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RECORD OF ISSUE/REVISIONS

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01/10/2004	01/10/2004	00	First approved issue. Initiated by Robert Meyer.

ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AEDE	Annual Effective Dose Equivalent
CAM	continuous air monitor
CCl_4	carbon tetrachloride
D&D	decontamination and decommissioning
DAC	Derived Air Concentration
DOE	U.S. Department of Energy
DU	depleted uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
HEPA	high-efficiency particulate air (filters)
HEU	highly enriched uranium
IREP	Interactive RadioEpidemiological Program
MDA	Minimum Detectable Activity
NIOSH	National Institute for Occupational Safety and Health
NTA	Nuclear Track Emulsion
MSE	Molten Salt Extraction
OCAS	(NIOSH) Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
PA	posterior-anterior (medical X-ray)
PPE	Personal Protection Equipment
R	Roentgen
RBE	Relative Biological Effectiveness
RCT	Radiation Control Technician
rep	Roentgen equivalent physical
RFP	Rocky Flats Plant
TBD	technical basis document
TCA	1,1,1 - trichloroethane
TCE	trichloroethylene
TLD	thermoluminescent dosimeter
TRU	transuranic
ZPPR	Zero Power Plutonium Reactor

2.1 INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is responsible for developing the technical capabilities and guidance for the implementation of the Energy Employees Occupational Illness Compensation Program Act (EEOICPA). Oak Ridge Associated Universities (ORAU) leads a team, the ORAU Team, to support NIOSH in the performance of this program. This technical basis document (TBD) represents a specific area of support to the ORAU Team related to documentation of historic practices at the Rocky Flats Plant (RFP). The information in this document is for the evaluation of internal and external exposures to unmonitored and monitored workers and may either supplement or substitute for individual monitoring data.

2.2 PURPOSE

The purpose of this TBD is to provide a RFP profile that contains technical basis information used by the ORAU Team to evaluate the total occupational dose for EEOICPA[1] claimants. This section provides information on RFP facilities and operations.

2.3 SCOPE

RFP operations played an important role in the U.S. nuclear weapons program. Operations included production of fissionable material components. This TBD contains supporting documentation to assist in the evaluation of worker dose from RFP operations and processes. Additional guidance is found in OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* (NIOSH 2002a) and OCAS-IG-002, *Internal Dose Reconstruction Implementation Guideline* (NIOSH 2002b).

The methods used to measure radiation exposure to workers have evolved since the beginning of RFP operations. An objective of this TBD is to provide supporting technical data to evaluate the total RFP occupational dose that can reasonably be associated with worker radiation exposure as covered under EEOICPA. This dose includes occupational external and internal exposure in RFP facilities, RFP occupationally required diagnostic X-ray examinations, and onsite exposure to RFP environmental releases. The document addresses evaluation of unmonitored and monitored worker exposure, and missed dose.

In addition, this TBD presents Information on measurement uncertainties, and describes how the uncertainties for RFP exposure and dose records are evaluated.

Section 2 describes RFP facilities and processes. Sections 3 through 6 provide historic information related to worker medical X-ray, internal, and external exposures, and environmental data for use if outdoor monitoring data are unavailable. Attachments related to sections 3 through 6 provide detailed data and tables for dose reconstructors to perform dose reconstructions.

2.4 SITE ACTIVITIES AND PROCESSES

A comprehensive history of the Rocky Flats Plant was prepared as part of Rocky Flats health studies conducted by the Colorado Department of Public Health and Environment during the 1990s (see reference list). Information in this TBD section is from these 1990s reports except as otherwise noted.

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1. The Energy Employees Occupational Illness Compensation Program Act, Public Law 106–398, provides for the payment of compensation benefits to covered employees and, where applicable, survivors of such employees, of the U.S. Department of Energy, its predecessor agencies, and its contractors and subcontractors.

2.4.1 History and Mission

The U.S. Atomic Energy Commission announced its decision on March 23, 1951, to build the Rocky Flats Plant in Colorado (see Figure 2-1). Ground-breaking occurred in July of 1951 for what is now building 991. In general, the primary mission and general activities at the plant remained essentially the same from the time the plant opened until 1989, when the U.S. Department of Energy (DOE) suspended plutonium operations. The Rocky Flats site had two major missions – production of plutonium triggers (or "pits") for nuclear weapons and processing of retired weapons for plutonium recovery. From the beginning the plant was a manufacturing facility. Plutonium triggers are components of fission bombs, used to initiate the second-stage fusion reaction in hydrogen bombs. The plant received plutonium from production sites (the Savannah River and Hanford Sites), and from retired warheads and residues. Parts were formed and machined from plutonium and uranium, and beryllium, stainless steel, and other nonradioactive materials (ChemRisk 1992).

In 1984, the site was proposed as a Superfund site and, in 1989, it was included on the National Priorities List for cleanup of environmental contamination. In December 1989, DOE suspended plutonium processing to review and upgrade the plant's safety systems. EG&G, Inc., assumed operation of the site on January 1, 1990, working toward the resumption of operations in the plutonium buildings. With the President's 1992 announcement of cancellation of the W-88 Trident Warhead Program, the Rocky Flats production mission ended permanently. In 1993, the Secretary of Energy formally announced the end of nuclear production at Rocky Flats. In 1994, the last defense production-related shipment was sent from Building 460. Kaiser-Hill is now managing permanent site closure, planned for completion in 2006.

There have been only three basic pit designs since the beginning of plant operations, with the manufacturing of the first two designs phased out within the first 5 years of production. The first two designs built at Rocky Flats were solid units made mostly of uranium. Design changed around 1957 to focus primarily on plutonium (ChemRisk 1992).

2.4.2 Site Development

The following paragraphs describe the chronological development of RFP facilities and operations. Figures at the end of this section show the location of these facilities as they were constructed. Attachment 2A lists facility functions by building.

1951–1954

Ground-breaking for the first permanent buildings at the Rocky Flats Plant began in July 1951 for what is now known as Building 991. Later that year, construction began on Buildings 771, 444, and 881. By April 1952, production operations reportedly had begun, but no production or shipment details are available for 1952 or the first part of 1953. At the beginning of 1953, some of the onsite utility facilities were still incomplete; water came from Boulder in tank trucks, and a locomotive brought to the site provided steam heat. Nevertheless, the first products were completed and shipped that year. By 1954, the plant was fully operational, with initial construction essentially complete with about 700,000 square feet of building space. Employment grew steadily from 133 people in 1951 to 3,101 in 1963.

Originally, the plant had four operational areas – A, B, C, and D Plants –- identified according to four primary types of work. The A Plant included Building 444 operations, which involved the fabrication of depleted uranium parts. Later known as Building 881, the B Plant recovered enriched uranium and manufactured enriched uranium components. The C Plant (later Building 771) housed plutonium operations, and the D Plant in Building 991 was the center of final product assembly operations. There were large spans of meadow between the areas, with gravel roads connecting them. Very few

people had clearances to get into more than one building, and most employees had no idea what occurred in areas other than their own. Plant employees were bussed from the front gate to their buildings, because personal vehicles were not allowed on the site.

1955
A major facility expansion began in 1955, referred to as Part IV construction.

1956–1957
This period saw the construction of Buildings 447, 776, 777, 883, 997, 998, and 999; and the expansion of Buildings 444, 881, and 771. These additions were directly related to the change of the weapon concept to a hollow unit and anticipated production increases. A few years later, roughly coincident with the onset of the Cold War, RFP became the primary manufacturer of pits under the single-mission concept. The result was a dramatic rise in production at the plant in the 1960s. By 1964, the workforce reached a level of around 3,000 people that lasted for about 15 years.

1967–Early 1970s
Buildings 559, 440, 707, 750, and 865 were constructed.

Early 1980s–1990
DOE built Buildings 371 and 460 during this period. The period showed a significant upturn in Rocky Flats employment, with a peak at 5,990 in 1984.

By 1990, total building space had grown to approximately 2.5 million square feet. Figure 2-2 shows the 1990 RFP layout, including the structures identified in the previous paragraphs.

2.4.3 Functional Areas

Rocky Flats operations included the following functional areas:

- Component Manufacturing and Assembly
- Material Recovery and Purification
- Research and Development
- Waste Processing
- Plant Support

To manufacture a fissionable product, RFP developed facilities, equipment, and personnel to conduct precision metalworking and to assemble fissionable and nonfissionable materials. Key nonfissionable components were made of beryllium, aluminum, and stainless steel.

Early work at the plant involved both ^{235}U and ^{239}Pu as fissionable materials. Enriched uranium contract work transferred to the Oak Ridge Reservation in 1964. Americium-241 recovery did not start until 1957, functioning as a step in the plutonium recovery process and producing a marketable product. Beryllium was not used in full-scale production operations until 1958. Stainless-steel component work began in 1966. Stainless-steel operations (known as the "J Line") took place in Building 881 until 1984, when they moved to Building 460.

2.4.3.1 Component Manufacturing

When the A Plant (Building 444) started operations in 1953, it was devoted entirely to depleted uranium manufacturing. Operations included casting and machining of components. While no details are available, processing of depleted uranium is not generally considered to be a significant hazard

from either an external (photon) or internal (alpha-emitter) perspective. RFP originally received depleted uranium from Paducah, Kentucky and, later, as feed material from the Feed Materials Production Center in Fernald, Ohio, as ingots in sealed cans. While TBD reviewer comments indicate that Paducah was processing recycled U beginning in 1953, available Rocky Flats records do not indicate whether fission product or TRU-contaminated U was processed at Rocky Flats.

Enriched uranium operations occurred in B Plant (Building 881), and initially involved a heavy workload. The basic operations involved casting and machining. The components were solid pieces of uranium, machined to particular shapes, which were assembled with plutonium, stainless-steel, and depleted uranium components in D Plant.

With development of new designs, the revised concept required a significant amount of rolling and forming of depleted and enriched uranium, and space in existing facilities became inadequate. Building 883 was built to handle the rolling and forming of uranium. Depleted uranium was cast in Building 444, but was shipped to Building 883 to be heated and rolled into sheets from which blanks were cut and formed to the required shape. The shaped pieces were shipped back to Building 444 to be turned, trimmed, and polished. In some cases, the component was coated with protective materials.

Building 883 was designed with two functional areas to prevent cross-contamination; the B side handled enriched uranium, and the A side rolled and formed depleted uranium. The plant was so pressed to begin production of the new type of weapon components that operations began in Building 883 before the roof was completed. To prevent emissions from these early operations and to protect machinery and materials from the elements, enclosures were placed around the process equipment. Details concerning early ventilation and other worker protection systems during this period were not found in the available literature.

Research and development (R&D) of depleted uranium-niobium alloys involved an electron-beam furnace. Alloying work began in 1966, although full-scale production did not occur until the early 1970s. An arc furnace installed in the mid-1970s provided the capability to produce depleted uranium-niobium alloys. This furnace melted elements such as zirconium and niobium more effectively than induction casting furnaces, thereby creating a more homogenous alloy casting.

In the early 1960s, Building 881 was idle while the enriched uranium areas were decontaminated and decommissioned. Conversion to accommodate stainless-steel operations began in 1966. Machining of depleted uranium continued in Building 444. In 1964, the B side of Building 883 was converted to beryllium rolling and forming.

After the Oak Ridge Reservation took over enriched uranium operations in 1964, it supplied RFP with finished uranium components for incorporation in final pit assemblies. RFP still received site returns that contained enriched uranium components. The plant processed those components with a spray leaching process to remove external plutonium contamination, and returned the oralloy parts to Oak Ridge for reprocessing. Oralloy leaching operations were originally in Building 881, but were moved to Building 771 in the mid-1960s. The oralloy leaching process remained in Building 771 through 1989 (ChemRisk 1992).

Early during facility operations, C Plant (Building 771) housed essentially all plutonium manufacturing and recovery. In the early years, plutonium metal was machined in a dry state (i.e., without oils, using only carbon tetrachloride as a coolant), with as little machining as possible. Handling the dry material required extra care to prevent spontaneous combustion. Plutonium components were cast, pressed into shapes, minimally machined to true them, and plated with cadmium, which enabled handling with

reduced personnel exposure to neutrons and alpha particles. The first weapons were designed such that they were to be armed (final assembly) in the aircraft on the way to the target. The protective coating grounded the parts against static electricity that might be generated while handling them in the field. The coating changed to nickel within a few years, using a process that employed nickel carbonyl. The use of nickel carbonyl lasted at least into the late 1960s, although its use in later years was reduced, due to design changes that enabled remote arming.

Building 776 machining operations (also involves Bldgs. 771, 777, 881, 460, 991, 707, 881, and 444)

Higher-volume machining of plutonium began in 1958, with new operations in Building 776 using Shell Vitrea, a cutting oil, followed by washing with carbon tetrachloride. Building 776 housed a centralized collection and separation point, and the solid and liquid fractions were sent separately to Building 771. In Building 771 most of the carbon tetrachloride was distilled from the oil, and the plutonium cuttings were recovered from the solids. At that time, Building 777 was the focal point for assembly operations. Facility staff members were unable to develop a satisfactory method for handling spent oils and residual solvents, which were placed in storage barrels outdoors to the east of the plant.

Buildings 776 and 777 went into service in 1958 to handle the increased plutonium workload, and Building 771 undertook recovery operations. Building 776 performed plutonium machining; Building 777 handled assembly operations. Building 991 was used for storage and R&D, although it was several years, (records indicate 1960), before all assembly operations had left the building. In 1969, a major fire in Buildings 776 and 777 resulted in some operations moving to other buildings. The machining and foundry operations in the fire-damaged areas of Building 776 became part of the operations in the new 707 assembly building. Those operations remained in Building 707, and solid waste treatment operations and size reduction moved into Building 707 after Building 776 returned to operation in 1972. (Building 776 in 1972 was being used for waste storage and waste size reduction.)

Final assembly of the early products was initially a relatively simple operation. The original final assembly building was D Plant, now known as Building 991. Later, the hollow-core weapons design involved more assembly complexity. As a result, Building 777 in 1957 began to provide assembly facilities. Operations involved drilling, welding, brazing, turning, and polishing. Building 707 began final assembly operations shortly after the 1969 fire, which shut down Buildings 776 and 777. Final assembly operations occurred in Building 707 through 1989.

Stainless-steel operations, the J-Line, began in Building 881 in 1966 and remained there until the completion of Building 460 in 1985. Stainless-steel operations from Building 881 and some operations from Building 444 were consolidated in Building 460 at that time. A significant portion of the stainless-steel work was the fabrication of empty tritium reservoirs. The reservoirs were later filled with tritium gas under high pressure at the Savannah River Site

In 1957, the new weapon design required beryllium components. There had been some beryllium operations in Building 444 in preparation for regular pit production, and in 1958 beryllium operations became a significant portion of RFP activities. The components manufactured in Building 444 no longer went directly to the Pantex Plant. Rather, they were incorporated in the final assembly operations in Building 777. The depleted uranium workload decreased significantly as beryllium use increased (ChemRisk 1992).

Beginning in 1952, thorium was used onsite in quantities small enough that effluents were not routinely analyzed for Th. Thorium quantities varied from as little a none to as much as 238 kg in a given month. The principal use was fabrication of metal parts from natural thorium metal (^{232}thorium) and from various thorium alloys. Thorium oxide might have been used as a mold-coating compound

in limited experiments. Thorium compounds were used in analytical procedures. In addition, twice between 1964 and 1969, thorium “strikes” were performed to remove gamma-emitting ^{228}thorium from uranium-233 metal needed for fabrication of test devices. The strikes involved a fluoride precipitation and filtration process using natural thorium. Photon radiation from ^{228}Th decay products would have been monitored by standard gamma dosimetry badges in use at the plant. In addition, thorium was used as a stand-in for plutonium or uranium components in development programs (ChemRisk 1992).

2.4.3.2 Material Recovery and Purification

Manufacturing produced wastes, which consisted of fissionable and nonfissionable materials, associated lubricating and cleaning compounds, and other materials such as rags, slags, clothing, tools, and paints. Wastes were stored in barrels in the 903 area just outside the main fence. In the late 1960s, waste oils were eventually treated by fixation in concrete and shipped off the site for burial. Cleanup of the 903 area resulted in some potential for worker exposure to airborne plutonium from disturbance of contaminated soil.

Plutonium Recovery and Purification
When Building 771 became operational in 1953, operations included plutonium recovery (from weapons manufacture and later from weapons recycle) and purification, and plutonium component manufacturing. Plutonium operations patterned after Los Alamos plutonium facility work began in the spring of 1953. Only one "Chem Line" was in operation; it had the capacity to produce plutonium buttons of approximately 300-gram mass. Later, in 1955, an "East Chem Line" started, with the capability to produce 2-kilogram buttons. Eventually, operational capacity reached 12 kilograms per day. In 1965, an expanded production area added five dissolution lines, increasing plutonium recovery by a factor of 20 over that of the original line (ChemRisk 1992). In 1968, the decision was made to replace Building 771 recovery operations. Groundbreaking took place in 1973 for what was to become Building 371. The new facility was plagued with problems from the onset of construction, and delays prevented cold startup before 1981. Design flaws resulted in the shutdown of Building 371 chemical processing in 1985 before achieving full-scale operation.

Originally, plutonium at Rocky Flats came from Hanford as plutonium nitrate in small stainless-steel flasks packaged in cylindrical steel carrying cases. The nitrate was vacuum-transferred into a vessel in which plutonium dioxide was precipitated. Chemical reduction converted the dioxide to metal buttons. Later, plutonium was received from Hanford in the form of buttons. Occasionally, plutonium nitrate feed was received from the Oak Ridge Reservation. In 1959, these shipments were reduced, and most of the plutonium feed to recovery and purification operations became recycled material from site returns, the foundry, or waste products from the recovery operation. Some plutonium that went through the system at this time came from outside sources in the form of plutonium dioxide. Later shipments of plutonium consisted of metal buttons from the Savannah River Site.

RFP produced components from other metallic radionuclides on a limited basis for incorporation in pits for special-order operations. The inclusion of these radionuclides (^{237}neptunium, ^{241}americium, ^{238}plutonium, and ^{244}curium) as tracers into the makeup of the pits enabled research elsewhere. The Special Recovery area processed the plutonium tracer materials. Eventually, leftover tracer materials had to be removed from the plutonium streams, which became part of Special Recovery operations. Special Recovery operations included the Oralloy and Part V Leaching lines, in which surface impurities were removed from enriched uranium and plutonium components.

The recovery process was often described in terms of functional divisions - "fast" and "slow" recovery operations. The fast cycle processed plutonium nitrate solution, turning the liquid to a solid (powder) and then to metal. The slow cycle received materials with higher concentrations of impurities

(requiring a greater degree of preprocessing before entering the fast cycle metal conversion process). Before the implementation of the molten salt extraction process in 1968, almost all plutonium-bearing materials went through slow recovery operations. These materials had to be converted to plutonium nitrate via the slow cycle and then introduced into the fast cycle line for conversion to a solid and reduction to metal. Since the introduction of the molten salt extraction (MSE) process in 1968, some of the essentially pure plutonium metal, such as the metal from site returns, went through MSE to remove americium ingrowth and then directly to plutonium foundry operations in Building 777 for casting and subsequent processing into plutonium components. As a result, slow cycle recovery received such materials as effluents and waste products from the fast cycle, rags, paper goods, sweepings, and other wastes. It no longer processed the purer forms of plutonium.

Slow recovery operations involved a variety of processes. For example, combustible residues such as plastic bags and Kimwipes were incinerated to reduce material bulk and to convert the plutonium into an oxide form. Before 1960, dissolution was followed by a solvent extraction step that used tributylphosphate as the solvent and dodecane as the diluent. The solvent extraction was followed by cation exchange. Around 1960, solvent extraction was eliminated from the recovery process line because the materials going through the recovery process were becoming more and more varied (ChemRisk 1992).

Uranium Recovery and Purification

Building 881 was built in 1952, and housed enriched uranium component manufacturing, including machining and fabrication of parts. When the chemical recovery line began enriched uranium recovery from metal residues created in the manufacturing processes in 1954, Building 881 housed all enriched uranium operations, from casting to forming, machining, assembly, recovery, and purification. The raw material came from the Oak Ridge Reservation, primarily in the form of hockey-puck-size “buttons" of pure metal.

Uranium recovery operations in Building 881 were modeled after processes developed during and after World War II at Los Alamos and the Oak Ridge Reservation. The Building 881 process was similar to the 1950s plutonium recovery process that included solvent extraction. Uranium recovery had fast and slow sides and involved similar chemistry, but dibutylethylcarbutol was used as the solvent, rather than the tributylphosphate and dodecane used as the solvent and diluent, respectively, in plutonium recovery. Overall, the basic plutonium and uranium recovery operations were similar (ChemRisk 1992).

Americium Recovery

There was a pressing need to deal with the americium in the plutonium handled at RFP, because in-growth of ^{241}Am from ^{241}Pu decreases the effectiveness of the plutonium and creates a gamma exposure problem. The plant had a backlog of americium-containing sludge generated from a plutonium recovery process. As a result, in 1957 an americium line began operation in Building 771. From the late 1950s until the late 1970s, americium was recovered and purified at the plant for resale. The demand for americium declined in the late 1970s, and the americium removed in the plutonium purification process went to Building 774 to be processed as a radioactive waste. Information for this period concerning the chemical form of extracted ^{241}Am was not discovered during our review. Americium operations were limited to MSE operations needed to purify plutonium metal.

In 1962, a slight change was made to the ammonium thiocyanate process by adding oxalate precipitation and calcination steps, which resulted in an americium oxide product that was preferred because of its stability. The process during this period was cumbersome, resulted in a disproportionate quantity of waste solutions, and created personnel alpha-contamination exposure problems due to required manual operations and maintenance.

In 1967, the MSE process became the feed source for americium purification. In MSE, molten americium-bearing plutonium came into contact with molten NaCl-KCl-MgCl2 salt. Oxidation-reduction reactions with the salt separated the americium from the plutonium by equilibrium partitioning. There were alpha-contamination personnel exposure problems associated with the hydroxide precipitation step, and in 1973 it was replaced with a cation-exchange procedure. The entire process underwent another major change in 1975, when the ammonium thiocyanate steps were eliminated and the americium was recovered from the anion effluent by oxalate precipitation with subsequent calcination to form the more stable oxide.

After 1976, MSE salts were sent to a “salt scrub” process rather than to americium purification. (A salt scrub removes Am and Pu from MSE salts.) Salt scrub made a "scrub alloy" of americium, plutonium, and gallium that was shipped to Oak Ridge for further processing. Americium recovery and purification operations shut down in 1980, and work was limited to that required to extract americium from plutonium metal in site returns (ChemRisk 1992).

2.4.3.3 Process Waste

When Building 774 was built in 1952, its primary purpose was to support Building 771 by treating its radioactive aqueous waste. The general mission of the waste operations was to reduce the volume of wastes. Liquids transferred to Building 774 were subjected to pH adjustment and sent through a precipitation step to remove radionuclides. The resulting slurry was sent to vacuum filters. The solids removed from the filters were combined with cement or another solidifying agent and shipped to long-term storage as transuranic (TRU) mixed waste. The aqueous waste from this first stage went through the process again. Before 1973, aqueous wastes from this process went to either the solar evaporation ponds or to the "B" series of holding ponds, depending on the concentrations of radioactivity. Maintenance and eventual cleanup of the solar ponds introduced potential worker exposure scenarios (Meyer and Till 1999).

Around 1965, an evaporator was installed in Building 774 to treat liquids that had accumulated in the solar evaporation ponds. Water and volatiles evolved from the evaporation process were discharged to the atmosphere. The concentrate from the evaporator was fed to a double drum dryer, on which the salt solution dried for removal by a scraping blade. Water vapor and volatiles from the dryer went through a scrubber and demister before venting to the stack, with the liquids from the scrubber and demister returning to the aqueous treatment process. The evaporator was removed from service in 1979, and liquids from the second stage of treatment and the solar ponds were transferred to Building 374. Figure 2-3 shows the locations of these ponds.

Building 374 went into operation in 1980 as an integral part of the new plutonium recovery facility, Building 371. Building 374 was designed to handle wastes generated in Building 371. The processes used in Building 374 were essentially the same as those used in Building 774, with more efficient equipment. Building 374 was also designed to provide greater safety of operation through improved containment, control systems, and separation of workers from operations.

While most hazardous and radioactive wastes were shipped off the site for disposal, approximately 178 inactive waste sites existed within the plant boundaries as production operations were completed in the late 1980’s, some of which had been the sites of burial, incineration, and land application (ChemRisk 1992).

Liquid sanitary waste operations were kept separate from the liquid process waste operations to prevent contamination of the sanitary waste streams. Holding tanks upstream from the treatment plant were sampled to check for plutonium contamination. Standard waste treatment was provided.

Final disposition of sludges has changed over the years. From 1954 to 1968, 100 tons of sanitary sludges were disposed of in onsite trenches (T-2 through T-8). At that time, some floor drains in the manufacturing buildings were not isolated from the sewage treatment plant, and the sanitary sludge became contaminated with uranium and plutonium. A second landfill that opened in 1968 received sludges until 1969. At that time, the sludges were declared low-level radioactive waste and shipped off the site to approved disposal sites.

There were instances of onsite burial of contaminated materials, most notably soils that were contaminated as a result of the 1969 fire and other soils excavated during cleanup of the laundry waste outfall formerly located on the north side of Building 771. In the early years of plant operation, laundry waste was discharged directly to Walnut Creek. The released water met then-current standards for concentrations of plutonium and uranium. On December 21, 1973, the release of laundry waste to Walnut Creek ended.

The original RFP landfill, on the south side of the plant, opened in 1952 and closed in August 1968. An incinerator was in operation at that time, in Facility 219 on the west access road. With a few exceptions, nonradioactive combustible waste was burned in the incinerator and the resultant ashes were buried adjacent to the incinerator. It is estimated that fewer than 100 grams of depleted uranium were incinerated in general plant waste between 1952 and 1968 (ChemRisk 1992).

Figure 2-4 shows the locations of waste disposal areas at the site.

2.4.3.4 Research and Development

Rolling of enriched uranium foil was conducted in 1964 in the northeast comer of the plant garage, Building 331. Interviews suggest that this area was also used for the development of depleted uranium and uranium alloy casting techniques, using electron beam heating, and uranium coating studies until Building 865 came on-line in 1970 (ChemRisk 1992).

In the mid-1960s, R&D work became a larger part of the activities at the plant, as Buildings 779, 559, and 865 were constructed. Much of this work focused on examining site returns to determine the effects of time and field conditions on the weapons, including corrosion and other forms of deterioration.

Building 779, a plutonium R&D facility, was constructed in 1965. Its purpose was to study the chemistry and metallurgy of plutonium and its interactions with other materials. In addition, Building 779 housed efforts to develop improvements to manufacturing processes, to find new ways to recover plutonium and associated actinides, and to better understand the aging characteristics and shelf-life of RFP products.

Building 865 began operations in 1970. It served as an R&D facility primarily for manufacturing processes using uranium and beryllium. The work involved metalworking and metallurgy techniques. The metallurgical operations involved the development of alloys and alloying processes, and fabrication of prototype hardware. Metalworking operations include melting and casting, forging, press forming, extrusion, drawing, rolling, diffusion bonding, hydrospinning, swaging, cutting and shearing, and heat treating. In addition, glove-box operations involved high-purity beryllium powder and machining operations that generally involved nonfissionable materials.

After 1964, Building 881 became a multipurpose facility for research and development, analytical work, plant support, and administrative offices. Operations included analytical laboratories, generation of chemical standards, activities to machine small parts for weapons and energy

generation research, gold plating of parts, assembling microscopic parts, and some large machining operations. The Special Weapons Projects group was involved in the development of engineering prototypes and full-scale models for military training. Recovery Technology activities included materials development, process instrumentation and control, and equipment design and development. The Waste Chemistry group supported engineering and development of onsite waste treatment processes, and Joining Technology conducted operations to join non-nuclear metals including beryllium, in some cases using brazing alloys including nickel. Other operations in Building 881 included Nondestructive Testing, Records Management and Storage, and various maintenance shops and activities.

Explosive bonding experiments occurred at the explosive forming area near Building 993 from 1965 until approximately 1968. The experiments were designed to explosively bond together flat plates of stainless steel and uranium alloy using dynamite. The explosive events took place below grade. No information was identified to indicate whether releases to the environment occurred during these tests, which typically involved relatively small amounts of explosives (192 grams of 40% dynamite were routinely used in the bonding tests). While available records do not indicate the isotopic composition of uranium used in these tests, the tests were designed to examine the chemical/physical characteristics of the explosive bonding process, and it is unlikely that enriched uranium would have been used in such tests.

Work for Others

The plant conducted Special Order work for other facilities in the weapons complex, the Department of Defense, or other Federal departments or agencies. Most Special Order work did not involve materials other than types used in production activities. The tracer work noted above was an exception. Neptunium-237 tracer work associated with uranium and plutonium components took place in Buildings 771 and 881. Exact dates of production and later recovery of these tracers (from recycled materials) are not readily available – such work was occurring at Rocky flats from the mid-60's to the late 70's, based on our interpretation of available information. There was considerable effort devoted to keeping tracer materials separate from the regular production material streams, and Special Recovery operations focused on recovering the materials.

For the Zero Power Plutonium Reactor (ZPPR) project, RFP manufactured approximately 4,000 stainless-steel-clad fuel elements consisting of plutonium, molybdenum, and uranium during 1967 and 1968. The plant manufactured the fuel rods for installation in the reactor at Argonne National Laboratory. These elements were made by alloying uranium and molybdenum in Building 444. The uranium-molybdenum alloy was sent to Building 771, where it was alloyed with plutonium by casting into plates of various sizes. The "ternary alloy" plates were clad in stainless-steel envelopes in Buildings 776 and 777 and sealed by welding. The plutonium used in this project originated in the United Kingdom and contained a higher percentage of ^{240}Pu than most Rocky Flats plutonium, so the project took care to keep it separate from other plutonium recovery and waste streams. TBD Section 5 provides additional details concerning the radionuclide makeup of ZPPR fuel.

During the late 1970s and early 1980s, RFP made thousands of calorimeter plates from depleted uranium for Sweden, Harvard University, and Brookhaven National Laboratory. In a large project that involved processing hundreds of tons of depleted uranium in Building 883 in the mid-to-late 1980s, the plant made armor plates for the M1A1 tank. In the mid-1980s, the U.S. Army developed an advanced type of layered Burlington armor that incorporated depleted uranium.

RFP was involved in "Project Plowshare," the effort to develop technology for using nuclear explosives for peaceful applications, such as excavation and uncovering of deep mineral deposits.

This involvement lasted from 1959 to the mid-1970s. An objective of the project was to use as little fissionable material as possible to limit fission product production.

2.4.3.5 Plant Support

The plant had a number of support organizations, including administration and finance, utilities, facilities management, and health and safety personnel. The plant also had some unusual support organizations, including the Criticality Laboratory (or Nuclear Safety Group), which was responsible for identifying and directing control of the potential for criticalities in plant activities. Another unique support function was provided by the Filter Testing group formed in 1979, which performed pre- and postinstallation testing of the high-efficiency particulate air (HEPA) filters used in ventilation exhaust systems and of personnel respirators.

The Nuclear Safety Group was at the plant beginning in 1953. At that time, the group did not have its own facility. In the early years, the group performed its work in the areas in which production materials were handled. The *in situ* experiments were always subcritical; neutron count rates were observed as criticality was approached (ChemRisk 1992).

In more recent years, the Nuclear Safety Group conducted its work in Building 886, which was commissioned in 1965. Since that time, this group conducted about 1,600 critical mass experiments using enriched uranium, and plutonium, in solutions (800 tests), compacted powder (300), and metallic forms (500). After 1983, criticality experiments were not conducted with solid materials; they were conducted primarily with uranyl nitrate solutions, which were reused. Building 886 housed the Critical Mass Laboratory, some offices, and a small electronics and machine shop.

Approximately half of the 1,600 criticality experiments in Building 886 achieved criticality. Experiments in the RFP laboratory generally involved power levels of no more than 10 milliwatts, for no more than an hour. Approximately six high-power experiments were taken to between 10 and 100 times the power of typical tests. Using a conversion factor of $3xl0^{16}$ fissions per megawatt-second, this power level and duration corresponds to a maximum of $1.01x10^{12}$ fissions from a typical RFP criticality experiment and a maximum of $1x10^{14}$ fissions from a high-power experiment. Records indicate that there were no incidents at Rocky Flats in which the power level of fissionable material became uncontrollable. The experiments were controlled by bringing the materials slowly to near-criticality, observing the neutron flux to observe the reaction state. There is no indication in the available records that gamma exposure or exposure to created fission products was a worker exposure problem during these experiments.

Beginning in 1965, airborne effluents from Building 886 were sampled for radioactive particulates. Between 1971 and 1989, reported plutonium effluents from Building 886 were no more than 5% of the site total (in 1978) and enriched uranium emissions were no more than 10% of the site total (in 1976).

Release of waterborne radioactivity from the Critical Mass Laboratory was limited to several incidents involving spills of uranyl nitrate solution (enriched uranium) and disposal of wastewater from such activities as mopping floors. The Laboratory floors were sealed and bermed to contain such spills. From the late 1960s to the late 1970s, wastewater from activities such as mopping was collected and periodically transferred to the solar evaporation ponds, after sampling and analysis indicated that the enriched uranium content of the water was much less than 1 gram per liter.

The Health Physics Laboratories, located in Building 123, performed analyses of personnel dosimeters and all airborne sample analyses, including stack samples and general room air samples. The laboratories were originally in Building 441. The Standards Laboratory, in Building 125, prepared

analytical stock solutions for the other laboratories and performed analyses on incoming radiological sources for quality assurance/quality control purposes. In addition, the Standards Laboratory performed equipment calibration and standardization. The Plutonium Analytical Laboratory in Building 559 conducted analyses to determine the purity of plutonium, concentrations of impurities, and makeup of plutonium alloys. The Building 881 Laboratories, also called the General Laboratories, opened in 1952 to perform wastewater, sludge, surface-water, and groundwater sample analyses. These laboratories analyzed production control samples from Buildings 460 and 444. When enriched uranium processes were in operation in Building 881, the laboratories also performed analyses of the products.

The Filter Testing Group formed in 1979 after an audit identified the need for independent in-place leak testing of HEPA filters. In-place testing began in response to a filter change, when there was visible damage to the filter or the supporting framework, when plenum monitoring indicated a problem, and according to the routine testing schedule for that particular bank of filters. In addition, the Filter Testing Group conducted quality assurance testing on a fraction of new filters (preinstallation testing).

Laundry Services provided cleaning, sorting, and distribution of coveralls and other reusable garments required in the manufacturing areas. Available information does not indicate whether or not there were contamination concentration limits on laundry to be processed. Laundry water was sent to the forced evaporation operations in Building 374. Before Building 374 became operational in 1980, laundry water was sent to the second stage of Building 774 aqueous waste operations and then through the Building 774 evaporator if (presumably alpha-emitter) concentrations were above 1,667 pCi/l. Below this level, laundry water was sent to Pond B-2. In the very early days, Buildings 881, 771, and 991 had their own laundry facilities, and Building 444 laundry went to Building 442. Around 1958, Building 778 became the laundry facility for all plutonium-handling buildings. When enriched uranium processing ended at Rocky Flats in 1964, laundry from Building 881 went to Building 778. Beginning in 1976, laundry from Building 444 depleted uranium operations was sent to Building 778 (ChemRisk 1992).

Attachment 2B lists RFP job categories and descriptions. Attachment 2E is a partial list of types of radiation exposures associated with various job categories. The data in Attachment 2E are not presumed to be comprehensive, but were developed from several readily available documents.

2.5 RELEASES TO THE OUTDOOR ENVIRONMENT

2.5.1 Airborne Emissions

Section 4 of the Rocky Flats TBD contains details concerning stack and other effluent monitoring operations through the life of the facility. The RFP began onsite ambient air monitoring at a single station in 1952. By early 1953, 10 onsite stations had been established. The July 1953 monthly site survey report states that calibration and regulation of samplers to a flow rate of 2 cubic feet per minute (cfm) was under way. In February 1954, Whatman 41 filter paper was substituted for HV70 paper on all offsite samplers, because HV70 filters ruptured during the week-long sampling. This implies that HV70 filters continued to be used for onsite (daily) sampling. In March 1956, manometers were installed on onsite units. In 1969, two more stations were added, for a total of 12 stations (ChemRisk 1992). Figure 2-5 shows key operations and notes plutonium air emissions associated with each facility during 1988.

For a large part of the operational history of the Rocky Flats Plant, emissions were measured in terms of long-lived alpha radioactivity. This was true from 1953 to 1973 for plutonium and americium, and from 1953 to 1977 for uranium. From 1974 through 1984, $^{239/240}$Pu releases through routine

operations were monitored by analytical techniques specific for the radionuclides. Americium-241 was not included in the monitoring scheme. Between 1985 and 1989, $^{239/240}$Pu and ^{241}Am were routinely sampled and monitored by alpha spectrometry following radiochemical separation but ^{241}Pu was not included. Reporting of total long-lived alpha activity continued for uranium facilities until about 1977. Even after 1978, not all uranium isotopes were routinely analyzed. For example, only ^{238}U and $^{233/244}$U emissions were reported for 1978 to 1980 and 1984 to 1989. For 1981 to 1983, only total uranium emissions were reported. Beginning in 1974, annual airborne tritium release totals were reported in annual RFP environmental reports. In 1974, data were reported for 12 vents, which expanded to 18 in 1977 and 23 in 1981 (ChemRisk 1992).

The largest routine releases of plutonium from RFP facilities occurred before 1975, primarily from the Building 771 stack and roof vents on Buildings 776 and 777. The largest routine plutonium releases from Building 771 occurred between 1957 and 1965; median release quantities after 1965 were below 1,500 µCi. After 1970, median annual releases were below 500 µCi. Estimated total plutonium emissions, summed from the late 1950s to the mid-1960s, range between 1.3 and 6.5 mCi (RAC 1999c).

2.5.2 Waterborne Emissions

There were two series of ponds at the site. The uncovered and unlined holding ponds were constructed on Woman Creek and on the north and south branches of Walnut Creek. The first three holding ponds were built in the early 1950s; eight more ponds were added over the years. The second series of ponds, called solar evaporation ponds, were built in the mid-1950s to enable the evaporation of liquids with low levels of radioactivity but high concentrations of nitrates.

Beginning in 1953, liquid effluent samples from RFP were collected and analyzed. The extent of the monitoring program, the spatial distribution of sampling, and the types of materials measured were limited until the early 1970s. Under the auspices of the Waste Disposal Unit, the Water Laboratory, which was part of the General Laboratory, conducted the analyses. The major focus of the analyses in the 1950s was on monitoring total solids and nitrates. With the exception of special circumstances, only gross alpha measurements were made before 1970. In general, there was no monitoring of plutonium, beryllium, or organic chemicals during this time, even though laundry wastes from Building 771 and effluents from the sanitary sewer system were discharged directly to Walnut Creek until 1974. As a result of the May 1969 fire, routine analyses of effluent and environmental water samples for plutonium began in September 1969. Plutonium and uranium were isolated from other long-lived alpha emitters by ion exchange, and their concentrations determined by alpha pulse-height spectrometry. Uranium recovery was determined by ^{232}U tracers.

2.6 ACCIDENTS

An extensive review of the Rocky Flats accident history occurred during Phases 1 and 2 of the environmental dose reconstruction. Researchers evaluated classified and unclassified accident-related databases and documents, resulting in the identification of thousands of small-scale releases and "accidents" over the 40-year operating history. Many events reviewed during the investigation resulted in releases that passed through filtered building ventilation systems. The associated releases were recorded as part of normal plant operating emissions. Attachment 2C is a list of some accidents and incidents with potential for worker exposures. Not all of the accidents listed in Attachment 2C are known to have been associated with worker exposures; several are included only because they were likely to have involved significant disruptive mechanical force.

Figure 2-6 shows gross alpha releases to the environment from 1953 to 1977.

2.6.1 Accidents and Contamination Control

In 1958, site personnel developed a gamma spectrometer wound counter to confirm the presence of plutonium in wounds. In August 1961, 55 Alpha Flashers (later Alpha-Mets) were placed on gloveboxes in plutonium areas for workers to self-monitor their hands and identify a failed glove before spreading contamination. Introduction of "COMBOs", combination hand and foot monitors, included floor areas in the contamination control program. Twenty continuous air monitors (CAMS) were in operation by April 1966 (locations unknown). Room air samplers were placed near exhaust ducts. Details concerning monitor types, introduction dates, minimum detectable activities, alarm characteristics and related information are provided in Rocky Flats TBD Section 5 where available. Additional study on the related topic of exposure of unmonitored workers proximate to Rocky Flats fires and other accidents has been identified as an important issue for the Rocky Flats TBD team to undertake during follow-up work.

Following the two fires that caused major damage to production buildings in 1957 and 1969, there were changes to minimize the occurrence and consequences of fires. To reduce the probability of a fire, nitrogen atmospheres, minimal combustible loading in all areas, and improvement of fire detection and suppression systems were emphasized. The controlled use of automatic water fire suppression systems was included in the design of a new plutonium facility, Building 707, in 1967. Criticality concerns were addressed by enforcement of fissile limits and prevention of water accumulation.

Figure 2-7 shows the locations of major accidents at the Rocky Flats Plant.

2.6.2 Accidents Involving Plutonium

(NOTE: The information in this section is from ChemRisk 1992.) Fire was a continuous hazard when working with plutonium at the plant. For example, RFP data indicate 623 reportable fires (most small) between January 1955 and December 1974. Of those fires, 387 occurred in plutonium processing areas. For perspective, records and interviews indicate that most fires were small and controlled, contained in glovebox or other airflow-controlled systems, and resulted in no inhalation exposure hazards to workers.

The accident report on the 1969 fire states that 164 fires were reported to the Fire Department from 1966 until the 1969 fire. Of these, 31 involved plutonium, of which 10 occurred in Buildings 776 and 777. Of the remaining 133 fires, 17 occurred in Buildings 776 and 777. There is no reliable estimate of the number of plutonium fires not reported to the Fire Department.

Chips from plutonium machining operations ignite easily if exposed to the air. Plutonium metal bums at a temperature near the 640°C melting point of plutonium, and there is no odor, smoke, or flames until other combustibles are involved. Small, relatively insignificant, plutonium fires were part of normal operations at RFP, and many such fires were not reported if they were confined in the production apparatus and there was no evident risk of human exposure. Emissions from most plutonium fires occurring during normal operations passed through multistage HEPA filter systems and contributed to normal operational releases of radionuclides. The 1957 fire was a significant exception.

The September 11, 1957, Fire
The September 11, 1957, fire (see Voillequé 1999a) began when metallic plutonium casting residues spontaneously ignited in a glovebox in Room 180 of Building 71 (later Building 771). The fire spread

to an exhaust filter plenum, Rooms 281 and 282, consuming a considerable quantity of filters and damaging the ductwork and fan system. No major injuries were reported in this fire.

Chronology of September 11 and 12, 1957:

10:10 p.m.	Fire discovered in Room 180.
10:12 p.m.	First fire truck arrived.
10:24 p.m.	Carbon dioxide extinguishers first discharged at fire.
10:25 p.m.	Fan system ordered on high speed.
10:37 p.m.	Water spray nozzles discharged at fire.
10:38 p.m.	Water shut off. Fire extinguished in Room 180.
10:39 p.m.	Explosion in exhaust system; building evacuated due to contamination.
10:40 p.m.	Fans went off.
10:58 p.m.	Second fire truck called.
11:10 p.m.	Electrical power failed in entire building.
11:15 p.m.	Water sprayed on filter bank.
2:00 a.m.	Filter fire knocked down.
11:28 a.m.	Final fire out.

Smoke from a burning glovebox, detected in a building hallway, led two watchmen to discover flames extending 18 inches from a Plexiglas window on a glovebox at approximately 10:10 p.m. on Wednesday, September 11, 1957. The fire started in a can of plutonium turnings in the “fabrication development line” in Room 180 (first floor) of the plutonium processing and fabrication building (Building 771). Because large quantities of plutonium were handled and stored in this area, people were delayed in fighting the fire until they could don adequate radioactive contamination protection. Attempts to fight the fire with carbon dioxide from hand extinguishers and a 100-pound cart were ineffective. A water spray nozzle was effective, although there was considerable uncertainty at the time about the potential for criticality.

During this time, the fire spread to the filters, which introduced hot gases through the ventilation booster system and the main exhaust duct. Fires in the box exhaust booster filters and main filter plenum on the second floor might have started around this time, but were not discovered until 10:28 p.m. An explosion of collected flammable vapors in the main exhaust duct at 10:39 p.m. resulted in spreading plutonium throughout most of the building. The Building 771 exhaust fans shut down at about 10:40 p.m. when power was lost. The only draft would have been that created by the natural updraft of the stack and through 100 feet or so of horizontal ductwork that leads to the base of the 150-175 foot stack. Supply fans might have created a positive pressure inside the building for about one-half hour. The fire in Room 180 was controlled at 10:38 p.m., but rekindled several times. The main filter fire was controlled at 2:00 a.m., and the fire was officially declared out at 11:30 a.m., Thursday, September 12, 1957.

One of the two prefilter systems leading to the main plenum burned through during the 1957 fire. This was a two-stage prefilter system for laboratory gloveboxes and hoods and for the production development laboratory on the first floor. The exhaust filter plenum consisted of a long concrete-block-walled room into which individual exhaust systems discharged. The 620 Chemical Warfare Service (CWS) 24-inch-square filters were held in a structural steel framework.

Contamination and Dispersal of Soil from the Building 903 Drum Storage Area

In July 1958, an area just east of the main plant site was designated a temporary storage area for contaminated oil drums. Many drums developed leaks due to stored chemical interactions, and plutonium-contaminated oil was deposited on the soil. Primarily between 1964 and 1969, the

contaminated soil was suspended during windstorms (see Meyer at al. 1996; Weber et al. 1999). The area was later covered by an asphalt pad.

The following significant events were associated with the Plutonium-Contaminated Drum Storage (903) Area:

- July 1958 - Drum storage area established. During subsequent years, drums that contained primarily plutonium-contaminated machining oils were continually added.
- July 1959 - First drum leakage discovered. Rust inhibitor, ethanolamine, was added to drums prior to storage to minimize corrosion.
- January 1964 - First evidence of large-scale deterioration of drums reported. Soil contamination reported increasing.
- January 1966 - Small building added to filter and transfer contaminated oil from leaking drums to new drums.
- January 1967 - Last drums added to storage area; removal to Building 774 began. Oldest drums shipped first.
- June 1968 - Last drum shipped to Building 774 for processing. High winds spread some contamination.
- July 1968 - Radiation monitoring and mapping of area completed. Levels of 2×10^5 dpm/g of soil to more than 3×10^7 dpm/g were reported. Penetration from 1 inch to 8 inches was reported.
- September 1968 - Preliminary proposal for containment cover prepared by RFP Facilities Engineering.
- July 1969 - First coat of fill material applied.
- August 1969 - Fill work completed, paving contract let.
- September 1969 - Overlay material, soil sterilant, and asphalt prime coat completed.
- November 1969 - Asphalt containment cover completed, including four sampling wells.

The first indication that drums were leaking in the field was in 1964. Contamination was detected on air samplers at the east fence following high winds. As a result, the storage area was fenced and contents of leaking drums were transferred to new drums. Approximately 420 drums leaked to some extent; of these, about 50 were totally empty. By the end of 1967, plant officials discovered that soil contaminated by the leaking drums had been resuspended in the air and redeposited.

The quantity redistributed was directly associated with the removal of the drums, which exposed contaminated soil; physical activity in the area; and the periodic high winds. In November 1968, grading began for applying an asphalt cap over the area. Most of the resuspension occurred between July 1968 and July 1969. The highest airborne concentration was 0.34 picocurie per cubic meter, measured at a monitor approximately 100 m east of the 903 pad, in the prevailing wind direction. Installation of an asphalt pad began in July 1969 and ended in November 1969. A round of soil

sampling in a 7-mile radius around the plant was completed in late 1989. Plutonium concentrations were highest just east of the plant (ChemRisk 1992).

The May 11, 1969, Fire

A major plutonium fire started in a glovebox in the North Foundry Line in Building 776 on Sunday, May 11, 1969 (see Voillequé 1999b). The fire burned for several hours, spreading through combustible materials in several hundred interconnected gloveboxes in Buildings 776 and 777. The first indication of a fire was an alarm in the Fire Station in the North Foundry Line at 2:27 p.m. The Fire Department responded promptly, but on its arrival the fire was moving rapidly through the Foundry Conveyor Line. The fire spread through an interconnecting conveyor to the Center Fabrication Line. It was brought under control about 6:40 p.m., but continued to burn or reoccur in isolated areas through the night. On Monday morning, a fire discovered in a glovebox on the South Foundry Line, which was quickly extinguished, caused little damage.

The dense smoke, crowded conditions, and presence of large quantities of combustible material in the form of Plexiglas windows and Benelex-Plexiglas shielding made the fire difficult to fight and extinguish. The fire did not breach the building roof, and ruptured only a minor part of one exhaust filter system. As a consequence, most of the smoke and essentially all of the plutonium remained in the building. One fire fighter received a significant internal body burden of plutonium. There is no evidence that a criticality incident occurred. The damage to Buildings 776 and 777 and equipment was extensive. In addition to actual fire and smoke damage, the buildings were grossly contaminated with plutonium. Adjacent buildings sustained minor exterior and interior contamination. After the fire, processing and production gloveboxes at RFP were converted to an inert nitrogen atmosphere to prevent the spontaneous ignition of plutonium.

The first indication of a fire in Building 776 came from an alarm received in the Fire Station at 2:27 p.m. The fire captain on duty and three firemen responded to the initial alarm. They arrived at the west end of Building 776 at 2:29 p.m. On entering the building they saw smoke coming toward them from the east. They proceeded further into the building and observed heavy smoke and fire in the North Foundry Line. The fire was out of the top of the line with flames about 18 inches high. One of the firemen heard two loud reports and saw two fireballs about basketball size go to the ceiling in the area of the North Foundry Line. This occurred while the firemen were laying out a fire hose, and before any water had been used on the fire. By 2:50 p.m., there was fire along the top of the North-South Conveyor Line. About this time the firemen on the second floor heard a loud noise and felt the floor shake. At approximately 3:20 p.m., the fire was spreading to the rolling mill on the Center Line, and at 3:40 p.m. the entire area from Columns G-J and 11-13 was glowing orange through dense smoke. There was also a fire in the ceiling in the vicinity of the North-South Conveyor Line.

Pressed plutonium briquettes composed of scrap metal and chips generated during rolling, forming, and machining operations self-ignited in metal storage containers in a Benelex and Plexiglas (transparent plastic materials) storage cabinet in the north line. Heat from the burning plutonium ignited the Benelex and Plexiglas in the glovebox line, which created large quantities of smoke. Visibility was nonexistent due to thick black smoke and the loss of lights in the main fire area. The crowded conditions in the fire areas made firefighting very difficult. The first attack on the fire with carbon dioxide was ineffective. Less than 10 minutes after the fire alarm was received, the fire captain initiated the use of water. Water was used on the fire almost exclusively, although some magnesium oxide was used on plutonium.

Because the conveyor lines and gloveboxes were open, it was impossible to avoid getting water on the burning plutonium. As the glovebox windows burned, plutonium oxide was released to the room. Because of the extensive plutonium contamination and smoke, personnel entering the area during the

fire were required to use self-contained breathing systems, which severely limited their time in the fire area. Attempts to pry or knock Benelex shielding from gloveboxes and conveyor lines were not successful. Although the firefighters were generally successful in “knocking down” the fire in some locations, by the time they returned with new air supplies or from directing their attention to other areas, the fire was again intense.

Some smoke came out the west end doors of Building 776, which were opened at about 2:29 p.m. Between 3:20 p.m. and 4:10 p.m., smoke was observed coming from the roof of Building 776. The smoke billowed over the side of the building toward Buildings 778 and 750. Firefighters sent to the roof saw smoke coming from exhaust vents. Although there were no signs of fire in the roof, the roof did soften in one area near the location of the 4 High Mill, Columns H-G and 6-7. The roof was sprayed with water and a fire watch maintained until after 5:00 p.m. By 6:40 p.m., the fire was contained. Between 7:00 p.m. and 8:00 p.m., a door on the second floor of Building 776 was opened and the main building exhaust system was changed from recirculating to single-pass in an effort to help clear the heat and smoke. By 8:00 p.m. the fire was largely extinguished, and a fire watch was established. During the early morning hours of Monday, May 12, the storage container in Glovebox 134-24 on the North Foundry Line continued to smolder and reignite. Water and magnesium oxide were used on this container. Between 8:00 a.m. and 9:00 a.m. on Monday the fire watch discovered a fire in the plutonium storage box on the South Foundry Line (Glovebox 134-70). This fire was quickly extinguished by breaking the Plexiglas windows and using water on both the inside and outside of the box. This was the only fire in the South Foundry Line.

The fire destroyed the gamma radiation alarm system in Building 776, but the Building 777 alarm system remained operational. Neither this system nor those in Buildings 559, 779 and other locations on the plant were set off during or after the fire. A Hurst dosimeter retrieved from Building 776 showed no evidence of being exposed to neutrons or gamma radiation. No one reported seeing a visible flash or any other sensory evidence that a nuclear criticality had taken place.

One area of the roof of Buildings 776 and 777 near the exhaust vent from Booster System No. 1 was contaminated with plutonium in the range of 10^5 - 10^6 cpm which corresponded to 0.2 µCi/100 cm^2. Adjoining ground areas and the exterior of Building 777 were contaminated on the order of 10^5 - 10^6 cpm. The ventilating, electrical, and other utility systems on the second floor of Building 776 were similarly contaminated with plutonium. Approximately 8 mCi of plutonium appears to have escaped from Buildings 776 and 777 and deposited on the roof or adjoining soil (Voillequé, 1999b). It was primarily deposited on the roof of the building and on the ground and one building adjacent to Buildings 776 and 777 (ChemRisk 1992).

The 1965 Glovebox Drain Fire

In 1965, a plutonium fire occurred during a maintenance operation on a plugged glovebox drain in Buildings 776 and 777 (see Voillequé 1999c). The fire vented to the room air and spread throughout the buildings through the normal ventilation system. About 400 employees, many without respirators, were potentially exposed to airborne plutonium dioxide. Body counter measurements indicated that 25 employees received 1 to 17 times the permissible lung burden. Lung concentrations greater than 0.008 µCi were found in fifteen employees.

At approximately 10:25 a.m. on Friday, October 15, 1965, a fire occurred during a lathe maintenance operation in Room 130 of Building 777. The operation involved unplugging a coolant recirculation line for a tape-controlled turning machine. Attempts to remove the obstruction from the glovebox end of the line failed; attempts were made to unplug the line through a drain leg near the glovebox. A cap was removed from the bottom end of the drain leg and a center punch was inserted to dislodge the

obstruction. Sparking was observed when the punch was struck, and a fire resulted, burning the bag enclosure for the punch and igniting a plastic and paper pen directly beneath the drain leg.

The fire lasted for one-half to 1-and-a-half minutes and was extinguished with carbon dioxide. It vented to the room atmosphere and combustion products were widely spread by the normal ventilation pattern. Residues of the fire and a drain leg removed from an adjacent lathe were analyzed. The analyses indicated that, during the fire, a chemical reaction occurred between plutonium and carbon tetrachloride. The burning of plutonium in air is generally nonviolent and described as smoldering. The reaction of plutonium and carbon tetrachloride can be violent.

Fifteen employees had greater than 0.008 µCi of plutonium in their chest counts. Plutonium contamination was spread through a major portion of Building 776 and through 25,000 square feet of Building 777. Major areas of the buildings were cleaned up by Monday morning, October 18, and nearly all production operations resumed at that time (ChemRisk 1992).

The 1974 Control Valve Release

Radioactive particulates escaped from an exhaust stack on the roof of Building 707-A following a glovebox atmosphere control valve accident at about 9:53 a.m. on April 2, 1974 (see ChemRisk 1992). At approximately 1 p.m., Wednesday, April 3, 1974, an elevated count was detected on the exhaust stack sample of Inert System No. 2 and Downdraft Plenum No. 4. Results of surveys showed the path of contamination movement in the inert system. A flow reversal had apparently occurred through the recirculating fans resulting in a release to the environment.

The accident resulted when the inert atmosphere exhaust valve from the Building 707 storage vault was being closed during a glovebox maintenance procedure. This resulted in a pressure surge that forced contaminated gas back upstream through the inert gas supply system. The contaminated gas was pumped into the atmosphere by the purge exhaust fans through the exhaust stack shared by Inert System 2 and Downdraft Plenum 4. This transport of contaminated gas in turn contaminated the exhaust ducts. In addition, the pressure surge caused contaminated gas to flow out the open window of glovebox 7-K-65, which had been removed for maintenance. This contaminated a nearby module to levels up to 100,000 counts per minute, and tripped the air monitors.

Table 2-1 summarizes releases to the environment for several Rocky Flats facility events.

Table 2-1. Plutonium release estimate distributions by event.[a]

Release event	Distribution of estimated release quantity (Ci)		
	5th percentile	50th percentile	95th percentile
1957 fire	11	21	36
1969 fire	0.013	0.037	0.062
903 Area[b]	1.4	3.1	15

a. Modified from Grogan et al. 1999).
b. Releases to air, primarily 1964-1969. Includes particles up to 30 µm AED; ~20% were estimated to be in the respirable size fraction (<15 µm AED). Rocky Flats TBD Section 5 considers particle size conventions and methods to convert from one system to another. Work remains to be done in this area for the Rocky Flats TBD, and this has been noted in TBD Section 5.

2.6.3 Tritium at Rocky Flats

Tritium has been present at Rocky Flats since 1964 as trans-shipments, for “special order” work, as standards, in contaminated materials, and as nondestructive testing sources. (ChemRisk, 1992). Two measurable releases of tritium occurred at the Rocky Flats Plant (ChemRisk 1992, 1994a, 1995). An

accident in 1968 led to the release of several hundred curies and another in 1973 released 500 to 2,000 Ci. The 1973 release occurred when tritium-contaminated-material was inadvertently processed. An estimated 60 Ci of tritium was released in water effluents, 100 to 500 Ci was retained in onsite ponds and tanks, and the remainder escaped to the atmosphere. There were five known sources of tritium effluent releases at RFP: Building 779; Building 561; Building 777, which released tritium in the 1973 incident; Building 774, where tritium-contaminated water was evaporated; and the four solar evaporation ponds adjacent to Building 779. The solar ponds were the source of water fed to the Building 774 evaporator (ChemRisk 1992). Figure 2-8 illustrates tritium operations locations.

2.6.4 Accidents Involving Uranium

Based on information gathered during an extensive investigation of accident records during the Phase 1 and 2 environmental dose reconstruction project, it is believed that incidents involving uranium at RFP have been relatively rare. One exception was associated with the practice of onsite burning of wood pallets. In May 1965, three depleted uranium sheets were accidentally burned as a result of shipment to RFP from Medina, Ohio, in a package that resembled a nonstandard size wooden pallet. Improper labeling and the nonconventional packaging apparently caused the depleted uranium to go undetected, and the pallet containing 60 kilograms of slightly radioactive depleted uranium was destroyed by burning on May 1, 1965.

Figure 2-9 illustrates the locations of uranium operations on the site.

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GLOSSARY

alloy
A substance composed of two or more metals blended together.

annual dose equivalent
The dose equivalent received in a year, expressed in units of rem (sievert).

alpha particles
Positively charged particles of discrete energies emitted by certain radioactive materials; alpha particles usually expend their energy in short distances and will not usually penetrate the outer layer of skin; they are a significant hazard only when taken into the body where their energy Is absorbed by tissues.

Atomic Energy Commission
Original agency established for nuclear weapons and power production; a predecessor to the U.S. Department of Energy.

beta dose
A designation (i.e., beta) on some external dose records referring to the dose from less-energetic beta, X-ray and/or gamma radiation (SEE ALSO *open window*, or *shallow dose*).

beta radiation
Radiation consisting of charged particles of very small mass (i.e., the electron) emitted spontaneously from the nuclei of certain radioactive elements. Most (if not all) of the direct fission products emit beta radiation. Physically, the beta particle is identical to an electron moving at high velocity.

curie
A special unit of activity. One curie equals 3.7×10^{10} nuclear transitions per second.

criticality
A self-sustaining nuclear fission reaction.

deep absorbed dose
The absorbed dose at the depth of 1.0 cm in a material of specified geometry and composition.

deep dose equivalent (H_d)
The dose equivalent at the respective depth of 1.0 cm in tissue.

detection limit (lower)
The minimum quantifiable exposure or neutron flux that can be detected.

Delayed neutron analysis (DNA)
Method adopted for both enriched and depleted uranium urinalysis analyses in about 1982.

dose equivalent (H)
The product of the absorbed dose (D), the quality factor (Q), and any other modifying factors. The special unit is the rem. When D is expressed in Gy, H is in Sieverts (Sv).
(1 Sv = 100 rem.)

dose of record
The dose files provided by DOE to NIOSH as part of the individual worker files.

dosimeter
A device used to measure the quantity of radiation received. A holder with radiation-absorbing elements (filters) and an insert with radiation-sensitive elements packaged to provide a record of absorbed dose or dose equivalent received by an individual. (SEE *albedo dosimeter*, *film dosimeter*, *neutron film dosimeter*, *thermoluminescent dosimeter*.)

dosimetry
The science of assessing absorbed dose, dose equivalent, effective dose equivalent, etc., from external or internal sources of radiation.

dosimetry system
A system used to assess dose equivalent from external radiation to the whole body, skin, or extremities. This includes the fabrication, assignment, and processing of dosimeters as well as interpretation and documentation of the results.

exchange period (frequency)
Period (weekly, biweekly, monthly, quarterly, etc.) for routine exchange of dosimeters.

exposure
As used in the technical sense, exposure refers to a measure expressed in roentgens (R) of the ionization produced by photons (i.e., gamma and X-rays) in air.

extremity
That portion of the arm extending from and including the elbow through the fingertips, and that portion of the leg extending from and including the knee and patella through the tips of the toes.

field calibration
Dosimeter calibration based on radiation types, intensities, and energies in the work environment.

film
In general, a "film packet" that contains one or more pieces of film in a light-tight wrapping. When developed, the film has an image caused by radiation that can be measured using an optical densitometer.

film density
SEE optical density.

film dosimeter
A small packet of film within a holder that attaches to a wearer.

fission
The splitting of a heavy atomic nucleus, accompanied by the release of energy.

fissionable
Material capable of undergoing fission.

gamma rays
Electromagnetic radiation (photons) originating in atomic. Physically, gamma rays are identical to X-rays, the only essential difference being that X-rays do not originate in the nucleus.

HEPA filter
High-efficiency particulate air filter; a dense filter capable of removing a high percentage of particulate material from an air flow

HEU
Highly enriched uranium

hydrofluorination
Chemical conversion to a form containing fluorine.

ionizing radiation
Electromagnetic or particulate radiation capable of producing charged particles through interactions with matter.

isotope
Elements having the same atomic number but different atomic weights; identical chemically but having different physical and nuclear properties

minimum detectable activity (MDA)
Limit of radionuclide activity detection for measurements of specific types and energies of radiation

near-net shape
Close to final shape.

neutron
A basic particle that is electrically neutral weighing nearly the same as the hydrogen atom.

neutron, fast
A neutron with energy equal or greater than 10 keV.

neutron, intermediate
A neutron with energy between 0.5 KeV and 10 keV.

neutron, thermal
Strictly, a neutron in thermal equilibrium with surroundings. In general, a neutron with energy less than about 0.5 eV.

neutron film dosimeter
A film dosimeter that contains a Neutron Track Emulsion, type A, film packet.

Nuclear Emulsion
Often referred to as “NTA” film and used to measure personnel dose from neutron radiation.

Nuclear Track Emulsion, Type A (NTA)
A film that is sensitive to fast neutrons. The developed image has tracks caused by neutrons

that can be seen by using an appropriate imaging capability such as oil immersion and a 1000X-power microscope or a projection capability.

open window (OW)
Designation on film dosimeter reports that implies the use of little (i.e., only security credential) shielding. Commonly used to label the film response corresponding to the open window area.

operating area
Designation of major onsite operational work areas.

optical density
The quantitative measurement of photographic blackening; density defined as $D = Log_{10} (I_o/I)$.

oralloy
Enriched uranium (containing 0.7 to 93% uranium 235) named for “O”ak “R”idge alloy.

pencil dosimeter
A type of ionization chamber used by personnel to measure radiation dose. The results can be labeled as “Pen” doses. Other names include *pencil*, *pocket dosimeter*, *pocket pencil*, *pocket ionization chamber*.

personal dose equivalent $H_p(d)$
Represents the dose equivalent in soft tissue below a specified point on the body at an appropriate depth (d). The depths selected for personnel dosimetry are 0.07 mm and 10 mm for the skin and body, respectively. These are noted as $H_p(0.07)$ and $H_p(10)$, respectively.

photon
A unit or "particle" of electromagnetic radiation consisting of X- or gamma rays.

pit
Nuclear weapon core, made of fissionable material.

quality factor, Q
A modifying factor used to derive dose equivalent from absorbed dose.

radiation
Alpha, beta, neutron, and photon radiation.

radioactivity
The spontaneous emission of radiation, generally alpha or beta particles, gamma rays, and neutrons from unstable nuclei.

radionuclide
A radioactive isotope of an element, distinguished by atomic number, atomic weight, and energy state

relative biological effectiveness (RBE)
A ratio of the absorbed dose of a reference radiation to the absorbed dose of a test radiation producing the same biological effects, other conditions being equal.

rem
A unit of dose equivalent equal to the product of the number of rad absorbed and the quality factor.

rep
Roentgen-equivalent-physical (mrep = millirep) used when reporting beta exposures, usually recorded in mrep.

Roentgen (R or r)
A unit of exposure to gamma (or X-ray) radiation. It is defined precisely as the quantity of gamma (or X-) rays that will produce a total charge of 2.58×10^{-4} coulomb in 1 kg of dry air. An exposure of 1 R is approximately equivalent to an absorbed dose of 1 rad in soft tissue for higher (~>100 keV) energy photons.

scrub or salt scrub

shallow absorbed dose (D_s)
The absorbed dose at a depth of 0.007 cm in a material of specified geometry and composition.

shallow dose equivalent (H_s)
Dose equivalent at a depth of 0.007 cm in tissue.

shielding
Any material or obstruction that absorbs (or attenuates) radiation and thus tends to protect personnel or materials from radiation.

sievert (Sv)
The SI unit for dose equivalent. (1 Sv = 100 rem.)

silver shield(s)
The 1-mm thick shields covering the film packet in early personnel film dosimeters.

site returns
Weapons components that have been retired and returned for disassembly and recovery of materials.

skin dose
Absorbed dose at a tissue depth of 7 mg/cm^2.

thermoluminescence
Property of a material that causes it to emit light as a result of being excited by heat.

thermoluminescent dosimeter (TLD)
A holder containing solid chips of material that when heated will release stored energy as light. The measurement of this light provides a measurement of absorbed dose.

transuranic
An element with an atomic number greater than uranium (92); all transuranic elements are radioactive and are produced artificially.

trigger

Fissionable core of nuclear weapon, used to trigger fusion energy release

whole-body dose

Commonly defined as the absorbed dose at a tissue depth of 1.0 cm (1000 mg/cm^2); however, also used to refer to the recorded dose.

X-ray

Ionizing electromagnetic radiation of external nuclear origin.

ATTACHMENT 2A
ROCKY FLATS BUILDINGS AND OPERATIONS

Buildings 122 and 122S

1953 Building constructed. Use designated as medical.

Building 218

Building 218 was actually two 10,000-gallon, above-ground, nonradioactive nitric acid storage tanks.

Building 371
Plutonium Recovery Facility

1968 A decision was made to replace the Plutonium Recovery Facility (Building 771) with a new building (Building 371).

1972 Construction began on Building 371

1976 Building 371 originally scheduled for startup

1978 Some equipment moved to Building 371

1981 Pilot-scale operations conducted. Due to engineering design problems production processes in this building never operated beyond pilot scale. Plutonium recovery (electrorefining) operations remained in B-771.

1982-1989 No accidents of any significance occurred in this building. In addition, effluent emissions were most likely of little significance to the offsite population because this building only ran on a pilot scale basis. Monitoring data for radionuclides were available for the life of this building. Emissions data are available for tritium, Pu-238, Pu-239/240, Am-241, U-233/234 and U-238 through 1989.

Building 374
Process Waste Treatment Facility

1978 Building brought on-line as the process waste treatment facility for many of the production buildings. Emissions data available for tritium, Pu-238, Pu-239/240, Am-241, U-233/234, and U-238 through 1991.

1980 Second stage of HEPA filters added.

1986-1988 An increase in waste load.

1988-1989 Condensate from the evaporator went to the cooling tower and was discharged to Pond B5. In 1989 this discharge was remedied by not allowing the cooling tower to overflow.

1991 The waste treatment facility was supporting the clean-up of the solar evaporation ponds and processing waste for Buildings 122, 123, 443, 444, 460. 559. 707, 774, 776, 778, 779, 865, 881, 883, and 889.

Building 439
Modification Facility

1971 Building constructed. Building 439 houses a machine shop, upholstery shop, battery, and office space for Building 439/440 support personnel. No radionuclides were known to have been handled here.

Building 440
Fabrication Facility

1971 Building constructed. Building 440 was a fabrication facility in which rebuild and rework operations to modify and maintain DOE vehicles and rail cars were performed. Operations in the building included metalworking, painting, electrical fabrication, and assembly. No radioactive material is known to have been present.

Buildings 444, 445, 450, and 455
Depleted Uranium and Beryllium Metallurgy

1953 Building 444 came on line in August, beginning DU processing.

1957 Building 445 added.

1958 Beryllium operations began in Building 444. Blanks received from commercial supplier were machined.

1968 Buildings 444 and 445 connected.

1980 Beryllium casting ended.

1981 Production plating laboratory began operations.

1983 Construction of new filter system for Building 444.

1984-1985 New filter system came on-line.

1987 Titanium stripping began.

1989 Uranium foundry shutdown

1990 Production plating lab shut down after a fire

B-450. Date of construction unknown. Building 450 houses the exhaust filter plenum and exhaust fans that handle a major portion of the air exhausted from Building 444. The plenum was comprised of a demister section and two stages of HEPA filters. Each stage contains 192 HEPA filter units mounted 32 units wide by 6 units high. Three exhaust fans pull the exhaust air through the filter plenum and discharge the air through vent 200 to the atmosphere. Additional facility history/equipment modification details are not available.

B-455. Date of construction unknown. This building was an exterior exhaust filter plenum consisting of a demister section and two stages of HEPA filtration. The plenum serves the production plating laboratory in Building 444. Each stage contains 16 HEPA filter units mounted 4 units high by 4 units wide. The exhaust fan for the plenum exhaust system was mounted on the roof of Building 444. The fan discharges through vent 82 to the atmosphere.

Foundry. Eight vacuum induction furnaces were used to produce ingots from scrap depleted uranium, depleted uranium alloys, silver, aluminum, and copper. Casting processes produce small quantities of particulates from mold coating compounds and metal oxidation reactions. All off-gases discharge through the Building 44 exhaust system to the Building 450 exhaust filter plenum vent 200. Particulate emission control consists of two stages of HEPA filtration.

Mold Cleaning. Graphite molds used in the foundry area in Building 444 for casting ingots were manually cleaned using wire brushes and other hand tools. The molds were recycled for reuse. Residual material in the mold after ingot removal includes Y_2O_3, depleted uranium oxide, graphite, and trace quantities of iron, silica, and other cast metals. This material was collected and transferred by house vacuum to a cyclone collector in the Building 444 Utilities Area. The cyclone was 85 percent efficient in removing particles greater than 15 microns. According to plant personnel, approximately 5% of the material was less than 15 microns. Particulates from mold cleaning discharge through vent 200 after passing through a vacuum cyclone separator and two stages of HEPA filtration.

Robot Crucible Cleaning. A robot device in Building 444 cleans the graphite crucibles used for heating and melting metals in foundry furnaces. The removed residue contains depleted uranium oxide with trace amounts of iron, silica Y_2O_3, graphite, and other cast metals from the crucible. Controls consist of the cyclone separator and two stages of HEPA filtration.

Depleted Uranium Machining. Depleted uranium machining operations in Building 444 include turning, facing, boring, milling, and sawing using numerically controlled lathes and conventional machine tools. Parts were fabricated from depleted uranium, depleted uranium alloy, depleted uranium with trace amounts of iron, silica, 71, aluminum, and stainless steel.

Buildings 447, 448 and 451

1956 Building 447 constructed. Manufacturing building for a variety of uranium and Be parts either for production or special orders.

1962 Building 448 constructed. Shipping, receiving, and storage building. Handling of radioactive materials not indicated in information reviewed.

1983 Construction of a new filter system for Building 447.

B-451. Exhaust Filter Plenum Building serves processes and facilities in Buildings 447 and 448.

Electron Beam Welding. An electron beam welder was used for welding vanadium, beryllium, aluminum, depleted uranium, and stainless steel. Welding operations are performed inside a vacuum chamber.

Electrochemical Milling Operations (ECM). The ECM machine was used for a variety of production and special order jobs. Some work involved milling tungsten, brass, copper, aluminum, and depleted uranium.

Vacuum Arc Melt Furnace. The vacuum arc melt furnace was used to melt material for casting consumable electrodes in 6-inch and 8-incli diameter copper molds. The metals melted include depleted U, and depleted uranium alloy with 6% niobium. The molds may be up to 5 feet long.

Chip Roaster. The chip roaster was used to oxidize depleted uranium scrap metal. The chip roaster was a four-tier, single-chamber, vertical roaster.

Building 460
Consolidated Manufacturing Facility

1984 Building constructed. This building was a non-nuclear facility for war reserve and special-order parts and assemblies.

Building 549

1957 Building constructed. This building contains the alarm systems.

1991 This building was used exclusively as an electrical maintenance shop and general staging support.

Building 559 and 561
Plutonium Analytical Laboratory

1968 Building Constructed. Plutonium Analytical Lab. The building contains laboratory facilities for conducting spectrochemical, chemical, and mass spectrometric analyses.

1973 Building 561 constructed. This building houses the exhaust plenums for Building 559.

Metals, liquids, oxides, oils, and sludges were analyzed for uranium content.

Plutonium Oxidation. Plutonium scraps and oxides remaining after sample analyses were oxidized in one of two gloveboxes prior to shipping the PuO_2 to another process on the plant. Scrap and oxide from all processes were collected in the two gloveboxes, and the oxidation process was run as needed (about once a month).

Building 566
Laundry Facility

Construction date unknown. This building was designed as a laundry facility for clothing and respirators contaminated with radioactive materials. However, available records related to laundry services at the plan do not list Building 566 as a laundry processing facility. We have not resolved this discrepancy.

Building 701
Waste Treatment Research and Development Facility

1965 Building constructed. Pilot Plant Development. Building 701 was a research and development facility used to design, build, and evaluate bench-scale and pilot-scale waste handling and treatment processes.

Building 705
Coatings Laboratory

1966 Building Constructed. This building includes coatings laboratories and associated offices. No evidence of radioactive materials use in Bldg. 705 was found.

- Vapor Deposition
- Beryllium Vapor Deposition
- Parts Cleaning
- Beryllium Parts Cleaning
- Polishing
- Sand Blasting
- Water Cooling

Building 707
Plutonium Fabrication/Pyrochemical Operations

1972 Construction completed. This building provides metallurgical support in the form of foundry and casting operations, as well as product assembly. The machining and foundry operations for plutonium came from Building 776 after the 1969 fire.

Plutonium Fabrication/Pyrochemical Operations. This building contains foundry and casting operations and products assembly.

Module A - Casting Operations. Carbon tetrachloride was used to clean interior glovebox walls where casting furnaces were located in which plutonium ingots were made.

Module J - Casting Operations. Plutonium ingots were made.

Module K - Casting Operations and Stacker Retriever. This operation stores and retrieves plutonium metal for distribution to other processes. Metal was weighed, melted in furnace, and formed into ingots.

Module B - Rolling and Forming. This process involves the forming and thermal treatment of plutonium metal ingots.

Module C - Briquetting. Metal turnings from Module C machining process and Module B scrap cutters were put in metal baskets and dipped in five carbon tetrachloride baths.

Module C - Machining Operations. Plutonium parts were machined.

Modules C and D - Inspection. Parts were cleaned with carbon tetrachloride.

Casting Operations - Module A. Plutonium ingots were cast into feed or production ingots in Casting Operations. Ingots were transported by enclosed, interconnected chain conveyors from storage to the foundry gloveboxes. The ingots were placed in crucibles and melted in electric induction furnaces, which operate under vacuum. Metal was poured through a funnel into the molds, which were allowed to cool. Crucibles and funnels were scraped clean and reused until worn.

Casting Operations - Module J. Two types of particulate emissions result from operations in this module. The first was from plutonium oxidation and the second was from casting operations.

Casting Operations and Stacker Retriever - Module K. Module K contains the stacker retriever, also known as the X-Y retriever, and casting furnaces. These operations were performed in an inert nitrogen atmosphere. The stacker retriever was used to store and retrieve plutonium metal for distribution to other processes in Building 707.

Module E, Assembly Operations. Cleaning of plutonium parts.

Module F, Assembly-Superdry. Cleaning of plutonium parts before they were assembled and welded into a weapons product.

Module G, Assembly-Welding and Cleaning. Ultrasonic cleaner used to clean plutonium parts following welding.

Module G, Assembly-Electron Bombardment Brazing/ Scanning. Cleaning of waste materials deposited on the walls of a bell jar during brazing of metals in the jar

Module H Assembly Testing. Cleaning parts prior to testing.

Modules D, E, and G. Assembly ultrasonic cleaners.

Room 173, Radiography. Cleaning plutonium parts prior to radiography (X-ray examination of parts).

Module D, Weighing. Cleaning prior to weighing of parts.

Module E, Eddy Current Testing. To check the depth of weld penetration on plutonium parts moved to and from gloveboxes.

Weld Scanners and Fluorescent Penetrant Operations. Area used to qualify welds on plutonium parts.

Module D, Production Control Operations. Cleaning plutonium parts following grit blasting.

Modules D and G, Calibration Laboratory. Cleaning gauges before precision measurements.

Building 771
Plutonium Recovery Operations

1953	Building constructed. The principal operation of Building 771 was the recovery of plutonium from plutonium-bearing residues.
1957	Americium line started.
1958	Carbon tetrachloride distilled out of the cutting oil and plutonium recovered from solids. The cutting oil, carbon tetrachloride mixture came from plutonium machining in B-776.
1958-1988	Incinerator used for the recovery of fissile material.
1953-1959	Purex process used for plutonium purification.
1959	Began using ion exchange for plutonium purification.
1968	Caustic scrubber installed.
1963-1975	Ammonium thiocyanate used for recovery of americium.
1975-1980s	Oxalate precipitation process used for recovery of americium.
Early 1980s	Discontinued americium purification but not recovery.

Dissolution. Dissolution processes were all similar in concept. The equipment consisted of a series of cascade dissolver vessels. Plutonium bearing material was fed into the first dissolver at a controlled rate by a special screw feeder.

Feed Evaporation. Feed evaporation was used to concentrate some solutions from previous operations. Concentration of these solutions was necessary to yield precipitation feed of an acceptable plutonium concentration.

Peroxide Precipitation. The peroxide precipitation process converted the plutonium pit in solution to a solid form.

Chemical Technology. Plutonium chemistry technology in Building 771 supported and developed improved methods for recovering, separating, and purifying actinides from acidic streams.

Calcination. The calcination process converted PuO_4 to PuO_2 and drove out residual water and HNO_3, leaving a dry, powdered product. The primary contaminant released from calcination was PuO_2 particulates.

Hydrofluorination. Plutonium oxide was converted to plutonium tetrafluoride (PuF_4) in a continuous rotary-tube hydrofluorinator.

Plutonium Oxidation. Plutonium oxidation converted pure plutonium metal, which is pyrophoric, to a more stable PuO_2. The PuO_2 was used as a feed to the dissolution operation.

Plutonium Metallurgy and Research and Air Emissions. The plutonium metallurgy group assisted the design agency and plant production in the development of processes that require metallurgical production of materials and related techniques. All plutonium metallurgy operations were conducted in gloveboxes.

Building 774
Process Waste Treatment Facility

1953 Building constructed to support Building 771. Originally designed as a nuclear waste packaging facility. Modifications and additions in 1963, 1965, 1966, 1967, 1970, and 1974.

1981 Converted to storage for Building 771 (drums).

Radioactive Decontamination Treatment. Nitric acid was used in the first stage of this process. This caustic precipitation process reduced plutonium and americium concentrations.

Caustic Precipitation. This process was the first stage in radioactive decontamination treatment. It was designed to reduce the plutonium and americium concentrations.

OASIS (organic and sludge immobilization system). TRU waste from 707 and 776/777. TCA, oils mixed with carbon tetrachloride were solidified with gypsum cement in a glovebox.

Buildings 776 and 777
Assembly and Manufacturing Buildings

1957 Buildings 776 and 777 constructed. Building 776: Manufacturing building; Building 777: Assembly Building. Assembly operations transferred from Building 991.

1958 First significant machining of plutonium begins using cutting oil, followed by washing with carbon tetrachloride.

1969 Fire in Building 776 on May 11, 1969.

1972 Operations in Building 776 transferred to Building 707. Building 776 converted to waste storage and waste size reduction.

1957-1969 Building 776 was the major user of carbon tetrachloride and TCE at RFP.

B-777. Briquetting. The pressing of plutonium metal machine turnings into pucks using hydraulic press. Turnings were cleaned in metal baskets that are dipped into four CCl_4 baths.

Machining, Rooms 131 and 134A. Parts were cleaned with CCl_4 on towels prior to machining.

Inspection, Rooms 130 and 430. Parts were cleaned with CCl_4

Disassembly operations. Disassembly occurred in room 430 and involved the disassembling of plutonium parts for further processing in the Molten Salt Extraction (MSE) Operation.

Special Weapons Projects. Special weapons projects perform R&D for fabricating classified parts and fitting specialty parts and materials. Plutonium oxidation was conducted to convert pyrophoric plutonium residues to non-pyrophoric PuO_2.

Tritium Environmental Control. Tritium was released during the disassembly of some types of contaminated parts. The tritium environmental control system removes tritium from gas sampling and glovebox exhausts by converting it to tritiated water and desiccating the air stream. Tritium water was collected in special containers for further processing.

B-777. Foundry Operations, Coatings.

- Disassembly Operations, Room 430. Pu parts were disassembled for further processing.
- Assembly Superdry, TCA Wash
- Ultrasonic Cleaning System, Room 430.
- Ultrasonic Cleaning System, Room 440.
- Plutonium Metallography Laboratory. TCA was used as a cutting agent for grinding with carbide grit to cut plutonium.
- Special Weapons Projects. R&D for fabricating classified parts and fitting specialty parts and materials.

Building 779
Plutonium Development Building
1965 Building constructed. Building 779 was an R&D facility that supported production.

Building 865, 867, and 868
Research and Development of Uranium and Beryllium
1972 Building Constructed. Material and process development

B-867. Date of construction unknown. Contained filter plenums for process exhaust routed from Building 865

B-868. Date of construction unknown. Contained filter plenums for process exhaust routed from Building 865.

High Bay. The High Bay area of Building 865 supported production through the research and development of metalworking processes. Most work was done with depleted uranium, beryllium, copper, tungsten, stainless steel, and other steel alloys. Processes include metal casting, machining, rolling, heat-treating, and isostatic: pressing. Chemical etching and cleaning were performed to prepare the part for inspection and to remove oily residues, respectively.

Metallography Laboratory. The Metallography Laboratory in Rooms 102, 106, and 108 conducted quality control analyses on metal samples.

High Bay. Production through R&D of metalworking processes.

Grit Blasters, Room 172. Surface cleaning of parts containing depleted uranium.

Building 866
Date of construction unknown. Building 866 was a transfer station. It received wastes from Buildings 865 and 889 and transferred them to Building 374.

Building 881

1953	Building constructed. Building 881 contained laboratories, maintenance shops, and plant support facilities. The original building was designed and built for processing enriched uranium. Small quantities of other radioactive materials such as ^{233}uranium and plutonium were also handled in the building.

Buildings 883 and 879
Beryllium and Uranium Machining Facility

1957	Building constructed as a rolling and forming (more commonly referred to as machining) facility for both enriched and depleted uranium. The building was divided into two sides: A side and B side. The A side rolled enriched uranium while the B side rolled depleted uranium.
1966	Enriched uranium operations curtailed at Rocky Flats. The A side of Building 883 was converted to beryllium rolling (this process was not enclosed). Depleted uranium rolling continued on the B side.
Mid-1970s	Beryllium machining stopped.
1957-1989	Nitric acid commonly used in a 50:50 water/nitric acid mixture for pickling uranium.
1980-1985	Increased processing of depleted uranium.

Rolling. Metal ingots, including uranium, were rolled in a rolling mill to reduce thickness and establish desirable grain structures.

Shearing. Uranium plates were mechanically cut into smaller pieces before being shaped in other mechanical processes. Uranium scrap was recycled by sending it to Building 444 for recasting.

Blanking/Trepanning. Uranium cut from a sheet with a press and die, and desired shapes were cut with trepanning tool. Uranium turnings are placed in a drum and sent to Building 447/448 for U chip roasting.

Forming. Uranium parts were formed into useful shapes.

Buildings 886 and 875
Nuclear Safety Facility

1965 Building 886 constructed.

1965--Present More than 1,600 criticality experiments were performed. Materials used in the experiments (uranyl nitrate metal powder) were re-used. Short-lived fission products were produced and none were indicated as having been released to the work or outdoor environment. The isotopes decayed rapidly and were contained until stable (ChemRisk, 1991).

Building 910 and Solar Ponds 207A, B, AND C

1957 Solar evaporation pond 207A put into use. Used to store and evaporate low level contaminated waste containing nitrates and radioactive substances (laundry wastewater including plutonium and uranium). The history of the ponds is developed further in Rocky Flats TBD Section 4.

1960 Solar Evaporation Ponds 207B and C put into service.

1977 Building 910 (Reverse Osmosis facility) constructed.

Building 991

1951 Construction began on D plant, now known as Building 991. This was the first building constructed at Rocky Flats.

1952 Final product assembly operations conducted

1958 Building 777 becomes focal point for assembly operations

1960 Building 991 used for storage and R&D. Emissions data for Bldg 991 include Pu-238, Pu-239/240, Am-241, U-233/234, and U-238.

Building 995
Air Handling System

1974 Building constructed. Building 985 houses the air handling system that supports the underground storage vaults 996, 997, and 999.

Buildings 990, 990a, 995, 988, 228a, 228b (Listed for completeness – no information is readily available concerning whether or not potential for worker exposure existed in these facilities.)

B-990 - Pre-Aeration Building
B-995 - Sewage Treatment Facility
B-988 - Tertiary Treatment Pump House

ATTACHMENT 2B
ROCKY FLATS JOB TITLES AND DESCRIPTIONS

1. Chemical Operators

Primary job duties included highly enriched uranium (Building 881) and plutonium (Buildings 771 and 371) metal reprocessing using dissolution, fluorination, calcine, and other wet chemistry methods to purify metal in preparation for foundry casting operations. Molten salt processing (Building 776) was an exceptionally high neutron process. Other typical job duties included waste treatment (Buildings 774 and 374) for waste solutions generated on the plant.

2. Metallurgical Operators

Primary job duties included casting (Building 881), rolling, and pressing highly enriched uranium (Building 883), plutonium (Buildings 776 and 707) and depleted uranium (Buildings 444, 447, and 883). Exposures tended to be less than those to Chemical Operators. Machinists, Assemblers, Material Analysts and Welders had similar exposures. Non-Destructive Testing (NDT) Technicians had similar, but probably lower exposures because work was often done on completed pits that inherently shielded the fissile materials. Experimental Operators had similar, but probably higher exposures because they often worked with prototype systems or processes that lacked shielding and other radiological controls as the regular production processes.

3. Maintenance Workers

Typical trades (i.e., machinists, pipefitters, welders, carpenters, painters, electricians) had varied exposures because they often did more intrusive work on contaminated systems than production personnel. Examples of intrusive work included repairing leaks on process lines (pipefitters), refractory replacement in casting and heat treat furnaces (carpenters), repair of mechanical systems (machinists), repair of instruments and controllers inside gloveboxes and other systems (electricians), and painting over contamination (painters).

4. Support Personnel

Support personnel included clerk packers, metrology technicians, janitors, and handymen who worked in process areas but did little or no hands-on work with radioactive materials. Exposures would be incidental to working in rooms with process equipment (metallurgical and chemical operations).

5. Analytical Laboratory Technicians

Analytical laboratory technicians worked primarily in Building 559 (plutonium samples) or 881 (highly enriched uranium or depleted uranium samples) and probably had lower exposures than operators performing hands on-work with significantly larger radioactive material quantities.

6. Site Support Personnel

Stationary operating engineers (SOEs, also known as boiler vent operators, BVOs), security guards, shift managers, and configuration control authority personnel, performed little if any hands-on radioactive material or radiation work, but had routine access to process areas. SOEs monitored the operation of exhaust systems, waste tanks, and process waste lines. Exposures would be incidental to working in rooms with process equipment (metallurgical and chemical operations).

7. Radiation Control Technicians

Radiation Control Technicians (RCTs) probably had exposures from supporting production chemical and metallurgical processes. Some significant exposures probably occurred during decontamination

activities, surveys of contaminated areas, upset conditions. There was no hands-on work *per se*, but RCTs generally worked side-by-side with production operators.

8. Decontamination & Decommissioning Workers

Decontamination and decommissioning (D&D) work included draining actinide systems, decontamination, size reduction and removal of contaminated equipment, gloveboxes, piping, ductwork, exhaust systems, waste packaging of removed equipment, low-level and TRU wastes. Work was often in high (>2,000 dpm alpha, removable) contamination areas with high air concentrations (see RF TBD Section 5 for exposure details. Personal Protective Equipment (PPE) included Air Purifying Respirators, Powered Air Purifying Respirators, or PremAir supplied air systems. There were some high exposures due to direct work with highly radioactive equipment and contamination events (See RF TBD Sections 5 and 6 for details).

ATTACHMENT 2C
OPERATIONAL ACCIDENTS AND INCIDENTS AT ROCKY FLATS PLANT

Date	Location	Description (exposure details – see also RF TBD Section 5)
Nov 21, 1952	Not specified	Boiler explosion (disruptive force, no known radionuclide involvement)
June 14, 1957	Not specified	Explosion from chemical reaction (3.2 µg Pu lodged in finger)
Sept 11, 1957	Bldg 771, Rm 180	Fire in a manufacturing building; Pu airborne release.
Oct 25, 1961	Not specified	Boiler explosion (disruptive force, no known radionuclide involvement)
Apr/June 1962	Not specified	Involved internal Pu exposures to three chemical operators
Mar 16, 1963	Not specified	Substation failure due to high-velocity winds, and fire (none)
Mar 19, 1963	Not specified	Failure of engine in building's compressor house (none)
Apr 23, 1963	Not specified	Contamination from nitric acid spill (none)
June 20, 1963	Not specified	Contamination leak and spill in line carrying high-level Pu solution (none)
June 12, 1964	Not specified	Chemical explosion in glovebox. Pu lodged in finger, thumb)
Mar 19, 1965	Not specified	Glove failed in a glovebox, releasing Pu resulting in measured lung deposition, one worker.
Apr 8, 1965	Not specified	Inspected parts knocked off shelf (none)
May 6, 1965	Not specified	Product feed sprayed out of loose flange, decontamination of three workers, details unavailable.
Oct 15, 1965	Bldg 777, Rm 130	Glovebox drain fire releasing Pu resulting in measured lung depositions, ten workers
Nov 9, 1965	Not specified	Glovebox fire (12 skin decons; no significant internal exposures)
Nov 27, 1965	Not specified	Wind damage to building roof (none)
Jan/Mar 1967	Not specified	Pu and Am residues accumulated in a fluorinator glovebox and required moving. Resulted in 3 worker exposures, details unavailable.
Jan/Mar 1967	Not specified	A process operator handled large Pu charges and castings and large amounts of material containing ^{241}Am
Apr 5, 1967	Not specified	Employee fell from a tractor, broke leg, died 5 days later. No known radionuclide exposures.
Apr/June 1967	Not specified	Three employees on the Am line, fluorinator, and oxide dissolution. Significant exposures (see RF TBD Section 5).
July/Sept 1967	Not specified	A DU-Pu-Mo alloy was processed as normal Pu but high gamma readings were reported. Details unavailable – 7 external exposures.
Sept 29, 1967	Not specified	Contamination spill from blowout of pipe plug. Nuclide data unavailable.
Feb 1968		Tritium release of 600 Ci.
1958-68	903 Pad	Plutonium-contaminated oil leaked from drums onto outdoor soil
Oct 14, 1968	Not specified	An employee inhaled Pu-239 from a fire in a hot waste drum. Details unavailable.
Jan 7, 1969	Not specified	High wind damage to buildings.
Apr 23, 1969	Not specified	Employee showed an unexplained ^{239}Pu lung burden (0.065 µCi)
May 11, 1969	Bldg 776	Glovebox fire in plutonium processing area. See RF TBD Section 5 for details.
June 20, 1969	Not specified	Molten metal released into furnace interior. Details unavailable.
July 30, 1969	Not specified	Fire in tunnel between buildings. Details unavailable.
July 30, 1969	Not specified	Two chemical operators screened Pu residues that caught fire when later stored (inhaled or ingested 0.15 – 0.99 µg)
Apr 20, 1970	Not specified	Contamination release from a plugged drain line. Details unavailable.
Aug 15, 1970	Not specified	Power lead short-circuited to bus bar
Sept 11, 1970	Not specified	Acid leaked from storage tank
Jan 20, 1971	Not specified	A process operator was exposed to ^{241}Am when removing a canned Pu button from a shipping container. Lung count noted contamination.

Attachment 2C (Continued)

Date	Location	Description (exposure)
Apr 12, 1971	Not specified	Corrosion caused steam condensate line to leak contamination. Details unavailable.
Apr 19, 1971	Not specified	Contamination spread from reduction furnace gasket failure. Details unavailable.
June 15, 1971	Not specified	A fire started in a shipment of drummed radioactive waste on its way to Idaho and self-extinguished (no exposures)
Aug 22, 1971	Not specified	Small container exploded and contamination spread by ignited plutonium. Measured lung burdens – two employees.
Sept 2, 1971	Not specified	Hole in a barrel liner allowed plutonium oxide to escape into room (<4 µCi)
Jan 5, 1972	Not specified	Electrical faulting of three main substations due to winds and snow
Jan 11, 1972	Not specified	Cell shrouding of cooling tower blew away
Apr 10, 1972	Not specified	Incinerator glovebox fire. Details unavailable.
Feb 8, 1972	Not specified	Incinerator fire and contamination caused by a punctured aerosol can (no exposures)
Sept 6, 1972	Not specified	Three employees exposed to Pu through a faulty glove on a glovebox
Feb 2, 1973	Not specified	Supplied air suits contaminated by ignition of a paper filter in the compressor Details unavailable.
Apr 1973	Not specified	Tritium release of 500 to 2000 Ci to atmosphere and waste streams during the processing of metal scrap
Sept 17, 1973	Not specified	Elevated levels of tritium were found in Walnut Creek and Great Western
Apr 2, 1974	Bldg 707	Control Valve Release due to filter system design error. Details unavailable.
Aug 30, 1974	Bldg 777, Rm 452	Tritium release,1.5 Ci
Nov 30, 1975	Not specified	Trailer blown over by high winds. Details unavailable.
May 19, 1976	Not specified	Contamination of R&D equipment and instruments. Details unavailable.
Aug 18, 1976	Not specified	Overheating caused coils in induction furnace to melt
Nov 18, 1976	Not specified	Source dropped in office area. Details unavailable.

Sources:

DOE, Rocky Flats Plant Site: Final Environmental Impact Statement, DOE/EIS-0064. April 1980.

AEC, Operational Accidents Within the USAEC 1943-1975, WASH-1192-REV, Fall 1975. Most of the summaries above were taken from this document, which was published in late 1975. We have not discovered a similar accident summary for later periods, and chose to incorporate this partial listing rather than not.

McLaughlin et al., 2000, A Review of Criticality Accidents, LA-13638, May 2000.

ATTACHMENT 2D
FIGURES

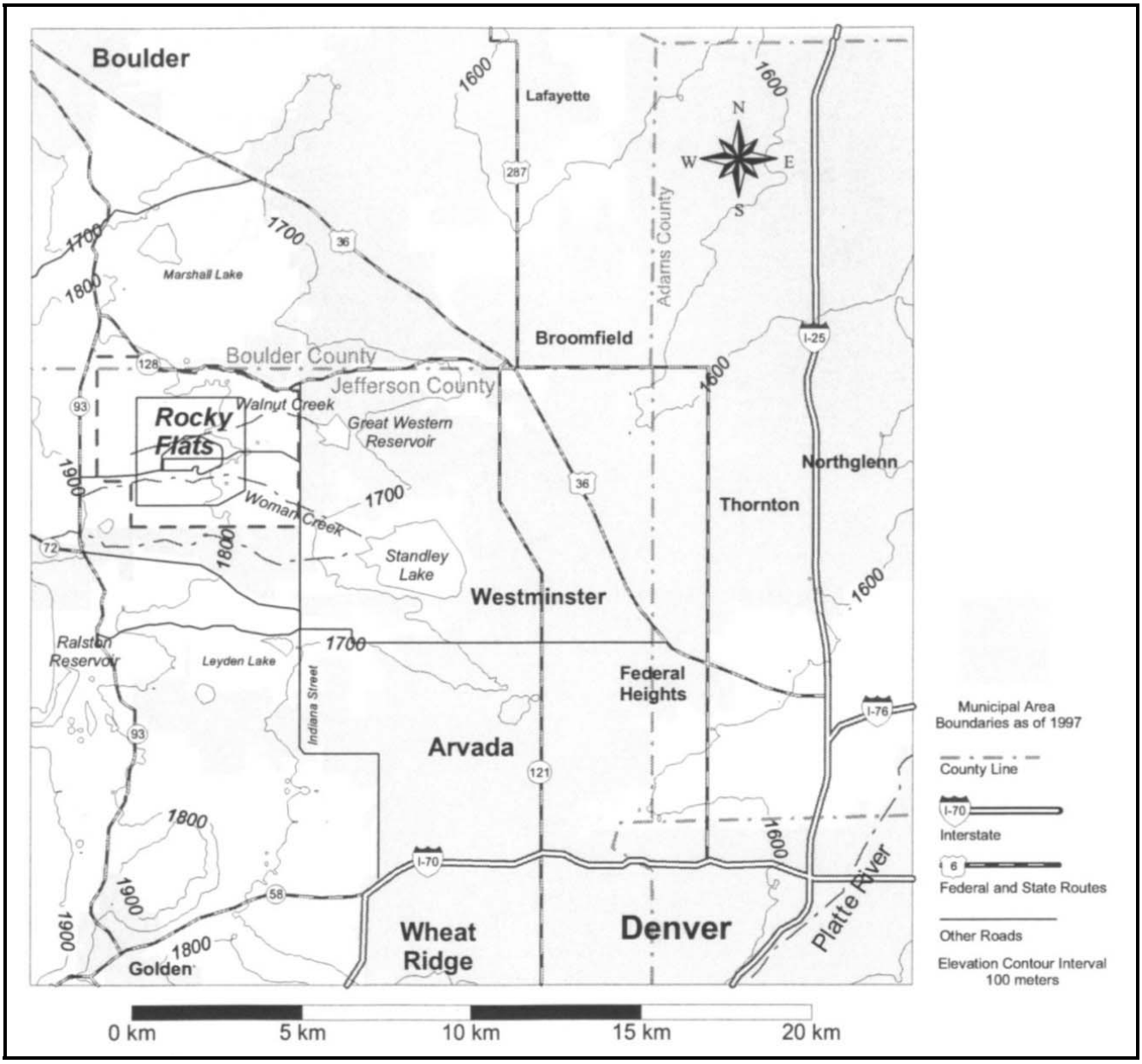

Figure 1. Location of the Rocky Flats Plant in Colorado.

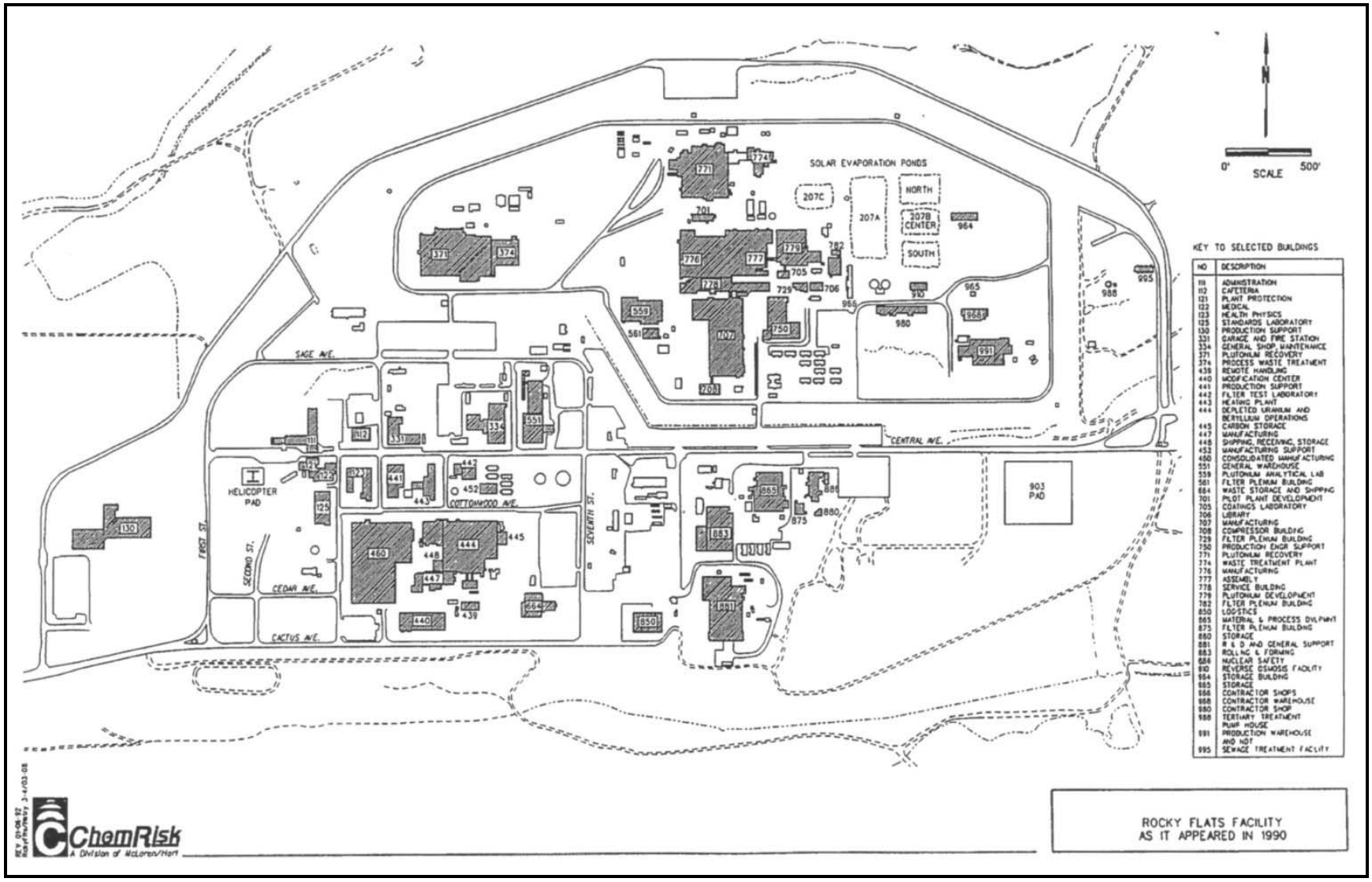

Figure 2. Rocky Flats facility as it appeared in 1990.

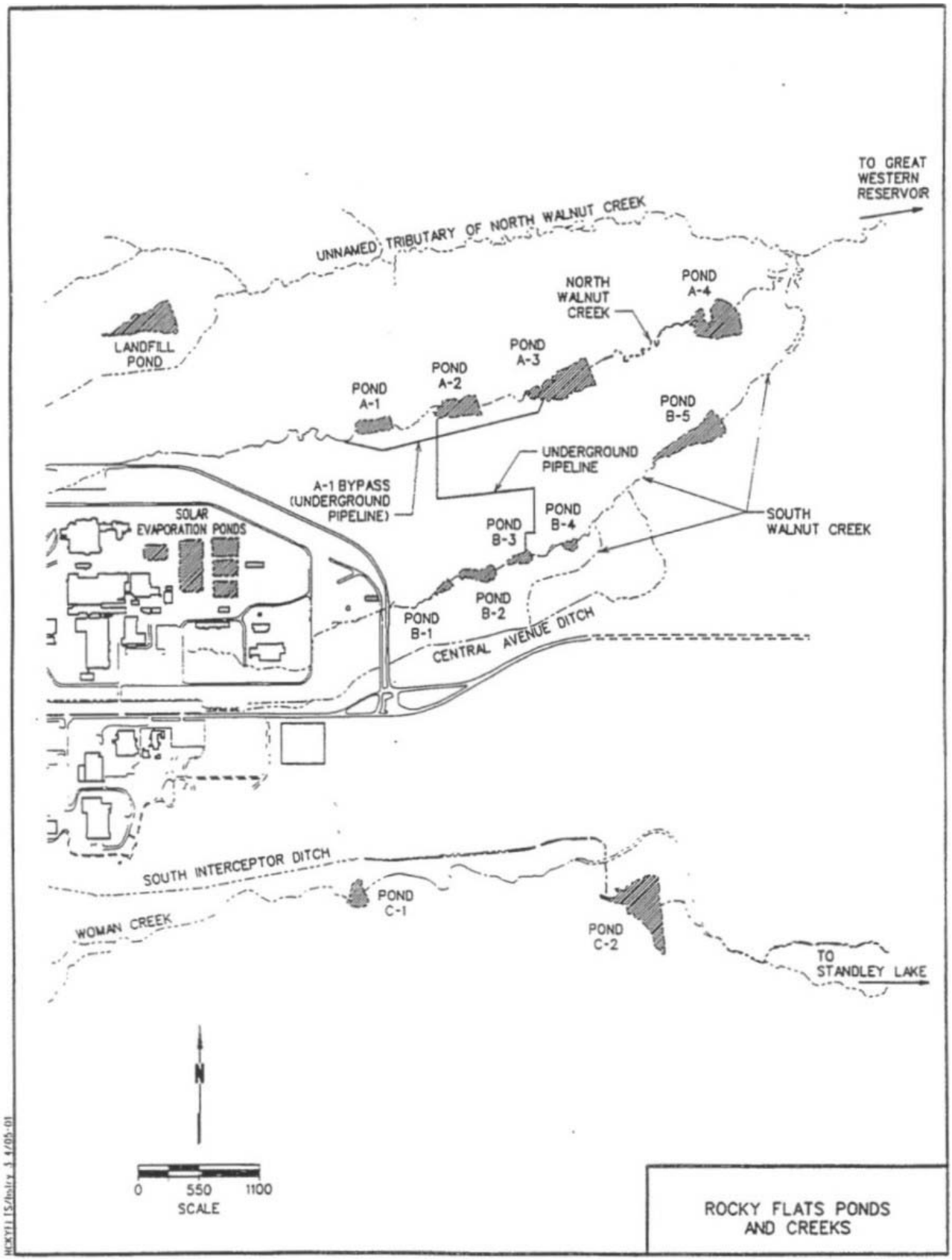

Figure 3. Rocky Flats ponds and creeks.

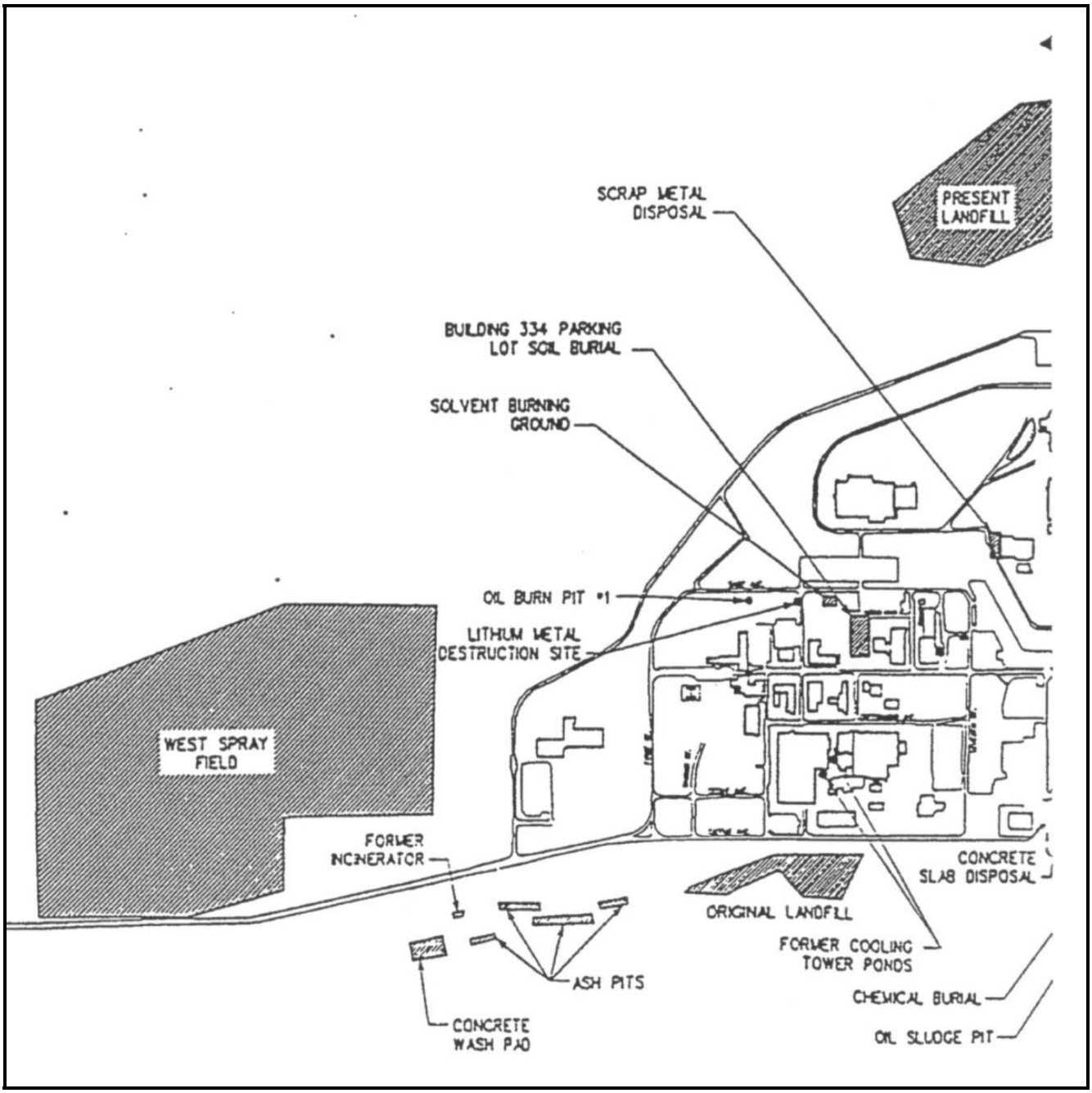

Figure 4A. Rocky Flats site waste disposal areas.

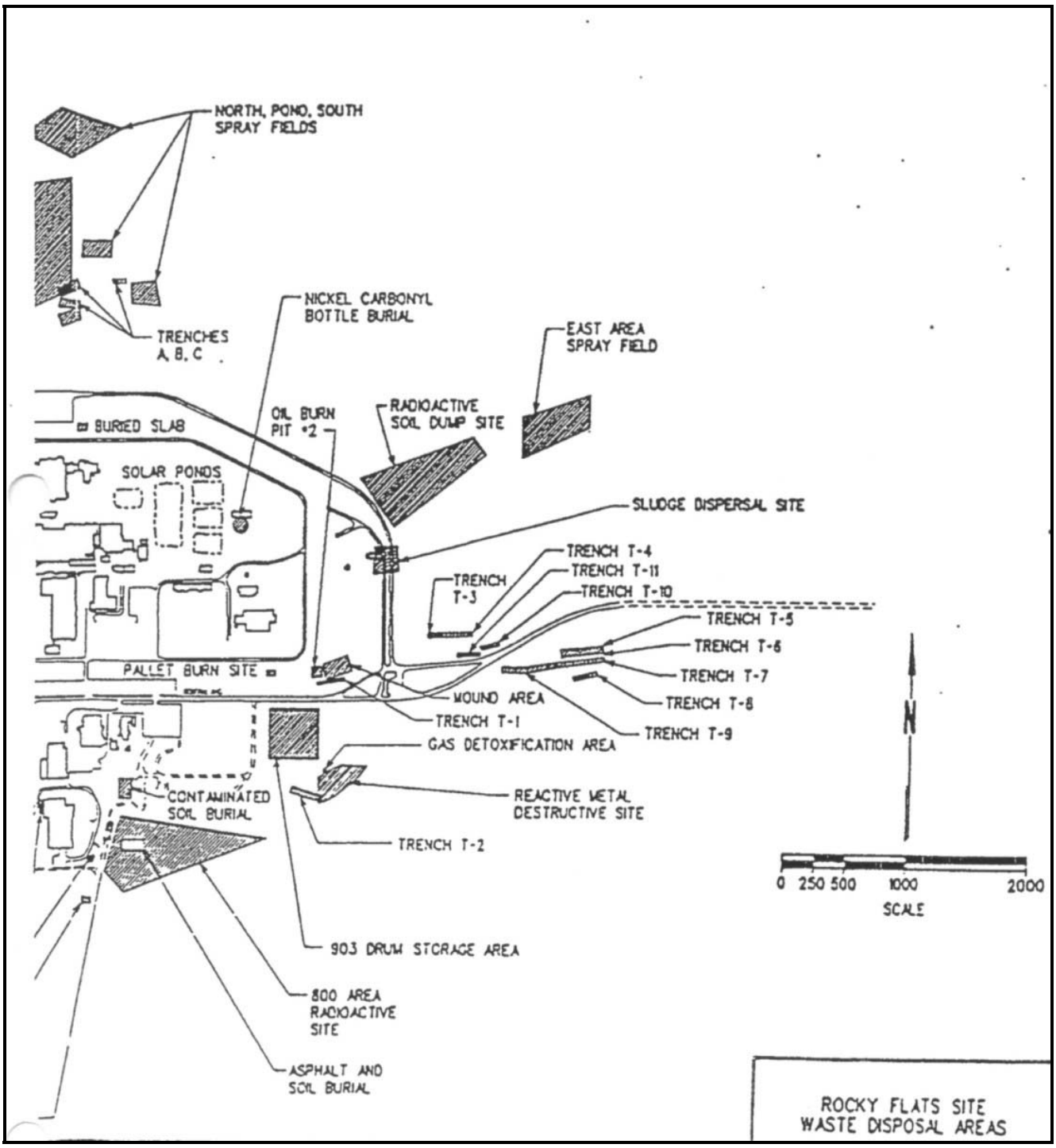

Figure 4B. Rocky Flats site waste disposal areas.

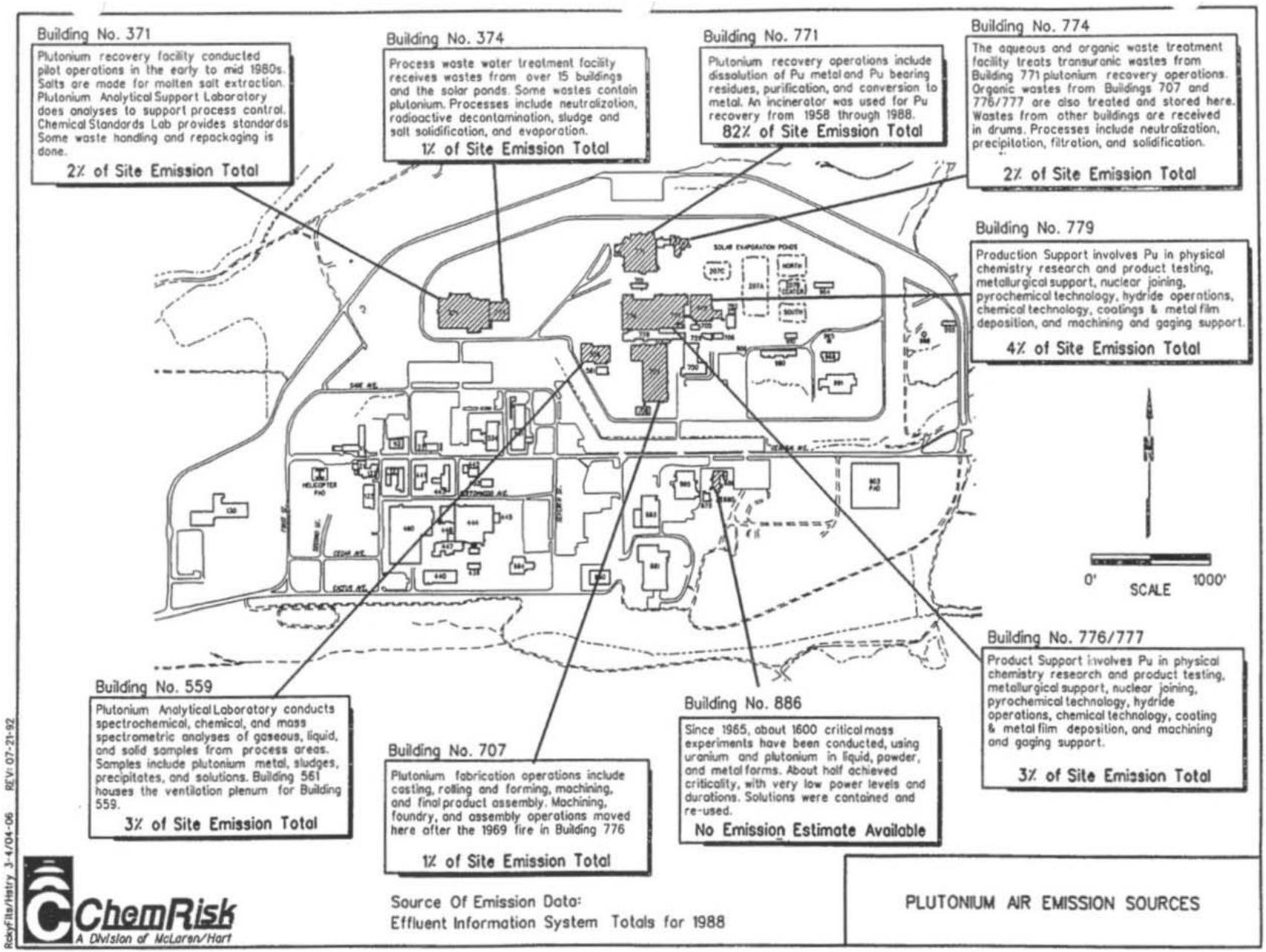

Figure 5. Plutonium air emission sources.

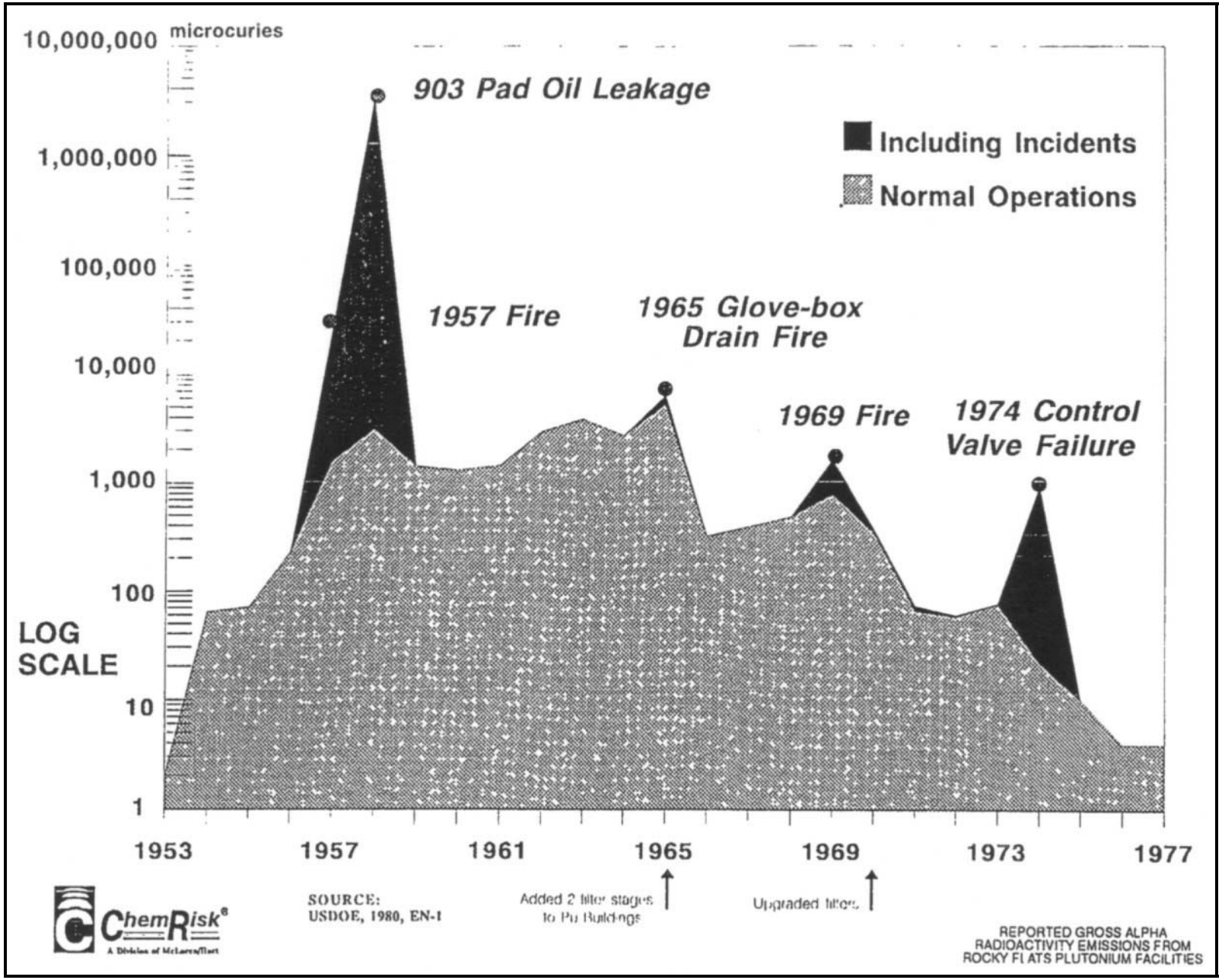

Figure 6. Reported gross alpha radioactivity emissions from Rocky Flats plutonium facilities.

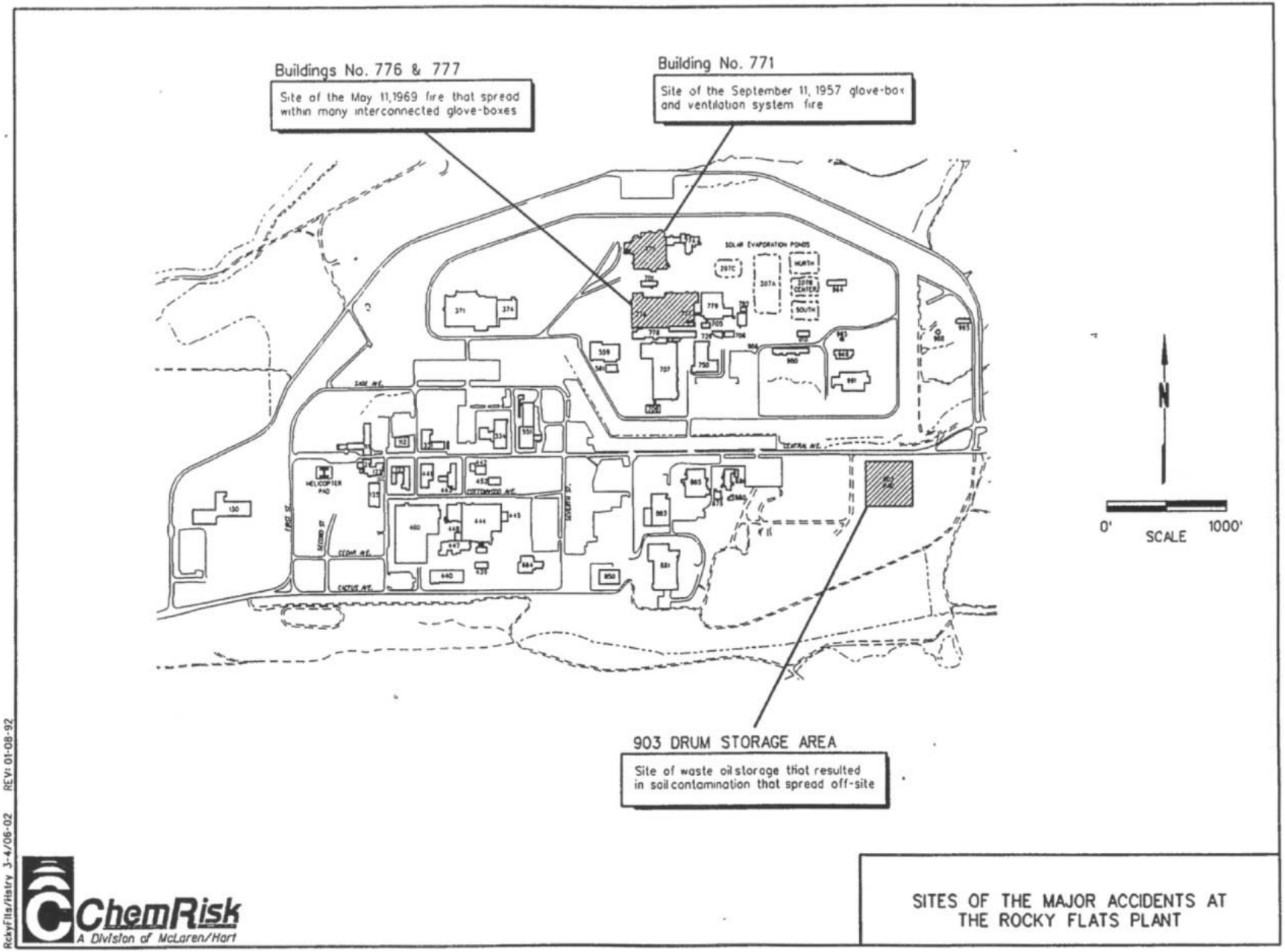

Figure 7. Sites of major accidents at the Rocky Flats Plant.

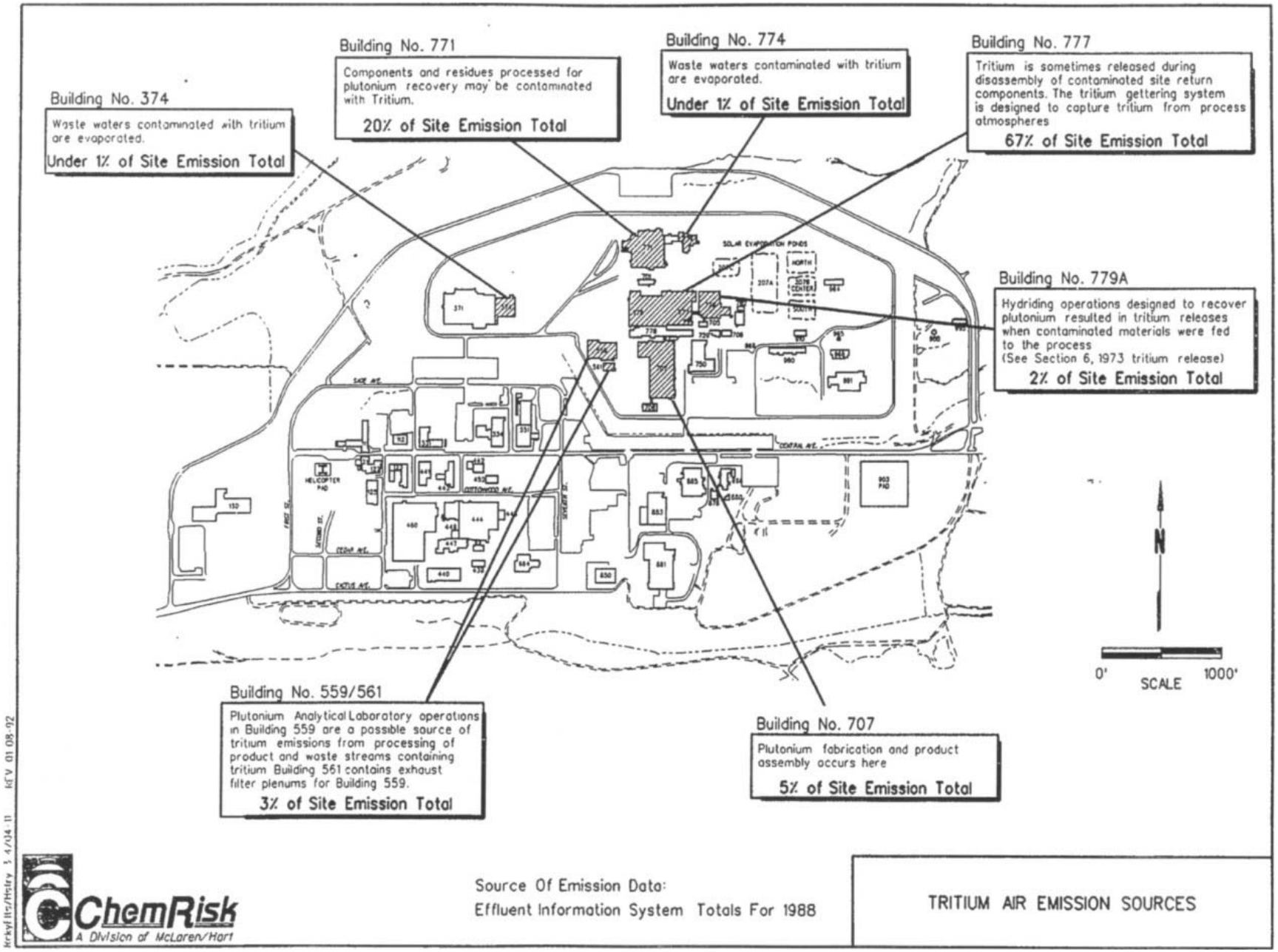

Figure 8. Tritium air emissions sources.

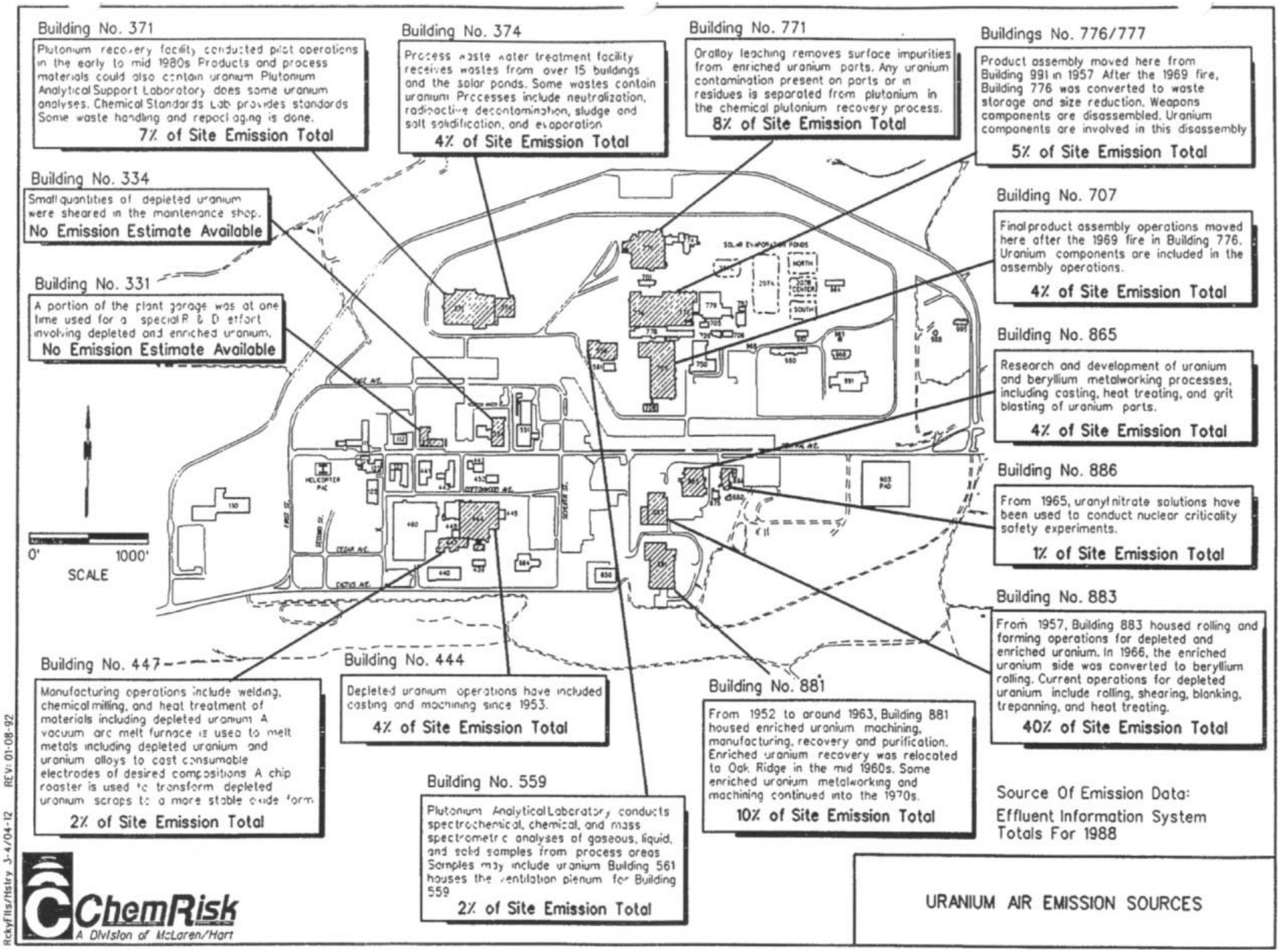

Figure 9. Uranium air emission sources.

ATTACHMENT 2E
PARTIAL LIST OF POTENTIAL HAZARDS ASSOCIATED WITH VARIOUS JOB DESCRIPTIONS AND LOCATIONS

Much of the data in the following table is taken from DOE Uranium Mass Balance Project report found at *http://tis.eh.doe.gov/legacy/reports/rockyflats/section1_2.pdf*. This table is not a comprehensive listing of potential radiological exposures associated with Rocky Flats, but is a summary of data readily available at this time.

Job title	Process description	Building	Type of work	Begin	End	Material	Primary radiation type	Maximum energy
Analytical laboratory technicians	Sample processing	559	Plutonium sample analysis			Pu	α	5.16 MeV
Analytical laboratory technicians	Sample processing	881	HEU or DU sample analysis	1953	1965	HEU	α	4.6 MeV
Assemblers	Pit Assembly	700	Handled "War Reserve" components					
Assemblers	Varied - similar to Metallurgical Operators depending on location	Varied	Handled metal parts					
Boiler vent operators (bvos)	Varied - depending on location	Varied	Monitor exhaust systems, waste tanks, and process waste lines					
Carpenters	Varied - depending on location	Varied	Refractory replacement in casting and heat treatment furnaces					
Chemical operators	Pu metal reprocessing	371	Handled contaminated reagents					
Chemical operators	Waste treatment	374	Handled contaminated reagents					
Chemical operators	Waste handling	447	Handled contaminated reagents	1956	1989	DU	α	4.2 MeV
Chemical operators	Component cleaning	447	Handled contaminated reagents	1956	1989	DU	α	4.2 MeV
Chemical operators	Waste handling	447	Processed waste materials	??	??	DU chips	α	4.2 MeV
Chemical operators	Electrolytic decon of legacy HEU contaminated with Pu	707	Handled contaminated reagents	1997	1999	HEU Pu	α	4.6 MeV 5.6 MeV
Chemical operators	Pu metal reprocessing	771	Handled contaminated reagents; Pu-contaminated $^{235}U_3O_8$ oxide	1965?	1989	Pu-^{235}U oxide	α	5.16 MeV 4.2 MeV
Chemical operators	Waste treatment	774	Handled contaminated reagents, liquid wastes from 881	1953	1989	HEU liquid wastes	α	4.6 MeV
Chemical operators	Molten salt processing	776	Handled contaminated reagents	1958	1969	Pu-239	α	5.16 MeV
Chemical operators	Process DU metal	865	Handled contaminated reagents	1953	1989	DU	α	4.2 MeV
Chemical operators	HEU metal reprocessing	881	Handled contaminated reagents	1953	1965	HEU	α	4.6 MeV
Chemical operators	Uranyl nitrate processing	886	Handled contaminated reagents					
Clerk packers	Varied - depending on location	Varied	Little hands-on work with radioactive materials.					
Configuration control authority personnel	Varied - depending on location	Varied	Routine access to process areas; little hands-on work					
Decontamination & decommissioning workers	Varied - depending on location	883	Deconned	1993	1995	HEU DU	α	4.6 MeV 4.2 MeV
Decontamination & decommissioning workers	Varied - depending on location	881 B side	Deconned	1965	1967	HEU	α	4.6 MeV

Attachment 2E (Continued)

Job title	Process description	Building	Type of work	Begin	End	Material	Primary radiation type	Maximum energy
Decontamination & decommissioning workers	Varied - depending on location	Varied	Drained systems, removed contaminated equipment. Often in high airborne contamination areas. Often wore PPE, including respirators with or without supplied air.					
Electricians	Varied - depending on location	Varied	Repair of instruments and controllers inside gloveboxes and other systems					
Experimental operators	Varied - depending on location	Varied	Operated prototype systems, often unshielded					
Handymen	Varied - depending on location	Varied	Little hands-on work with radioactive materials.					
Inspection technicians	Dimensional Inspection	881	HEU	1953	1965	HEU	α	4.6 MeV
Inspectors	Testing	444	Inspected completed parts	1953	1994	DU	α	4.2 MeV
Janitors	Varied - depending on location	Varied	Little hands-on work with radioactive materials.					
Machinists	Pit Assembly	700	Handled “War Reserve” components					
Machinists	Machining of Pu parts	776	Operated machining equipment	1958	1969	Pu-239	α	5.16 MeV
Machinists	Plutonium assembly	777	Drilling, turning, polishing		1969	Pu-239	α	5.16 MeV
Machinists	Process DU metal	865	Machined DU and DU alloys	1953	1989	DU	α	4.2 MeV
Machinists		881	Stainless steel boost reservoirs, etc.	1966	1967			
Machinists	Rod mill grinding	881	Machined HEU parts	1953	1965	HEU	α	4.6 MeV
Machinists	Rolling, forming, machining	881	HEU	1953	1965	HEU	α	4.6 MeV
Machinists	Presses, rolling mills	883 - B	Operated machining equipment	1957	1965	HEU	α	4.6 MeV
Machinists	Roll and press DU into sheets	883 - C	Rolling mills, shears	1983	1992	DU	α	4.2 MeV
Machinists	Rolling, forming, machining	883-A	Operated machining equipment	1957	1992	DU, DU alloys	α	4.2 MeV
Machinists	Varied - similar to Metallurgical Operators depending on location	Varied	Repair of mechanical systems					
Material analysts	Varied - similar to Metallurgical Operators depending on location	Varied	Collected metal samples					
Metallurgical operators	Casting and machining	444	Operated metal handling equipment	1956	1989	DU	α	4.2 MeV
Metallurgical operators	Casting and machining	444	Operated metal handling equipment	1980	1984	DU	α	4.2 MeV
Metallurgical operators	Casting and cleaning	444	Operated metal handling equipment	1967	1969	DU/Mo	α	4.2 MeV
Metallurgical operators	Trim and polish DU sheets	444	Operated metal handling equipment	1953	1989	DU	α	4.2 MeV
Metallurgical operators	Roll and press DU	447	Operated metal handling equipment	1956	1989	DU	α	4.2 MeV
Metallurgical operators	Roll and press Pu	707	Operated metal handling equipment			Pu-239	α	5.16 MeV
Metallurgical operators	Roll and press Pu	776	Operated metal handling equipment	1958	1969	Pu-239	α	5.16 MeV
Metallurgical operators	Plutonium assembly	777			1969	Pu-239	α	5.16 MeV
Metallurgical operators	Casting, rolling, forming, shearing, and cleaning	865	Operated metal handling equipment	1979	1988	DU, DU alloys	α	4.2 MeV
Metallurgical operators	Casting, extruding, machining	865	Operated metal handling equipment	1979	1988	DU, DU alloys	α	4.2 MeV
Metallurgical operators	Process DU metal	865	Machined DU and DU alloys	1953	1989	DU	α	4.2 MeV
Metallurgical operators	Uranium casting	881	Operated metal handling equipment	1953	1965	Uranium	α	4.6 MeV
Metallurgical operators	Melting and casting	881	HEU	1953	1965	HEU	α	4.6 MeV
Metallurgical operators	Annealing	883 - B	Operated metal handling equipment	1957	1965	HEU	α	4.6 MeV
Metallurgical operators	Roll and press DU into sheets	883 - C	Operated metal handling equipment	1983	1992	DU	α	4.2 MeV
Metallurgical operators	Roll and press DU	883 A side	Operated metal handling equipment			DU	α	4.2 MeV
Metallurgical operators	Roll and press HEU	883 B side	Operated metal handling equipment	1953	1964	HEU	α	4.6 MeV

Attachment 2E (Continued)

Job title	Process description	Building	Type of work	Begin	End	Material	Primary radiation type	Maximum energy
Metallurgical operators	Roll and press Be	883 B side	Operated metal handling equipment	1964	??	Be metal		
Metallurgical operators	Casting, rolling, forming, shearing, and cleaning	883-A	Operated metal handling equipment	1957	1992	DU, DU alloys	α	4.2 MeV
Metrology technicians	Varied - depending on location	Varied	Little hands-on work with radioactive materials.					
Non-destructive testing tech	Testing	444	Tested parts	1953	1994	DU	α	4.2 MeV
Non-destructive testing tech	Tensile testing, etc.	447	Tested parts	1956	1989	DU	α	4.2 MeV
Non-destructive testing technicians	Varied - depending on location	700	Sampled completed pits					
Non-destructive testing technicians	Casting, extruding, machining	865	Operated metal handling equipment	1979	1988	DU, DU alloys	α	4.2 MeV
Non-destructive testing technicians	Testing	881	HEU	1953	1965	HEU	α	4.6 MeV
Non-destructive testing technicians	Varied - depending on location	Varied	Sampled completed pits					
Painters	Varied - depending on location	Varied	Paint over contamination					
Pipefitters	Varied - depending on location	Varied	Repair leaks on process lines					
Radiation control technicians	Varied - depending on location	Varied	Monitoring in support of chemical and metallurgical processes; exposures similar to chemical and metallurgical operators					
Security guards	Varied - depending on location	Varied	Routine security patrols					
Shift managers	Varied - depending on location	Varied	Routine access to process areas; little hands-on work					
Stationary operating engineers (SOES)	Varied - depending on location	Varied	Monitor exhaust systems, waste tanks, and process waste lines					
Welders	Welding	444	Welded parts as necessary	1953	1994	DU	α	4.2 MeV
Welders	Electron-beam, tungsten-inert gas welding	447	Welded parts as necessary	1956	1989	DU	α	4.2 MeV
Welders	Plutonium assembly	777	Welding, brazing		1969	Pu-239	α	5.16 MeV
Welders	Varied - similar to Metallurgical Operators depending on location	Varied	Welded metal parts					