhydrous HF, cryogenic fluids	Closed system for collection and condensation of HF from towers; face shield, rubber gloves, apron, and hood; area roped off and impermeable suit used when systems open	Moderately effective	1957-1977
Landfill operations	C-746 K, S & T(inert)	Asbestos and ash from coal fired plant, dust from contaminated building rubble	None; in early 1980s, added controls on asbestos and building rubble disposal	Ineffective	1950s-1980s
Lubrication	All	PCBs, solvents, process gas, U_3O_8	PPE	Moderately effective when used correctly	1950s-1990
Machining	C-720	Lead, process gas, solvents, uranium, beryllium	PPE	Effective when used correctly	1952-1990
Maintenance on roof	C-340	Venting of HF and uranium to roof from reduction towers	None; roof access controls implemented in December 1973	Ineffective	1957-1977
Midnight negatives	C-331, C-333 C-335, C-337	Release of UF_6, HF, UO_2F_2, transuranics, and uranium daughters to environment	Procedures limited practice to only purging cells with <10 ppm UF_6	Effective, but may have been ignored in some cases	Prior to April 1986
Mixing UF_4 powder with Mg powder, loading into bomb	C-340	Airborne UF_4 powder, Mg metal powder, dust	PPE, film badge or TLD, Building dust collection system; spark proof tools provided for work in the magnesium room; operators on urinalysis	Moderately effective when used correctly	1957-1962, 1967-1977
Neptunium recovery	C-400, C-710	High concentrations of neptunium-237 in process solution; potential internal dose from leaks	PPE	Moderately effective when used correctly; some air samples high	1958 to mid-1960s

Description	Plant Location	Hazards	Controls	Effectiveness	Time Period
Product withdrawal during normal operations	C-310	RAD, exposure to UF_6 gas from positive pressure system leaks and cylinder change-outs	PPE, worker rotation, film badges or TLD, stay times, bioassay program, ambient air flow	Moderately effective when used correctly	1952-1990
Pulverizer operations and maintenance	C-400	RAD and inhalation of dust containing uranium and concentrated daughter products, fission products, thorium, and transuranics; including neptunium and plutonium	PPE, worker rotation, film badges or TLD, stay times, bioassay program, ambient air flow	Moderately effective when used correctly	1952-1964, 1968-1976
Release response	Process and support buildings; C-331, C-333 C-335, C-337 C-310, C-315 C-340, C-400 C-410, C-420	Inhalation of radioactive materials/skin contamination, chemical burns	PPE, ventilation	Effective when used correctly; ventilation systems were frequently inoperable	1952-1990
Removal of "000" compressor stub shaft	C-720	Possible release of UF_6, HF, UO_2F_2, transuranics, and uranium daughters to shop area	PPE, UF_6 negative procedure, local area exhaust, and pit and shop evacuation	Moderately effective when used correctly	1952-1990
Removal of compressor seals	C-400, C-720	Possible release of UF_6, HF, UO_2F_2, transuranics, and uranium daughters to shop area	PPE, UF_6 negative procedure, and shop evacuation	Moderately effective when used correctly	1952-1980s
Removal of converter shell internal fixtures	C-409	Possible release of UF_6, HF, UO_2F_2, transuranics, and uranium daughters to shop area	PPE, UF_6 negative procedure, additional purge in cell and in shop, shop evacuation	Moderately effective when used correctly	1975–1981 During CIP/ CUP
Replacement of full UF_6 cylinder valve	Outside C-400	Possible release of UF_6, HF, UO_2F_2, transuranics, and uranium daughters on repair team and into environment	PPE, repair procedure, cooling cylinder to sub-atmospheric, and emergency response procedures	Effective	1952-1990
Slag recovery	C-340 Slag Plant	Uranium oxides and MgF_2 dust	PPE, film badges	Not typically noted in operations instructions	1957-1977
Smelting	C-746	Airborne uranium, transuranics, process metals, RAD, HF, process gas	PPE, air samples, film badges or TLD, bioassay program	Moderately effective when used correctly	1950s-1990

Description	Plant Location	Hazards	Controls	Effectiveness	Time Period
Spraying cooling towers with fungicide	Cooling towers	Pentachlorophenol	PPE, procedures, and monitoring	Moderately effective when used correctly	1952-1990
Technetium recovery	C-400	High concentrations of technetium-99 in process solutions; potential skin and internal dose from leaks	PPE	Moderately effective when used correctly; no problems evident in bioassay results	1961-1963, 1970s
UF_6 reduction to UF_4	C-340 "Powder" Room (5th and 6th floors of the tower)	UF_6 leakage, UF_4 leakage, HF leakage, and airborne uranium	PPE, film badge or TLD, building dust collection system, operators on urinalysis	Moderately effective when used correctly	1957-1962, 1967-1977
Unplugging feed plant transfer lines, hoppers, and conveyers using sledge hammers and rods during normal operation	C-410, C-420	RAD, inhalation of uranium dust, noise	PPE, bioassay program, ambient air flow	Moderately effective when used correctly	1952-1964, 1968-1976
Unplugging fluorination towers	C-410	RAD, exposure to UF_6 gas, and inhalation of dust containing uranium and concentrated daughter products, fission products, and transuranics	PPE, film badges or TLD, stay times, bioassay program, ambient air flow	Moderately effective when used correctly	1952-1964, 1968-1976
Uranium powder conveyer, hopper, and other equipment maintenance and replacements	C-410, C-420	RAD and inhalation of uranium dust	PPE, bioassay program, ambient air flow	Moderately effective when used correctly	1952-1964, 1968-1976
Uranium recovery (by solvent extraction)	C-400	Concentration of technetium-99; transuranics and uranium daughters provided potential radiation exposure and radioactive effluents	Rubber gloves and respirators available; effluents were sampled and release limits were applied	Moderately effective when used correctly; little guidance or directionon use of respirators; PPE worn at discretion of operator	1950s to mid-1970s
Welding	C-410, C-411, C-420, C-600, C-720, and all process buildings	Heat stress, acids, process gas, asbestos, HF, thermal burns	PPE	Effective when used correctly	1950s-1980s

Key:

CIP	Cascade Improvement Program
CUP	Cascade Uprating Program
HF	Hydrogen Fluoride
PCB	Polychlorinated Biphenyl
PPE	Personal Protective Equipment (includes one or more of: respirator, shoes, ear plugs, and anti-contamination clothing)
RAD	Includes one or more of alpha, beta, or gamma radiation
TCE	Trichloroethene
TLD	Thermoluminescent Dosimeter

Abbreviations Used in This Report

AEC	Atomic Energy Commission
ACGIH	American Conference of Governmental Industrial Hygienists
ALARA	As Low As Reasonably Achievable
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CIP/CUP	Cascade Improvement Program/Cascade Uprating Program
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
ES&H	Environment, Safety, and Health
HF	Hydrogen fluoride or hydrofluoric acid
IVRML	In Vivo Radiation Monitoring Laboratory
JHA	Job Hazard Analysis
KOW	Kentucky Ordnance Works
KPDES	Kentucky Pollutant Discharge Elimination System
MAC	Maximum Allowable Concentration
MPC	Maximum Permissible Concentration
MTM	Material Terminal Management
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission
OR	Oak Ridge Operations Office
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
PCB	Polychlorinated biphenyl
PCP	Pentachlorophenol
PGDP	Paducah Gaseous Diffusion Plant
PPE	Personal Protective Equipment
ppm	parts per million
PSO	Paducah Site Office
RCRA	Resource Conservation and Recovery Act
RCG	Radiation Control Guide
SPP	Standard Practice Procedure
SWMU	Solid Waste Management Unit
TCE	Trichloroethene
TLV	Threshold Limit Value
TSCA	Toxic Substances Control Act
USEC	United States Enrichment Corporation