SAFETY ANALYSIS REPORT FOR THE ²³⁸PuO₂ FUEL FORM FACILITY

by

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SAFETY ANALYSIS REPORT FOR THE ²³⁸PuO₂ FUEL FORM FACILITY

1. INTRODUCTION

The Plutonium Fuel Form (PuFF) Facility has been constructed at the Savannah River Plant to manufacture 30 to 60 kg/yr of ²³⁸Pu fuel forms for space power applications. This facility is located in the existing Building 235-F near the geographical center of the Savannah River Plant (SRP) site. Pilot production is scheduled to begin in July 1977, with full-scale production in April 1978. The process line of the facility consists of nine separate, interconnected shielded cells; five shielded wing cabinets or glove boxes; three hoods; and contained auxiliary equipment. These process enclosures will be, for the most part, under an atmosphere of recirculating inert gas.

The products of the facility will be dense fuel forms manufactured from PuO₂ powder with a nominal isotopic composition of 80% ²³⁸Pu-20% ²³⁹Pu. This powder, made from calcined oxalate, has been produced safely at a rate of about 20 kg ²³⁸Pu/yr in the H-Area B-Line in Building 221-H for approximately ten years.

Initially, the fuel forms will consist of ~1-1/2-in. diameter spheres of ²³⁸PuO₂ encapsulated in iridium, designated pure plutonium-oxide (PPO). Manufacturing operations for PPO spheres are based on a powder ceramic process developed jointly by Los Alamos Scientific Laboratory (LASL) and Mound Laboratory of Monsanto Research Corporation (MRC).¹ Fabrication operations will include ¹⁶O enrichment, milling, cold pressing, and crushing into large particles (shards); sizing, sintering and hot pressing of the shards to produce ²³⁸PuO₂ fuel spheres; heat treatment of the pressed fuel spheres and encapsulation in iridium to produce the final PPO forms; and quality assurance analyses and final packaging before shipment.

This report describes design objectives, nature of operations, potential hazards and limiting factors, facility response to postulated accidents and failures, and environmental effects. The results of the analyses described in this report indicate that the facility has the capacity to prevent or sufficiently reduce accidents that represent potential risks to health and safety. The safety analysis in conjunction with process requirements provides the bases for Technical Standards for operation. The analysis also documents the degree of conformance of the facility design with the General Design Criteria - Plutonium Facilities² and the Environmental Statement.³

2. SUMMARY

Analyses of potential hazards and postulated accidents and evaluations of engineered safety features and administrative controls show that the PuFF Facility can be operated safely for all products and processes presently required.

The design and construction of the PuFF Facility complies, with very few exceptions, with the General Design Criteria — Plutonium Facilities² and the Environmental Statement.³ Deviations of the design from these criteria and guidelines are discussed in Appendices C and D. In most cases, these design deviations provide at least equivalent protection of the facility against possible failures or accidents which could lead to the release of activity.

This safety analysis concludes, as have previous analyses of other SRP and SRL ^{238}Pu facilities^{4,5} that the release of dispersible, fine $^{238}\text{PuO}_2$ powder and its assimilation by operating or onsite personnel is the most significant potential hazard. Such releases are, however, shown to result in doses within established dose guidelines,^{2,6} except in the case of an airplane crash (very low probability). Safety features provided in the design and precautions taken in operation make the occurrence of serious contaminating accidents or the release of significant radioactivity beyond the immediate area improbable. These safety features include:

- Remoteness of the facility from the plant boundary.
- A backup, nonflammable sand filter which provides the final filtration stage for all exhausts from the facility.
- Controlled access of personnel into the fenced area surrounding the PuFF Facility and the other 200-F Area buildings.
- Class I structural design of the building housing the PuFF Facility (i.e., resistance to external blast pressures up to 1000 lb/ft²).
- Compartmentalization of rooms within the facility and the use of air locks to form barriers against the spread of potential contamination.
- A ventilation system which maintains air flow from clean to progressively more regulated compartments.

- Leak-tight, stainless steel process enclosures under negative pressure with respect to surrounding rooms.
- Use of recirculated inert gas ventilation in containment enclosures where dispersible PuO_2 forms are processed.
- Multi-staged HEPA filtration of all process exhausts.
- Cooling water systems either singly or doubly isolated by heat exchangers from the cooling tower primary water supply.
- High-velocity continuous air monitors which actuate evacuation alarms when airborne radioactivity exceeds conservatively set levels.
- Routine monitoring of equipment and operating personnel by operations and Health Physics for the presence of contamination and for radiation exposure.
- Fire detectors and alarms which initiate *Halon 1301* extinguishing systems in all air enclosures and in the rooms of the facility.
- The extensive administrative control system, outlined in Reference 7, featuring independent controls by four internal organizations and operating requirements and guidelines in the form of Technical Standards and Operating Procedures.
- Limitation of the total in-cell inventory of $^{238}\text{PuO}_2$ to a value significantly less than the critical mass, and of dispersible $^{238}\text{PuO}_2$ forms to minimum quantities commensurate with efficient production.

The risk to offsite personnel from PuFF operations is 9×10^{-6} rem/yr. This risk includes that for severe accidents such as a design-basis tornado or airplane crash that result in a direct release of PuO_2 particulates to the environment. This risk value is the product of the frequency of occurrence of the event and the consequence in terms of the 70-yr integrated dose to an individual at the nearest plant boundary. Frequencies of occurrence were estimated using the techniques of Fault Tree Analysis. Doses were calculated from conservative estimates of the quantity of dispersible powder released from primary containment by the event. Only in the event of an airplane crash would the dose (100 rem/event) exceed the guide value of 75 rem.* However, the very low expected frequency of this event makes the risk acceptably small.

* ERDAM 6301 states that 75 rem is the guideline value for dose to the public when the liver is the critical human organ;² the analyses presented in Appendix B show that the liver is the critical organ for the PuO_2 to be processed in PuFF.

Events of moderate (maximum) frequency, $>10^{-1}$ events/yr, include untoward occurrences in the sand filter or stack and routine cell entries required for product removal or equipment maintenance. Expected releases to the environment from these events are very small, $<10^{-3}$ $\mu\text{Ci}/\text{event}$; the resulting risk to offsite personnel is negligible, 10^{-8} rem/yr or less. The risk to operating personnel performing the cell entries is low (2×10^{-5} rem/yr).

Events of low frequency, 10^{-1} to $10^{-5}/\text{yr}$, include the design-basis earthquake and releases inside the Building 235-F from such occurrences as cell pressurization, glove rupture, or breaks in ventilation ducts. Of these events, the earthquake results in the largest release to the environment; 0.4 Ci with a corresponding risk to offsite personnel of 5×10^{-6} rem/yr. The risk to operating personnel from releases inside the building is also low, 1×10^{-2} rem/yr.

Events of very low frequency, $<10^{-5}/\text{yr}$, include events such as a design-basis tornado and an airplane crash, which result in large, unfiltered releases of $^{238}\text{PuO}_2$, and an explosion in the hot press, which is considered to be the maximum process accident. The largest release (1000 Ci) would be expected during a tornado, but because of the extensive dispersion would result in a dose to offsite personnel (20 rem/event) less than the guideline value of 75 rem for the liver (critical organ). The largest offsite dose is 100 rem expected from an airplane crash. The differences in calculated doses result from the different dispersion heights and conditions for the respective accidents.

An explosion in the hot press results in the maximum expected release inside the building, ~ 300 Ci. Although the potential consequence to operating personnel in the immediate area is high, ~ 850 rem, the risk is very low, 1×10^{-9} rem/yr. The release to the environment from this event is low, 0.15 Ci, because the activity would first pass through the sand filter. The corresponding off-site risk is 2×10^{-12} rem/yr.

The only significant, although minor, impact of normal operations on the environment are: 1) the routine release to the atmosphere of concentrations of activity significantly below the 5 mCi/yr cited in the Environmental Statement,³ and 2) the small volumes ($<10^3$ Ci/yr) of contaminated wastes that are routinely removed for safe disposal.

3. DISCUSSION

3.1 DESCRIPTION OF FACILITIES AND OPERATIONS

3.1.1 General Site^{3,8}

The Savannah River Plant occupies an area of about 300 square miles in South Carolina. The entire site is federally controlled for the purpose of health, safety, and national security. The site is adjacent to the Savannah River, about 22 miles southeast and downstream of Augusta, Georgia. While operated primarily for national defense needs, it has also become a main source of special radioisotopes, such as ^{238}Pu and ^{252}Cf , which are used for industrial, space, research, and medical applications.

Present ^{238}Pu processing activities are carried out in Building 221-H located in H-Area. The new PuFF Facility is located in an existing building (Building 235-F) in F-Area approximately 5-1/2 miles from the nearest plant boundary (Figure 1). F- and H-Areas are the two separations areas at SRP where reactor fuel and target elements are chemically processed to recover radioisotopes and where related operations, such as the packaging of $^{238}\text{PuO}_2$, are performed.

For security and material safeguards, both F- and H-Areas are operated as separate exclusion areas contained within a primary exclusion area defined by the plant perimeter. Both areas are completely surrounded by chain link fences, with access through guard-operated gates. Only authorized personnel with appropriate clearance are allowed to enter.

The large exclusion area of the plantsite and the surrounding low population zone minimize the chance of an accidental release of activity affecting large segments of the population. Significant dispersion of accidental releases would occur before activity could reach the nearest large population centers, which are Aiken, South Carolina (population ~28,000; distance 20 mi.) and Augusta, Georgia (population ~180,000; distance, 25 mi.).

3.1.2 Building 235-F

Building 235-F (Figure 2), which houses the PuFF Facility, is located near the geographical center of the Savannah River Plant (Figure 1). This two-story building was constructed as a Class I structure to resist exterior pressures of 1000 lb/ft²

FIGURE 1. Savannah River Plant

1. Radiography (Existing)	10. Elevator
2. Darkroom (Existing)	11. PuO ₂ Experimental Facility (PEF)
3. Fuel Form Vault	12. Conference
4. Supervisors Offices (Existing)	13. Alloy Line
5. Np Facilities (Existing)	14. Change Rooms
6. Future Process Room	15. Fire Protection Equipment
7. Regulated Storage Room (PuFF)	16. Health Physics
8. Maintenance Areas (PuFF)	17. Compressor Room
9. Operating Area (PuFF)	18. Change Room
	19. PEF Supervisor's Office

FIGURE 2. Building 235-F

that might be incurred during an explosion. The building is constructed of reinforced concrete with walls 14 in. thick, no windows, an 8-in.-thick concrete roof, a 6-in.-thick concrete first floor ceiling, and a building layout designed to provide indirect access to all processing areas.

In addition to PuFF, Building 235-F also contains the Plutonium Experimental Facility (PEF) in which processes to be used in PuFF are tested, and two glove lines in separate areas in which $^{237}\text{NpO}_2\text{-Al}$ mixed powder and $^{239}\text{Pu-Al}$ alloy billets are fabricated for extrusion as reactor targets. The building includes auxiliary service areas, maintenance shops, and radiation survey facilities. Lunchrooms and offices are separate from the process areas. Exhausts from PEF and target fabrication process are combined with exhaust from PuFF processes and passed through HEPA filters and the sand filter to the existing 61-m stack. The room air from offices and nonprocess areas is exhausted on the building roof without any HEPA or equivalent filtration.

3.1.3 Plutonium Fuel Form Facility

The PuFF Facility provides capability for processing up to 60 kg of ^{238}Pu /yr. Processing involves converting ^{238}Pu oxide powder into fuel forms for heat sources by powder ceramic and metallurgical processes. The final products will be compacted $^{238}\text{PuO}_2$ fuel shapes.

The $^{238}\text{PuO}_2$ will be fabricated and encapsulated in six manipulator cells filled with inert gas,* three air-filled manipulator cells, five wing cabinets (glove boxes) filled with inert gas,** and three hoods (Figure 3). The process enclosures are located on the first floor of the PuFF Facility. As shown in Figure 3, the manipulator cells are divided into two parallel and facing lines (east line and west line) with an operating area between and separate maintenance areas behind the lines. The manipulator cells, which are separately vented, are interconnected by transfer locks to protect the purity of cell gas during inter-cell transfer. An enclosed conveyor in the transfer tunnel beneath the floor connects the two cell lines.

The second floor area immediately above the PuFF operating and maintenance areas is occupied by auxiliary equipment (Figure 4) which includes ventilation system components, such as HEPA filters,

* For the purposes of this Safety Analysis Report, Cell 9 will be considered as an air-atmosphere cell. The cell will have a recirculating helium atmosphere only during welding campaigns (~3 days/month) when finished plutonia spheres are encapsulated in aluminum shipping cans; the remainder of the time (90%) the atmosphere will be air.

** Two cabinets (3 and 5) will be blanked-off initially with potential future use for storage and maintenance during PPO operations or Plutonium-Molybdenum Cermet (PMC) production.

FIGURE 3. First Floor of PuFF Facility in Building 235-F

FIGURE 4. Second Floor of PuFF Facility in Building 235-F

blowers, and ducts; gas recirculator-purifiers for the inert gas cells; a metallographic laboratory; electrical controls; equipment associated with the process and chilled water cooling loops; vacuum systems and hydraulic systems; and a motor generator for the hot press.

Both floors of the facility are compartmentalized and isolated by surrounding corridors and air locks to minimize the possible spread of contamination (Figures 3 and 4). Room pressures within the facility are regulated to assure air flow from clean to progressively more regulated areas. The encompassing walls of the facility have a 2-hr fire rating. Combustibles used in construction are limited primarily to vinyl flooring, wall paint, seals, plastic bags, neoprene gloves, manipulator boots, acrylic plastic and *Lexan* (registered trade name of General Electric) windows in cabinets, and electrical insulation. The rooms comprising the facility are provided with fire detectors and automatic *Halon 1301* fire suppression systems.

3.1.4 Sand Filter

All room and HEPA-filtered process exhausts from the PuFF Facility will receive a final stage of filtration in a below-ground, nonflammable sand filter before venting through a 61-m-high stack. This sand filter is a key element in minimizing radioactive releases in the event of severe accidents in the PuFF facility.

The new sand filter was constructed to accommodate exhausts from all Building 235-F operations and separation operations in the canyon building (221-F). This filter is located between the two buildings about 300 feet from Building 235-F. It consists of a 7-1/2-ft-thick bed of layered grades of gravel and sand 100 ft wide by 360 ft long. Incoming building exhausts, drawn by fans at the foot of the stack, are distributed at the bottom of the filter bed and exit the top through a collection plenum to the stack. The filter has the capacity to filter 205,000 cfm of air with a 7 to 12-in. (water) pressure drop. The exhaust from the PuFF Facility represents 30,000 cfm of the total.

Similar sand filters have been operating successfully in both H- and F-Areas for many years. Analyses have shown the sand filter and concrete exhaust tunnel connecting Building 235-F are capable of withstanding a design basis tornado and earthquake.^{9,10} The filter will also continue to function effectively even if subjected to heavy smoke loading from a fire in either Building 235-F or Building 221-F.¹¹

3.1.5 Process Enclosures

The general layout of the process cell lines is given in Figure 3. Figure 5 shows a cross section of a typical manipulator cell.

FIGURE 5. Cross Section of Typical Processing Cell in the PuFF Facility

The manipulator cells and attached glove cabinets are leak-tight enclosures with a design leak rate of less than 0.02 vol %/hr at a differential pressure of 2-in. water. In-place leakage tests were made on individual cells following installation to confirm the leak tightness of the cells. The wing cabinets and the interior walls of the cells are constructed of Type 304L stainless steel. All process enclosures contain coved corners, flush-mounted accessories, and concealed services to minimize the buildup of contamination and facilitate decontamination. Consideration in design of the cells and cabinets was given to the decontamination and equipment disassembly required for future decommissioning. The cells are of modular construction and are interconnected only through transfer locks. HEPA filters are located at the exhausts from each cell to minimize the spread of contamination to ducts. In addition, HEPA-filtered vacuum cleaning systems are installed in the cells with potential dusting problems to keep the background contamination as low as practical.

Shielding for the process enclosures was designed to give radiation levels of 0.5 mrem/hr or less in the operating area and 5.0 mrem/hr or less in the intermittently occupied maintenance areas for anticipated inventories of PuO_2 (Section 3.1.6.2). Cell shielding for the operating area is provided by 21-in.-thick limonite concrete walls and water-filled, lead glass shield windows. Deionized water is recirculated through the front shield windows by pumps located on the first floor. The maintenance areas are shielded from activity within the cells by 14-1/2-in.-thick limonite concrete walls with composite glove port windows of 1-in.-thick lead glass and 4-in.-thick water equivalent. Glove ports are mounted in the rear of the cells to provide access for in-cell equipment repairs. When not in use, the glove ports and glove port windows are enclosed behind water-filled, lead-lined carbon steel doors to provide additional shielding (Figure 5). Wing cabinet shielding is provided by 4-in.-thick water equivalent and 1/2-in.-thick lead.

The space or annulus between the process cells and their shielding is purged with air that is exhausted through the sand filter. The access trench under the cell lines is connected to this annulus. The air pressure maintained in the annulus is less than that in the operating and maintenance rooms but greater than the pressure inside the cells. These pressure differentials assist in controlling the spread of contamination accidentally released from the cells.

All cells are equipped with storage spaces made of schedule 80 pipe that are recessed into the floor of the cell. These spaces are shielded by a water-cooled jacket mounted below and external to the cell. The furnaces located in Cells 1 and 5 are also recessed into the cell floor and are water-cooled in a similar manner. In

both cases, cooling water is supplied from outside the cell by a closed-loop, process cooling-water system (Section 3.1.7.3) that provides contamination control and minimizes in-cell flooding. This system is equipped with temperature indicators and low-flow alarms.

Services to the process enclosures include vacuum systems to operate wands and vacuum cleaners and to evacuate transfer locks. Inert gas is supplied to purge the recirculating inert gas loops, to operate motors, to cool furnaces and for use as a welding gas. Cells 1, 2, 3, 5, 6, and 9 are also equipped with electric hoists to assist in moving and positioning equipment and process containers. Electrical services enter cells and wing cabinets through sealed, leak-proof connectors. The enclosures with air atmospheres, including three process cells and the metallographic glove box line on the second floor, are equipped with automatic fire detectors and *Halon 1301* fire suppression systems. These systems are not installed in cells or wing cabinets with inert gas atmospheres.

3.1.6 Processes in the PuFF Facility

3.1.6.1 Scope

The PuFF Facility is designed to produce dense $^{238}\text{PuO}_2$ fuel forms at rates from 30 kg/yr (10 shifts per week) to 60 kg/yr (21 shifts per week). The five cells and connected wing cabinets of the east line (Figure 3) contain all the processing operations up to and including gaging of the final fuel forms. The west line consists of four cells and is used for welding iridium hemispheres around the PPO fuel form and for decontamination and final packaging of the encapsulated PPO fuel spheres. The iridium-clad spheres are radiographed through shipping containers in another room within Building 235-F (Figure 2). Up to about 30 kg of $^{238}\text{PuO}_2$ in various forms will be stored in the vault of Building 235-F.

Metallographic examinations and analyses required for quality control will be performed on the second floor of the PuFF Facility (Figure 4). The metallographic facility consists of interconnected glove boxes with air atmosphere in which grinding, polishing, chemical etching, and inspection of sample intermediates from PuFF Facility will be conducted. Chemical analyses will be performed in laboratory facilities located in Building 772-F, the control laboratory for the separations areas. Calorimetry of the finished fuel will be carried out in Building 221-H, B-Line. Defective manipulators will be bagged out and repaired in existing facilities in the 3/700 Areas.

On occasion, intact or failed isotopic generators (RTG's) may be processed in the PuFF Facility to recover the ^{238}Pu and precious

metals. These generators will be shipped in casks and, if not contaminated, the heat source assemblies (HSA's) will be unpacked in the PuFF Facility maintenance area and transferred into Cell 2 for disassembly. Contaminated generators will be disassembled in other SRP facilities, and the heat source will be transferred to Cell 2 of the PuFF Facility.

3.1.6.2 $^{238}\text{PuO}_2$ Inventory

A typical operating inventory of 6 kg of $^{238}\text{PuO}_2$ powder ($\sim 4\frac{1}{4}$ kg ^{238}Pu) will be distributed within the PuFF Facility cell line. This is equivalent to about 71,000 Ci of ^{238}Pu plus 65 Ci of ^{239}Pu . During the manufacture of PPO spheres, about one-half of the 6 kg of PuO_2 product is expected to be contained in sealed containers located in the in-cell storage spaces. This inventory may be exceeded when an HSA is disassembled in Cell 2; however, the ~ 6 kg of PuO_2 involved will be in nondispersible, dense fuel forms.

The maximum allowable inventory of PuO_2 product within the cell line will be 11.9 kg, based upon criticality considerations (Section 3.2.4). Except for special operations and for short time periods (e.g., disassembly of an HSA), the in-cell PuO_2 inventory will be maintained in configurations that will limit exposure in the operating area to 0.5 mrem/hr or less.

The anticipated operating inventories for producing PPO spheres are categorized in Table 1 according to the form of $^{238}\text{PuO}_2$. The form of the $^{238}\text{PuO}_2$ determines its potential hazard, and thus influences the safety assessment. As discussed in Section 3.2.2, fine feed and ball-milled powders are more dispersible and respirable than shards or dense fuel forms. Therefore, the quantity of powder outside of sealed containers will be restricted by administrative controls to the minimum quantity commensurate with efficient production, 510 g of feed powder or 85 g of ball-milled powder (one batch).

3.1.6.3 *Operations Within Individual Cells, Wing Cabinets, and Hoods*

The principal operations performed in the process enclosures and the services provided to the enclosures are described below and summarized in Figures 6-8. A flowsheet giving the order and location of the process operations for PPO is shown in Figure 9. Details of specific operations are contained in References 1 and 12. Potential health hazards associated with the operations and cells are discussed in Section 3.2.

TABLE 1

Anticipated $^{238}\text{PuO}_2$ Inventory for PPO Fuel, g^a

<i>Form</i>	<i>Outside of Storage Container^b</i>	<i>In Process Containers or Storage Containers^b</i>
Milled powder (1-3 μ avg dia.)	85 ^c	500
Feed powder ($\sim$ 5 μ avg dia.)	510 ^c	500
Unsintered shards (<125 μ dia.)	250	500
Sintered shards (<125 μ dia.)	500	1250
Dense forms	1250 ^d	3750 ^d
Waste (various forms)	<400	<400
Total $^{238}\text{PuO}_2$	<2800 ^d	6000 ^d
Total $^{238}\text{PuO}_2$ powder	510	<900

-
- a.* Does not include additional powder and dense forms stored in containers outside the PuFF Facility line.
- b.* All weights are given as the mixed oxide, nominally 80% $^{238}\text{PuO}_2$ and 20% $^{239}\text{PuO}_2$.
- c.* Assumed to be nonsimultaneous.
- d.* Except during recovery of material from a returned RTG, during which normal processing operations will be suspended.

FIGURE 6. PuFF Facility - Cells 1 and 2

FIGURE 7. PuFF Facility - Cells 3, 4, and 5

FIGURE 8. PuFF Facility - Cells 6-9

FIGURE 9. Flowsheet of PPO Processing Indicating Sequence and Location of Process Steps

3.1.6.3.1 Hood 1 - Receiving (Air Atmosphere)

Feed powder from H-Area, B-Line is shipped to the PuFF Facility in triple-containment shipping casks (Certificate of Compliance USA-5320-BLF-ERDA-SR), which comply with packaging standards given in ERDAM 0529.¹³ The feed powder enters the east process line through Hood 1 in the maintenance area.

The secondary and nested primary containers are removed from the cask, brought into Hood 1, and transferred through a door into an adjacent glove cabinet. A protective cap is removed from the secondary container, and the nested containers are fitted to a breechlock transfer device in preparation for introducing the feed into the line. The secondary container plug is removed in the breechlock, and the primary container is withdrawn into the wing cabinet (Cabinet 1) and then transported to Cell 1.

After the feed powder is removed in Cell 1, the primary container, either empty or containing scrap, is returned to Cabinet 1 and placed into the secondary container in the breechlock. The secondary container is removed from the breechlock, decontaminated as required, transferred to Hood 1 and then replaced in the shipping cask for return to B-Line. Hood 1 also serves as the entry-exit point for intermediate products (e.g., shards) stored out of the line.

Services are electric power and sufficient exhaust to provide 200 linear ft/min air flow across the opening into the hood.

3.1.6.3.2 Cabinet 1 - Cold Press (Argon Atmosphere)

Calcined powder and intermediate products are transferred between Cabinet 1 and Cell 1 using the cold-press transfer device. Milled powder from Cell 1 is cold pressed automatically and remotely into pellets of about 75 g in a 75-ton press. The press hydraulic cylinders (3000 psi) are outside the box and transmit motion via pistons sealed with O-rings and metal-bellows. An interlock prevents the use of the cold press during glove-assisted maintenance operations in the cabinet. Services include electrical and hydraulic power to the cold press, and argon supply from the recirculating argon system.

3.1.6.3.3 Cell 1 - Powder and Shard Preparation (Argon Atmosphere)

Operations include opening and emptying the primary shipping container, crucible loading, $^{16}\text{O}_2$ isotope exchange at about 700°C , outgassing at about 1000°C , weighing, milling, cold-press die loading, crushing, sizing, sintering at temperatures up to 1650°C , and storage. Transfer of materials between Cells 1 and 2 is made through a transfer lock.

Equipment includes the exchange and outgassing furnace, sintering furnace, balance, ball mill, jaw and gyratory crushers, Denver-Davis pulverizer, and powder sifter. Services are electrical power, oxygen and argon furnace gases, a vacuum system for handling mechanisms and vacuum cleaning, and a recirculating argon atmosphere system.

3.1.6.3.4 Cabinet 2 - Equipment Maintenance (Argon Atmosphere)

Defective equipment, primarily from Cell 1, is transferred by overhead hoists into Cabinet 2 where it is repaired using gloves rather than manipulators. Replacement or repaired parts are passed through the evacuation lock into Hood 2 (air atmosphere). If required, retired or defective heat source assemblies will be brought into the cell line through Hood 2 and the evacuation lock. The HSA's will be transferred by hoist into Cell 1 and then passed through the transfer lock into Cell 2.

3.1.6.3.5 Cell 2 - Disassembly (Argon Atmosphere)

The thermally hot HSA's containing up to 6 kg of $^{238}\text{PuO}_2$ are disassembled to recover $^{238}\text{PuO}_2$ and noble metals. A special cooled storage well is provided in the cell floor to accommodate the HSA before recovery; recovered spheres are stored in regular storage spaces before recycle.

Equipment includes special can and capsule cutters and overhead hoist. Services are electrical power, a recirculating argon atmosphere system, and vacuum systems for handling devices and evacuating transfer locks.

3.1.6.3.6 Cabinet 3 - Maintenance (PPO) or Molybdenum Coating (PMC) (Argon Atmosphere)

Cabinet 3 is attached through a transfer lock to Cell 3 but initially will be blanked off. Possible future uses include storage or maintenance, as required for PPO production, or in the production of Plutonia-Molybdenum Cermet (PMC) heat sources. If PMC production is required, this cabinet will house a molybdenum coater for coating $^{238}\text{PuO}_2$ shards. A safety assessment of PMC operations, in which Mo-coating represents the only process step of a hazardous nature not also associated with PPO, will be made in an addendum to this Safety Analysis when required.

3.1.6.3.7 Cell 3 - Weighing (PPO) and Blending (PMC) (Argon Atmosphere)

Shards are received from Cell 1, weighed, and stored or passed to Cell 4. If PMC production is required, a blender will be installed. Services are electrical power, a recirculating argon atmosphere system, and vacuum systems for handling devices and vacuum cleaners.

3.1.6.3.8 Cell 4 - Die Loading and Unloading (Argon Atmosphere)

Weighed batches of shards received from Cell 3 are loaded into graphite dies and transferred through Cabinet 4 by conveyor to the hot press. After hot pressing, dies are cut apart with a saw and torque tool; any fine chips are collected by vacuum. The PPO spheres are weighed and stored or passed to Cell 5.

Services include electrical power, a recirculating argon atmosphere system, and vacuum systems for handling devices, vacuum cleaning, and evacuating transfer locks.

3.1.6.3.9 Cabinet 4 - Transfer (Argon Atmosphere)

Loaded graphite dies are received from Cell 4 and transported by a remotely operated transfer mechanism to the hot press. After hot pressing, loaded dies are returned to Cell 4. Scrap die pieces are bagged out; new dies are bagged in and stored. Repair of in-cell equipment will be performed as required.

The services are electrical power, an argon atmosphere supply, and pressurized argon to power the transfer mechanism.

3.1.6.3.10 Hot Press (Vacuum)

Dies loaded with $^{238}\text{PuO}_2$ shards are received and remotely positioned in a shielded vacuum hot-press for pressing at temperatures up to 1530°C and forces of about 5,300 lb (3000 psi). The entire pressing process including heatup, holding, and cool down is automatically controlled. The furnace wall is the containment for this operation and has a 4-in. water-filled annulus. The stainless steel containment chamber contains two glove ports with vacuum-tight covers and two viewing ports. The hydraulic cylinders for the press are outside the furnace and transmit motion via rams sealed to the chamber by metal bellows. The graphite dies are heated by a water cooled, copper, radio-frequency, induction coil inside the vacuum furnace enclosure. Interlocks prevent heater operation when gloved operations are performed during repair of furnace parts or when cooling water is not flowing.

Services include electrical power, instrument power, hydraulic power, vacuum, and cooling water. Argon from Cabinet 4 will be admitted into the furnace chamber to facilitate cooling when die temperature reaches $\sim 500^\circ\text{C}$. Alarms and automatic shutdown features are initiated by excess temperature, loss of vacuum, loss of cooling water flow, and other malfunctions (Section 3.3.4).

3.1.6.3.11 Cell 5 - Post-Hot-Pressing Heat Treatment and Gaging (Argon Atmosphere)

PPO spheres are decarburized at 1200°C and given post-hot-pressing heat treatments up to 1440°C in $^{16}\text{O}_2$ gas or 4% H_2 -Ar mixtures. The spheres are gaged and visually inspected before transfer to Cell 6.

Services include electrical power, vacuum systems for handling devices, and evacuating transfer locks, $^{16}\text{O}_2$, 4% H_2 -Ar and argon furnace gases, and a recirculating argon atmosphere system.

3.1.6.3.12 Cabinet 5 - Maintenance and Machining (PMC) (Argon Atmosphere)

Cabinet 5 is attached to Cell 5 through a seal plate for possible future use in the machining of PMC disks. Until PMC production is required, Cabinet 5 will be sealed off, or used for glove-assisted maintenance operations.

3.1.6.3.13 Transfer Tunnel (Air Atmosphere)

An underfloor tube in a tunnel purged by air as part of the annulus system connects the two cell lines between Cells 5 and 6. The tube, supplied with either argon or helium gas, contains a mechanical conveyor to transfer product containers.

3.1.6.3.14 Cell 6 - First Welding Cell (Helium Atmosphere)

PPO spheres are Tungsten-Inert-Gas (TIG)-welded into iridium hemishells. Welds are inspected through optical equipment.

Services include electrical power, a vacuum system for handling mechanisms and holding devices, helium for welding, positioning devices, and motor drive, and a recirculating helium atmosphere system. The welder function is interlocked with the gas coolant flow to the welder.

3.1.6.3.15 Cell 7 - Decontamination (Air Atmosphere)

Iridium-encapsulated PPO spheres are ultrasonically decontaminated in nitric acid or surfactant solution. Scrubbing with abrasives may also be required. An alpha monitor in the ultrasonic bath effluent line indicates when decontamination is complete. Decontamination liquids are supplied from limited volume head tanks on the second floor. Waste liquids are transferred to the waste-handling station (Hood 3) by vacuum.

Services include electrical power; fire detection and *Halon 1301* suppression system; a once-through air system; and vacuum systems for handling devices and evacuating transfer locks, and acid, water, and waste-handling lines.

3.1.6.3.16 Cell 8 - Decontamination, Leak Check (Air Atmosphere)

The iridium-encapsulated PPO spheres are transferred from Cell 7 to Cell 8 through a contamination barrier tank (liquid seal) which is ultrasonically agitated. In Cell 8, the PPO spheres are rinsed and then probed and smeared for contamination. If necessary, they are scrubbed with abrasive for further decontamination. Iridium welds on PPO spheres are helium leak-checked in a chamber in the wall of Cell 8 by a vacuum mass spectrometer located on the second floor.

3.1.6.3.17 Cell 9 - Final Welding (Air or Helium Atmosphere)

Encapsulated PPO spheres are placed in graphite felt liners and inserted into stainless steel cans, which are TIG welded. Welds are inspected with an optical system. Packaged fuel is removed through the loadout lock and placed in storage casks in the west maintenance area. Cell atmosphere will be air, except during welding operations when helium will be recirculated through the cell.

Services include electrical power, vacuum for handling devices and evacuating transfer locks, helium weld gas, fire detection and *Halon 1301* suppression systems, and a recirculating helium atmosphere system.

3.1.6.4 Metallographic Facility

The metallographic facility is located on the second floor of Building 235-F (Figure 4). It consists of an interconnected series of glove boxes ventilated with once-through air. Single-stage HEPA filters are installed on the box inlets and outlets.

Gram quantities of potentially dispersible material will be handled in the metallographic facility. Portions of $^{238}\text{PuO}_2$ fuel spheres and shard intermediates will be manually transferred from the cell line below for metallographic preparation and examination. Operations include sample cutting, mounting, grinding, polishing, and etching with acids. Water used in the cutting, grinding, and polishing operations is filtered of suspended ^{238}Pu -bearing material and recirculated. Considerable bag-out operations are required to remove liquid and solid wastes and recovered $^{238}\text{PuO}_2$.

Services include electrical power, funnels for water and chemical addition, fire detection and *Halon 1301* suppression systems, and a once-through air system.

3.1.7 Process Services

3.1.7.1 Ventilation System

A schematic diagram of the several interconnected ventilation systems in relation to PuFF Facility barriers is shown in Figure 10.

Supply air to the rooms and inert gases for process ventilation and services are provided from outside the PuFF Facility. Two independent exhaust systems handle exhausts from the rooms

FIGURE 10. Ventilation Diagram for PuFF Facility

and process enclosures. Both systems discharge into the concrete-encased duct on top of Building 235-F which connects with the underground tunnel leading to the sand filter and 61-m stack.

To minimize the buildup and release of contamination, the ventilation systems are equipped with a series of filters. Supply air to the rooms passes through dust stop filters. Air and inert gas (argon and helium) to process enclosures with once-through ventilation receive one stage of HEPA prefiltration. Recirculated inert gas receives three stages of HEPA filtration on leaving the cells and one stage on returning. All process cells have HEPA cabinet filters on their outlets. Finally, two stages of HEPA filtration are provided for all process exhausts before discharge to the main exhaust duct. All room air from the PuFF Facility and HEPA-filtered process exhausts receive a final stage of filtration in the underground sand filter before release to the stack.

3.1.7.1.1 Room Ventilation

Conditioned air is supplied to the PuFF Facility from a supply fan and conditioning equipment located outside Building 235-F. Conditioned air is supplied to the rest of Building 235-F by an existing independent system. The rooms of the PuFF Facility are purged once-through from the supply and exhausted directly through the main exhaust (roof) duct to the sand filter. Fans located between the sand filter and stack draw exhausted air from the PuFF Facility and 235-F billet areas through the sand filter at a rate of about 30,000 cfm. Air from clean rooms outside the PuFF Facility is unfiltered and exhausted through vents on the roof of Building 235-F.

HEPA filtration is not provided for the room air exhaust in order to maintain a clear, unobstructed exhaust path in the unlikely event of fire. As discussed in Section 3.4, the action of the sand filter alone reduces concentrations of released activity to well within established guidelines^{2,6} for all credible facility-initiated accidents that cause a breach in process containment.

Room air to the various compartments of the PuFF Facility is supplied directly from the supply system and by natural flow from adjacent compartments. Pressure differentials between the compartments are maintained by barometric dampers to ensure natural air flow from clean to progressively regulated areas and to minimize the back flow of possible contamination (e.g., compartments in order of decreasing air pressure are air locks, operating rooms and maintenance areas). Fresh air enters the ceilings of all compartments and exits at floor level to minimize the inhalation of contamination.

The supply fans will be shut off in emergencies, such as fire or loss of vacuum in the roof exhaust tunnel. This action prevents pressurization of the rooms of the PuFF Facility and the potential release of contamination out of the unfiltered room exhaust of Building 235-F. The building exhaust header (room air) is equipped with a modulating isolation damper (D3 in Figure 10) which maintains this header at -0.5 in. (H₂O). This damper will close when there is a loss of negative pressure in the roof tunnel to prevent backflow of contaminated gases from Building 221-F or PuFF processes into the rooms of the facility.

3.1.7.1.2 Process Ventilation

Ventilation of the process cells and wing cabinets, glove boxes, and hoods includes both once-through and recirculated systems. Helium or argon is supplied from cylinders or tanks located outside the building to the inert gas recirculation loops on the second floor. Once-through argon or helium is also supplied to the cells for furnace gas, back-fill of airlocks and furnaces, gas-operated motors and valves, and welding electrodes. The static space between the shield windows and the cell windows may be purged with argon or helium. Air-purged enclosures and hoods receive air from the maintenance rooms or second-level process rooms.

All process exhaust gases, after primary HEPA filtration, are drawn through the process exhaust header and two final stages of HEPA filters by one of two (one spare) process exhaust fans. This filtered exhaust then discharges into the main exhaust duct leading to the sand filter and stack. The process exhaust header is also equipped with an automatic isolation damper (D4 in Figure 10) that will close on loss of negative pressure in the roof exhaust tunnel. This action prevents possible pressurization of Building 235-F from external events (pressurization from canyon in Building 221-F).

3.1.7.1.2.1 Recirculated Atmospheres

Seven cells and three wing cabinets are connected to recirculator-purifiers, forming nearly closed-loop systems. The argon system services Cells 1 through 5 and the three wing cabinets; two separate helium systems service Cells 6 and 9, respectively. The inert gas exhausted from an individual cell passes through one HEPA filter at the cell outlet and through two additional HEPA filters before entering the purifiers located on the second floor.

The argon purification system has a total capacity of about 600 cfm to accommodate five cells and five wing cabinets (two initially blanked off). Argon is drawn from the cells by one of two blowers (one spare) that circulates the gas through the purifier, cooler, molecular sieve and back to the cells and cabinets. In the purifier, oxygen is removed by reaction with a nonexplosive 4% H₂-96% Ar mixture supplied from a tank outside the building. The heat load in the argon is exchanged with an independent chilled-water system, which condenses water formed in the purifier. This water is removed by one of two parallel molecular sieve dryers; one is regenerated while the other is in use. The argon is finally returned to the cells and cabinets through a single HEPA filter.

Helium for Cell 6 is purified by one of two parallel independent systems (one operating and one spare). Each system consists of a heat exchanger (see Section 3.1.7.3), blower, titanium-filled reactor, and a second heat exchanger. The helium is drawn from the cell by the blower through the first heat exchanger to remove the heat from the cell and minimize high temperatures in the reactor. Oxygen, nitrogen, and water are removed by reaction with the titanium (replaceable cartridges). Excess heat from this reaction is removed by the second heat exchanger before the gas is returned to the cell through a single HEPA filter. Helium for Cell 9 is purified by a single similar system.

Continuously increasing concentrations of residual impurity gases caused by inleakage and diffusion of the gases into the cells, and possibly by small amounts of hydrogen introduced in the purifier, are accumulated in the argon recirculation atmosphere. In order to maintain these impurity concentrations below required levels, up to about 10 cfm of recirculated argon must be vented and pure argon must be supplied for makeup from the liquid argon storage tank. The vented inert gas (or once-through air when the cell is occasionally opened to air for maintenance) is exhausted through the process exhaust header and receives two additional stages of HEPA filtration.

The entire cell ventilation system features extensive controls to assure that the cells and wing cabinets remain at a nominal 0.8-in. (H₂O) negative pressure with respect to the surrounding rooms to minimize the consequences of a breach of containment. These controls, discussed in greater detail in Section 3.3.2, include pressure regulators, automatic high-speed valves in the inert gas recirculation and fill lines, and the two exhaust lines, and oil-filled seal pots that automatically relieve any pressurization or evacuation of Cells 1 through 6 and 9. (Seal pots are not installed in Cells 7 and 8 because of the low potential for pressurization and contamination.)

3.1.7.1.2.2 Purged Atmospheres

The air atmosphere process cells, glove boxes, and hoods in the maintenance areas on the first floor, as well as the metallographic glove boxes and the glove boxes housing pumps on the second floor, are ventilated once-through with room-supplied air. Air to the cells and glove boxes receives single-stage HEPA filtration on entrance and exit from each enclosure. The air enclosures are also maintained at a nominal 0.8-in. (water) negative pressure with respect to the surrounding rooms. Exhausts from all purged process systems discharge through the process exhaust header to two stages of HEPA filters, the roof exhaust tunnel, and the sand filter before release to the stack.

When a panel must be removed from a cabinet or cell for equipment replacement, or when higher airflow is required during a sudden breach of process containment, the affected enclosure will be purged with room air through the opening at rates of 200 linear ft/min to prevent the release of activity into the room. This air purge is accomplished by opening a damper (automatic in case of a major rise in cell pressure) in the maintenance exhaust line and bypassing the normal exhaust (Section 3.3.2.1). This action causes the enclosure to exhaust through the maintenance exhaust header into the process exhaust duct.

The cell annulus described in Section 3.1.5 is purged with room air in order to minimize the spread of contamination in the event of leakage from the cells. The pressure in the annulus is less than that of the surrounding rooms and greater than that of the cells. The exhaust from the annulus is discharged through the building exhaust duct and roof exhaust tunnel to the sand filter.

3.1.7.2 Electrical Services

Normal power to most PuFF systems and equipment is supplied underground from a new substation located east of Building 235-F. Three phase, 13.8 kV power from the F-Area process loop is reduced to 480 V by a 1000 kVA transformer in the substation and distributed through circuit breakers to motor control centers (MCC's) in electric control rooms on the second floor of Building 235-F (Figure 11). An existing 750-kVA transformer supplies the rest of Building 235-F and some shared equipment. An alternate primary feeder, independent of the F-Area process loop, is not provided as required by the General Design Criteria - Plutonium Facilities.² (See Section 7.5.1, Appendix C.)

750 kVA Trans
13.8 kV/480 V

ACB 1A 1B 1C

MS-1 F-1

MCC-1

CB

MCC-2

MCC-3

750 kW Diesel

Gen

CB E1 E2 E3

ATS-1

MS-2

ATS-5

MS-3

MS-4

F-2 F-3

B A

Exhaust Fans

MCC-E1

F-4

ATS-4

EPP

1000 kVA Trans
13.8 kV/480 V

ACB 2A 2B 2C

ACB 3A 3B 3C

Spare

PDP

PDP-3

MCC-N1

MCC-N2

Legend:

- MCC - Motor Control Center
- ATS - Automatic Transfer Switch
- PDP - Power Distribution Panel
- CB - Circuit Breaker
- F - Fuse
- EPP - Emergency Power Panel
- MS - Manual Switch

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TABLE 2

CRITICAL EQUIPMENT SUPPLIED WITH EMERGENCY POWER

(MCC - Motor Control Center; ATS - Automatic Transfer Switch)

ATS-1, MCC-2*

Breathing Air Compressor
Instrument Air Compressor
Fence Lighting
Emergency Lighting
Process Instrument Power

ATS-3, MCC-E2

Air Monitor Fan B
Argon Blower B**
ATS-4, Emergency Power Panel
Cooling Water Pump B
Chilled Water Circ. Pump B
Secondary Chilled Water
Pump B (H.P.)
Secondary Chilled Water Pump B
(H.P. Auxiliaries)
Helium Purifier
Argon Refrigeration Unit B
Transformer, Sintering Furnace
Helium Blower B

ATS-4, Emergency Power Panel

Argon Recirculating System Controls
(Cells 1-5)
Helium Recirculating System Controls
(Cell 6)
Air Atmosphere Controls (Cells 7-9)
Air Monitoring Instruments, Alarms
Fire Protection System
Alarms and Annunciators
Chart Drives, Recorders
Cell Manipulators
Pressure Relief Valve (Hot Press)
Purge Gas Purifiers
Hydrogen Analyzer
Gas Chromatograph
Cold Press
Under Cell Transfer
Various Instrument Panels

ATS-2, MCC-E1

Argon Blower A**
Air Monitor Exhaust Fan A
ATS-4, Emergency Power Panel
Cooling Water Pump A
Chilled Water Circulation Pump A
Secondary Chilled Water Pump A (Hot Press)
Secondary Chilled Water Pump A
(H.P. Auxiliaries)
Transformer, ¹⁶O₂ Furnace)
Transformer, Final Heat Treatment Furnace
Argon Regenerator Blowers
Argon Dryer Heater
Argon Refrigeration Unit A
Helium Blower A
Helium Dryer

ATS-5

Process Exhaust Fan A
Process Exhaust Fan B

Battery Supplied Emergency Power

Fire Detection and Suppression
Emergency Diesel Starter
Emergency Lighting Units

* MCC-2 services primarily existing Building 235-F critical equipment.

** This equipment must be re-started manually after switching to emergency power.

The stack exhaust fans (4 fans, 2 or 3 operating with 1 or 2 spare) in Building 292-F are powered from two independently fed 13.8 kV/480 V transformers (2 fans from each transformer). Two of the fans are on separate emergency MCC's one of which will, on loss of normal power, be automatically supplied with emergency power from a 600 kW diesel-generator. Tertiary power backup to these fans can be provided, as required, by manual tie-in to Building 221-F emergency generator system. Thus, a complete loss of power in the PuFF Facility does not preclude ventilation.

The diesel-generator servicing the PuFF Facility emergency power system is housed in a separate building adjacent to Building 235-F. This structure is designed to protect the generator from the Design Basis Earthquake or Tornado.² Building 292-F housing the stack exhaust fans and their emergency generator is a Class I structure similar to, but smaller than, Building 235-F.

Emergency power from batteries is supplied to the fire detection and suppression systems, the diesel-generator starter, and emergency lighting units.

3.1.7.3 Cooling Water

The cooling water systems for the PuFF Facility are shown schematically in Figure 12. Main cooling water for the closed-loop heat removal systems within the Facility is supplied by and returned to the 200-Area cooling tower, which is located several hundred feet from Building 235-F. Secondary and tertiary closed-loop systems are used for the process operations, with heat rejection to the cooling tower water system (CTWS) through heat exchangers. This design provides barriers between cooling loops to prevent the spread of contamination if leakage should occur. Elimination of penetration for water lines directly into the cells minimizes the potential for flooding.

Two secondary closed loop systems are provided: the Process Cooling Water System (PCWS) and the Chilled Water System (CWS). The PCWS removes heat from furnaces and the in-cell and vault storage spaces. Cooling water to both furnaces and storage spaces, which are recessed in the floors of the cell lines flows through externally mounted water jackets. Heat from the PCWS is rejected through a heat exchanger to the Cooling Tower Water System (CTWS).

The CWS removes heat from heat exchangers serving the argon and helium recirculation systems and also from heat exchangers serving the two tertiary hot press cooling loops. Tertiary cooling is provided for the hot press, because it has the highest potential for leakage and contamination spread. Heat from the CWS is rejected through two condenser-chiller units to the CTWS.

FIGURE 12. Simplified Schematic of Process Cooling Water System for the PuFF Facility

Controls and alarms provided for these coolant systems are discussed in Section 3.3.3.

3.1.7.4 Process Gases

Argon, helium, 4% H₂ in argon, and oxygen-16 are provided without HEPA filtration for a variety of purposes. The gases are supplied and appropriately regulated from bulk tanks or cylinders located outside of Building 235-F. Flow rates into the cells are limited so that the capacity of the controls on the recirculators or the capacity of the purged systems cannot be exceeded and negative pressure in the enclosures can be maintained. Section 3.3.2 describes the controls and alarms provided to indicate and correct abnormal pressure conditions within the cells. Expended gases undergo a minimum of two stages of HEPA filtration before discharge through the sand filter and stack.

3.1.7.5 Vacuum Systems

Vacuum service is supplied to cells and cabinets for handling mechanisms (Wands), vacuum cleaners, and transfer locks (evacuatable chambers connecting cells for transfer of materials; see Figures 5-8). Gases withdrawn from the enclosures receive a minimum of three stages of HEPA filtration before reaching the vacuum pumps located on the second floor. Gases discharged from these pumps receive additional stages of HEPA filtration in the process exhaust header before discharge to the sand filter and stack.

Because filtering the gas between the hot press vacuum chamber and the high vacuum pumps is impractical, these pumps are located in a separate glove box in the east maintenance area adjacent to the hot press. Gases discharged from these pumps receive a minimum of three stages of HEPA filtration before discharge to the sand filter.

Vacuum pumps and piping are sized to minimize the potential for excessive cell depressurization should misoperation occur. Cells are equipped with automatic pressure control instrumentation including alarms which indicate the existence of abnormal conditions (Section 3.3.2).

3.1.7.6 Process Liquids and Liquid Waste

Process water and chemical solutions are used in Cells 7 and 8 for decontamination and also in the metallographic glove box for sample preparation. These liquids are added to the enclosures in sufficiently small amounts to preclude the possibility of flooding the individual cell or box.

Liquid decontamination wastes will be transferred from the ultrasonic cleaner in Cell 7, the barrier transfer tank in Cell 8, and the rinse tank in Cell 8 by vacuum into the waste transfer tank located in a glove box (Hood 3) in the west maintenance area. The liquid is transferred by vacuum into a waste-holding tank and then fed by gravity into a polyethylene bottle. The bottle is transferred through a bag port into a stainless steel drum containing vermiculite; the drum is transported to HB line for normal waste disposal (see Section 3.5.4).

Small quantities of filtered water in the metallographic line are vacuum transferred into a filtrate tank, and then gravity fed to a polyethylene bottle. The bottle is transferred through a bag port into a stainless steel drum containing vermiculite. Bottles of spent reagents are similarly transferred to steel drums. Wastes containing fluorides will be complexed with aluminum nitrate before removal from the glove box. The steel waste drums are transported to HB line for normal waste disposal.

3.1.7.7 Breathing Air

Breathing air is supplied to various points in the rooms of the PuFF Facility to be used in conjunction with protective suits and hoods for entry into the facility in the event of a release of contamination or a major repair requiring removal of a panel on an enclosure. The breathing air system meets the requirements of ANSI Standard Z88.2 except that no in-line sorbent beds for organic materials are provided. However, in-line filters for particulates are provided. Sorbent beds are not believed necessary because routine analyses of the air (performed quarterly¹⁴) have shown adequate purity.

3.1.7.8 Deionized Water

Deionized water with corrosion inhibitors added is used to fill the front shield windows of the cells initially, and later to make up losses to the windows. Once filled, the water in the shield windows is recirculated by two pumps located in the west maintenance area. In the unlikely event that the shield windows should inadvertently be drained, the limited volume of water would spill onto the operating room floor where it could be removed by wiping with absorbent materials according to established procedures. Because there are no floor drains in the PuFF Facility, no water would be able to enter the sanitary sewer and spread contamination outside of the facility.

3.1.7.9 Sanitary Sewer

Building 235-F has a sanitary sewer system that is entirely separate from any water used in the PuFF Facility. This waste is pumped to the 200-Area sanitary waste treatment area where it is monitored.

3.2 POTENTIAL HAZARDS

Specific hazardous equipment and conditions associated with process operations in the PuFF Facility cell line are identified in the following sections. The consequences of potential accidents initiated by these hazards in which radioactive particulates are released from the process enclosures are evaluated in Section 3.4. Safety features and controls installed to alleviate or minimize potentially hazardous conditions are described in Section 3.3.

Operation of the facility involves potential hazards in four general categories: contamination, radiation, criticality, and industrial hazards. The safety implications are discussed in this section.

3.2.1 Specific Hazards

Various combinations of the hazards discussed below exist for the production of ceramic ^{238}Pu heat sources in the cell enclosures. Specific hazards identified with operations in each enclosure are summarized in Table 3. The most serious hazards involve release of contamination from the process enclosures; mechanisms for such releases are noted in the following paragraphs.

Inert gas (to purge recirculating gas loops, operate motors, cool furnaces, and use as a weld gas) and vacuum (to operate handling mechanisms, evacuate transfer locks, and for vacuum cleaning) services are supplied to most cells and wing cabinets. The potential for over or underpressurizing enclosures as a result of a malfunction in the control of these services is minimized by automatic pressure control systems (Section 3.3.2).

Other hazards with the potential to cause the release of contamination from the enclosures include glove and bag failures, leaks in seals (e.g., ram seals on presses), and enclosure failure caused by excessive pressure, or internally generated missiles. Except possibly for the unlikely events of die fragmentation in the cold press or a steam explosion in the hot press (Section 3.4), the resulting consequence of the above would be minor. Leakage of radioactive particulates from small openings in the enclosures

TABLE 3

Hazards Associated with PPO Processing

Enclosures

Hood 1 (Entry and Exit)

Wing Cabinet 1
(Cold Press and Transfer)Cell 1
(Powder and Shard Preparation)Wing Cabinet 2
(Maintenance)Cell 2
(Disassembly)Cell 3
(Blending and Weighing)Cell 4
(Die Loading, Unloading)Wing Cabinet 4
(Transfer)

Hot Press

Cell 5
(Post-Hot-Pressing Heat Treatment)Cell 6
(First Welding cell)Cell 7
(Decontamination)Cell 8
(Decontamination and Leak Check)Cell 9
(Final Welding)

Metallographic Glove

Box Line

*Potential Hazards*Spread of contamination
Hand exposures
Fire
Pinch pointsHand exposures
Glove failure
Pinch points
Flying fragments from die failureCell pressurization or depressurization
Flying fragments from failure of motor-
ized equipment
Pinch points
Hot surfaces on furnacesGlove or bag failure
Pinch points
Failure of windows from impact of heavy
equipmentFlying fragments from cutting tool failure
Pinch points
High radiation fields
Pressurization or depressurizationPinch points
Pressurization or depressurizationFlying fragments from failure of die
cutting saw
Pressurization or depressurizationGlove or bag failure
Pinch pointsFlying fragments from die failure
Steam pressurization from failed induction coil
Implosion of viewing window or glove ports
Radio frequency burns/high voltage
Pinch points
Leakage through ram sealsPressurization or depressurization
Pinch points
Hot surfaces on furnacesHot spots
Pinch points
Pressurization or depressurizationCorrosive liquids
Fire
Limited floodingCorrosive liquids
Fire
Transport of contamination to He leak detector
Limited floodingHot spots
Fire
Pinch pointsFire
Limited flooding
Pinch points

would normally be minimized by action of cell ventilation system controls (Section 3.3.2). Flying fragments generated by equipment failure inside the enclosures, with the possible exceptions of the cold press and hot press, would not result in the release of contamination. A blow-down line connecting the hot press to the vacuum equipment cabinet will relieve any steam pressurization (Section 3.4.4.3).

The hazard of fire within the process enclosures and rooms of the facility is minimized by the combination of either inert gas atmosphere or automatic *Halon* fire suppression systems with the minimal use of potentially flammable material. Inventories of potentially flammable material in the enclosures are limited to such items as neoprene gloves, plastic glove cartridges, plastic manipulator boots, sealing gaskets, electrical insulation, some shield window materials, and cloth and paper used for decontamination.

3.2.2 Contamination

Inhalation and ingestion of plutonium oxide powder are the principal hazards that may be encountered during both normal and abnormal operations. Mechanisms by which there might be a release of $^{238}\text{PuO}_2$ and subsequent inhalation and ingestion by personnel within the PuFF Facility, within Building 235-F, and on the SRP site, and by the public offsite are evaluated in Section 3.4.

The feed powder from HB line is introduced into the PuFF Facility as a finely divided ($\sim 5\text{-}\mu\text{m}$ median particle size) solid solution of the oxides of several plutonium isotopes (Table 4). Except for negligible quantities of radioactive decay products, the isotopes retain their relative concentrations in the solid solution throughout processing. As shown in Table 4, ^{238}Pu is the limiting isotope with regard to the biological hazard because of its high specific activity and very low maximum permissible intake (MPI).¹⁵ The level of airborne contamination within the facility or onsite should not exceed the 40-hr week maximum permissible concentration of $2 \times 10^{-12} \text{ }\mu\text{Ci/cm}^3$.¹⁶

Inhalation has been assessed to be the critical dosage pathway because of the large discrimination factor (10^7 to 10^9) against plutonium in the vegetation intake and uptake pathways.¹⁷ As discussed in Appendix B, only the fine powder and a very small percentage (<2%) of the shards are considered to be respirable (i.e., PuO_2 particles with diameters <3 μm). Deposition in the pulmonary tract and retention of the contaminants within the body increases with decreasing particle size.^{18,19} Also, the finer particles will be more readily dispersed in the event of an accident; shards and dense fuel form intermediates are relatively nondispersible.

TABLE 4

Maximum Permissible Intake (MPI) and Relative Hazard of Isotopes in 80% Assay $^{238}\text{PuO}_2$

	Specific Activity (SA), Ci/g	Typical Fraction Isotope (f_i)	MPI, Ci ^a	Relative Hazard ^b for 80% Assay per gram
^{238}Pu	1.66×10^1	0.803	2.04×10^{-8}	6.53×10^8
^{241}Pu	1.12×10^2	.008	1.15×10^{-6}	7.79×10^5
^{239}Pu	6.13×10^{-2}	.162	1.67×10^{-8}	5.95×10^5
^{240}Pu	2.27×10^{-1}	.024	1.68×10^{-8}	3.24×10^5
^{241}Am	3.21×10^0	.0003	5×10^{-8}	1.93×10^4
^{242}Pu	3.85×10^{-3}	.002	1.8×10^{-8}	4.28×10^2
^{237}Np	6.87×10^{-4}	.0014	3.28×10^{-8}	2.93×10^1
^{232}Th	1.11×10^{-7}	0.0021	4×10^{-8}	5.83×10^{-3}
			Total	6.55×10^8

a. MPI represents the activity of a given isotope required to give a dose equal to the guideline value for the critical organ. Values shown are taken from Reference 15 only to illustrate relative hazards; similar, but slightly lower, values were used in the accident analyses, as discussed in Appendix B.

b. Relative hazard defined by: $\text{RH} = (\text{SA} \times f_i)/\text{MPI}$.

The greatest contamination hazard with respect to inhalation is associated with Cell 1, where milled powder of small particle size ($\sim 2 \mu\text{m}$ mass median diameter) is processed. For the most part, the remaining cells and wing cabinets contain shards and/or dense fabricated forms.

Process design and operating procedures will emphasize the controlled handling of the PuO_2 product, especially the finely milled powder in Cell 1; dusting and dispersal of $^{238}\text{PuO}_2$ in the cell will be minimized. The quantity of powdered forms (feed or milled PuO_2) exposed to the cell atmosphere will be limited to the minimum amount, and the exposure will be for the shortest time commensurate with efficient production (Table 2 gives nominal weights of the various PuO_2 forms). The larger forms of PuO_2 (shards and dense fuel forms) exposed to the cell atmosphere will also be limited to the smallest quantities practical. When not being processed, all

forms of PuO_2 will be contained in storage containers (see Appendix B) or process equipment designed to provide an additional layer of containment in the event of an accidental breach of the primary containment.

The release of airborne contamination to the environment during normal operation of the PuFF Facility has been evaluated (Section 3.5.2) using a conservative source term and taking minimum credit for the number of filtration stages. The result is an annual stack emission of about $0.05 \mu\text{Ci/yr}$, which is several orders of magnitude less than the value estimated in the Environmental statement.³ Releases of airborne contamination during accident conditions are evaluated in Section 3.4.

3.2.3 Radiation

Soft gamma and neutron radiation are the limiting radiation hazards. Exchange of ^{16}O for the $^{17,18}\text{O}$ in PuO_2 effectively lowers by a factor of three the neutron emission from α, n reactions with ^{17}O and ^{18}O . The facility has been shielded to limit whole body dose rates to 0.5 mrem/hr or less in the operating area, and to below 5 mrem/hr in the maintenance areas and other intermittently occupied areas for the following single-cell inventories:²⁰ 300 g of unexchanged $^{238}\text{PuO}_2$; 900 g of exchanged $^{238}\text{PuO}_2$; and 1500 g of exchanged $^{238}\text{PuO}_2$ in in-cell storage. Except for special operations and for short time periods, the in-cell $^{238}\text{PuO}_2$ inventory will be maintained in configurations that will limit potential exposure rates in the operating area and maintenance areas to within the values cited above.

Most processing operations will be conducted from the operating area using master-slave manipulators. However, glove-assisted operations will be required periodically for short time periods in the maintenance areas. To estimate hand exposures for such operations, dose rates for both $^{16}\text{O}_2$ -exchanged and unexchanged $^{238}\text{PuO}_2$ as a function of shielding and distance have been calculated and measured.²¹ Typical dose rates anticipated for freshly made $^{238}\text{PuO}_2$ (6 months since separation) are shown in Table 5.

Hand doses, particularly from soft gamma radiation, will be limiting for the glove-assisted work. Lead gloves and thick-walled vessels will provide radiation protection during such operations. Containers for glove-assisted work will, where practicable, provide a minimum of 0.25 in. of stainless steel, or equivalent shielding, and a minimum distance of 3 in. between hands and the PuO_2 .

Both internal and external exposures to radiation of operating personnel will be controlled administratively (Section 3.3.5) with support of extensive monitoring. Operations of a similar nature

have been successfully controlled for several years in the glove box facility of HB line for similar quantities of $^{238}\text{PuO}_2$. Radiation exposure data for operating personnel will be reviewed monthly. Special readings will be made of personnel radiation monitor badges if radiation levels are excessive. Radiation levels will be regularly monitored by both Health Physics and operating personnel. Appropriate measures will be taken to keep radiation fields to the minimum practical level.

The enclosure design in conjunction with administrative controls and other engineered features of the facility will permit all operations without exceeding the radiation exposure guide values required by ERDA (Table 6)¹⁶ or those used at SRP. The design and operating objective is to meet the "as low as practicable" guideline of ERDAM 0524;¹⁶ i.e., limit radiation exposures to less than 1/5 the permissible dose values of Table 6 for normal operations.

TABLE 5^{21,22}

Typical Radiation Dose Rates for 80% Assay $^{238}\text{PuO}_2$

$^{16}\text{O}_2$ Exchanged	Distance	Shielding	Dose Rate (n+γ) mrem/(hr)(g)
Yes	Contact	None	1.1×10^4
Yes	Contact	0.030 in. leaded gloves	1.4×10^3
Yes	Contact	0.25 in. steel + 0.030 in. leaded glove	1.2×10^2
Yes	3 in.	0.25 in. steel + 0.030 in. leaded glove	2.0
No	18 in.	None	2.7
Yes	18 in.	None	1.2
No	18 in.	0.25 in. steel + 1.00 in. lead + 4 in. water	2.15×10^{-2}

TABLE 6

Maximum Radiation Exposure Limits

<i>Type of Exposure</i>	<i>Period</i>	<i>Dose Equivalent (rem)^{14,16}</i>
Whole body, head and trunk, gonads, lens of the eye, red bone marrow, active blood forming organs.	Year	3
	Calendar Quarter	3
Unlimited areas of the skin (except hands and forearms). Other organs, tissues, and organ systems (except bone).	Year	15
	Calendar Quarter	5
Bone	Year	30
	Calendar Quarter	10
Forearms	Year	30
	Calendar Quarter	10
Hands and feet	Year	75
	Calendar Quarter	25

3.2.4 Nuclear Criticality

The PuFF Facility will be safe from criticality accidents. The total operating inventory distributed within the PuFF cell lines will be administratively controlled (see Section 3.3.5) to less than the criticality limit of 11.9 kg of PuO₂ product.²³ Quantities of ²³⁸PuO₂ stored in the vault will exceed the criticality limit, but they will be stored in safe arrays and adequately monitored (a Nuclear Incident Monitor is provided). Special procedures must be written and approved (following ERDA guidelines²⁴) before any operations which might require an in-cell inventory exceeding the criticality limit; e.g. disassembly of retired generators.

The criticality limit, or maximum safe mass, of 11.9 kg for handling and processing of the ^{238,239}PuO₂ is based on calculations for a theoretically dense oxide sphere composed of 75% ²³⁸PuO₂ - 25% ²³⁹PuO₂ surrounded by an infinite water reflector.²³ A k_{eff} = 0.9 was used to define the maximum safe mass. The 80% ²³⁸PuO₂ - 20% ²³⁹PuO₂ to be used will have a somewhat larger safe mass because of the higher ²³⁸Pu content. The maximum accumulation in any one cell and associated wing cabinet will be administratively controlled to less than half of the calculated limit. The conservative assumptions inherent in the calculations (e.g., theoretical density, water reflector, and k_{eff} = 0.9) compensate

for any uncertainties in the fission cross sections used in the calculation. Controlled distribution throughout the cell lines provides additional assurance that criticality incidents will not occur. The anticipated inventory during normal process operations will be about 6 kg (Table 2), or about one-half the allowed limit.

The existing vault in Building 235-F, which contains a criticality monitor with automatic alarm, will be used to store $^{238}\text{PuO}_2$ powder, intermediates, scrap, and fabricated heat sources. A shielded area consisting of water-cooled locations for up to 70 kg of oxide assures storage in safe arrays. The contents of each storage location will be administratively controlled to <1 kg. The calculated reactivity of the array is very low, $k_{\text{eff}} = 0.4$, assuming that each location contains a theoretically dense cylinder of $^{239}\text{PuO}_2$ weighing 1 kg.²⁵ The reactivity of the array during normal storage will be even lower because of the high ^{238}Pu content of the oxide and the lower density of the oxide forms. Thus a criticality incident in the storage vault is not a credible event (see Section 3.4.5). Transfers of material between the cell lines and the vault will be monitored by Health Physics personnel. Criticality during these transfers is also not credible because high radiation fields and heat generation would occur before the safe mass could be exceeded.

3.2.5 Industrial

The hazards inherent in operating the facility that are not related to radiation exposure or the release of contamination are evaluated to be minor; they will not affect more than one or two persons, and will not shut down operations unduly or compromise significant investments. Such hazards are protected against by design and procedures based on many years of operating experience in similar facilities. Typical hazards are those normally found in maintenance operations on electrical and mechanical equipment and in the handling of heavy casks, machinery, or manipulators, compressed gases, and chemicals.

3.3 CONTROLS AND SAFETY FEATURES FOR ACCIDENT PREVENTION AND MITIGATION

Those factors, including engineered safety features and controls, which contribute to the radiological safety of the PuFF Facility are emphasized in this section. The primary protective devices which control and minimize exposure to radiation and the release of contamination are the containment barriers, filtered ventilation systems, monitoring systems including alarms and interlocks, and the administrative control system.

3.3.1 Containment Barriers

The design of the PuFF Facility and the related portions of Building 235-F provides multiple levels of confinement against the release of radioactive particulates to the environment. The barriers for the first floor, where the operating part of the facility is located, are shown schematically in Figures 2, 3, and 5. Similar barriers are shown for the second floor in Figure 4.

The primary barrier consists of the individual cells or wing cabinets designed to be leak-tight enclosures (Section 3.1.5). Within this containment barrier, most of the $^{238}\text{PuO}_2$ inventory (Table 1), including all powder forms, will be further contained locally in either process equipment or storage containers when not involved in processing or transfer. The cells are isolated from one another by transfer locks; the cells and the wing cabinets are operated at a negative pressure with respect to the surrounding rooms to reduce the consequences of leaks. The primary enclosures are penetrated for ventilation through HEPA filters and for general services such as power, gas, vacuum, manipulators, and gloves.

The second barrier against the release of activity is the cell annulus which consists of the space between the process cells and their shield walls; the barrier also includes the access trench beneath the cell floors. The annulus receives air from adjacent rooms which is exhausted through the sand filter. The air pressure in the annulus is lower than that of the operating and maintenance areas and greater than that of the cells.

The third barrier consists of the walls and associated air locks enclosing the regulated areas of the PuFF Facility (Figures 2 and 3) and the auxiliary equipment rooms on the second

floor (Figure 4). The walls surrounding the process areas of the PuFF Facility (first floor) are constructed to withstand a 2-hr fire.

The final barrier is the external structure of Building 235-F. As described in Section 3.1.2, the building is a Class I structure having 14-in.-thick reinforced concrete walls with no windows and an 8-in.-thick reinforced concrete roof.

3.3.2 Ventilation Systems

The ventilation systems (Section 3.1.7.1 and Figure 10), in conjunction with the sand filter, have been designed to limit chronic stack emissions to <5 mCi/yr for normal operations, to provide maximum protection for operating personnel, to provide containment within the building for accidents occurring inside the facility, and to minimize releases to the environment in the unlikely event of a natural disaster or major fire in the building. The ventilation systems are designed to provide fail-safe operation.

As described in Section 3.1.7.1, two separate exhaust systems discharge into the main exhaust duct leading to the sand filter: the building exhaust, which receives no HEPA filtration, and the process exhaust (includes maintenance exhaust), which receives two final stages of HEPA filtration. Suction for the building exhaust is provided by the sand filter exhaust fans and for the process exhaust by a combination of a process exhaust fan located downstream from the HEPA filters and the sand filter exhaust fans. Both the stack and process exhaust fans have on-line spares and are provided with emergency power from separate diesel generators (Section 3.1.7.2).

Two recirculating inert gas systems provide ventilation for seven of nine cells and their attached cabinets. The other two cells are supplied by once-through air. In addition, pressurized process gases are supplied for recirculation system make-up, welding, furnaces, etc. Controls and alarm annunciators for the various systems are located in the operating (control) room.

3.3.2.1 System Controls and Interlocks

The air supply and exhaust systems, the inert gas recirculation systems, and the purged gas systems have interlocking controls which maintain negative pressures in the cells and adjoining wing cabinets and provide air flow in the rooms from clean to progressively regulated areas.

3.3.2.1.1 Cell Atmosphere Controls

Automatic control of pressures within individual cells is provided to counteract potential leaks and excessive variations from the normal operating pressure of -0.8 in. (H₂O) with respect to the surrounding rooms. Pressure sensors will initiate alarms and automatic controls on either pressurization or evacuation of the cells and cabinets.

An increase in pressure within a recirculated inert gas cell will initiate three responses by the automatic pressure control system at three preset pressure levels. These responses involve automatic removal of the individual cell from the recirculating gas system with the concurrent purging of the cell atmosphere directly to the process exhaust header. (The purged gases will receive two stages of HEPA filtration before discharge through the sand filter and stack.)

If the cell pressure increases to between -0.6 to -0.7 in. (H₂O), an alarm will sound to alert operating personnel to a deviation from normal conditions. If the pressure increases further to -0.5 in. (H₂O), a second alarm will sound and the cell will automatically be removed from the recirculating system and purged with inert gas directly from the supply and vented through a 2-in. exhaust line to the maintenance exhaust header (in Figure 10, Valves V4 and V5 close and Valves V1 and V3 open). If the cell pressure subsequently increases to -0.3 in. (H₂O), another alarm sounds and the larger (10 or 14 in.) maintenance exhaust line will open automatically (V2).

The exhaust controls on the air atmosphere cells will function similarly during a pressurization. Valve V1 will open at a cell pressure of -0.5 in. (H₂O) and V2 will open at -0.3 in. (H₂O).

In the unlikely event of a malfunction of the automatic valving system, the oil-filled seal pots will relieve the pressure at 0.0 in. (H₂O) (i.e., equivalent to the operating room pressure). The seal pots are connected to the maintenance exhaust line between the cell and the maintenance exhaust valve (V2) and are equipped with liquid-level detectors to ensure that the oil is at the proper level for relief at the desired pressure (the silicone oil used in the seal pots does not represent a significant hazard). On Cells 1 through 6 (inert atmospheres), the seal pots discharge into the maintenance exhaust header so that the exhaust receives two stages of HEPA filtration before passing to the sand filter and stack. Cells 7 through 9 do not require seal pots because they are air-atmosphere cells, and the potential for contamination and pressurization is lower than the other cells. Any pressurization would be relieved by a reversal of air flow in the inlet line from the West Service Room on the second floor. However, a seal pot has been connected

to Cell 9, with discharge into the building exhaust header, because this cell will be operated with a helium atmosphere during welding operations.

A decrease in pressure within a cell will initiate similar responses. If the pressure decreased to -1.0 in. (H₂O), an alarm will sound and the pumps supplying the vacuum services (transfer locks, handling mechanisms, and vacuum cleaners) will be automatically shut off. If the pressure decreases further to -3.0 in. (H₂O), the seal pots will automatically relieve.

The maintenance exhaust system is designed to provide an air flow of 200 ft/min across the opening created by removal of a cell shield window. Operating personnel must close Valves V1 and V2 manually (alarms and valve position indicators in control room) to return a cell to its normal status after the ventilation imbalance has been eliminated. For maintenance operations in which removal of a cell window is required, the cell will be first isolated from the recirculating gas system, and the maintenance exhaust line will be opened to provide the flow of air into the opening.

3.3.2.1.2 Facility Air Supply and Exhaust Controls

Controls for the air supply and exhaust systems and the cell ventilation systems are interlocked with fire detectors and pressure sensors in the roof exhaust tunnel to prevent pressurization of the building in the unlikely event of a fire or a pressurization from the separations canyons (Building 221-F).

Initiation of a fire alarm automatically stops the air supply fan and closes the supply dampers (D1 and D2 in Figure 10). Also, the supply valves for the mixed gas (4% H₂ in Ar) and oxygen-16 systems close and the respective vent valves open (these valves are located outside Building 235-F). All other systems continue to function in a normal manner (building and process exhaust, recirculating inert gas). These actions assure that neither the cells nor the process rooms are pressurized and that combustion products are vented through the sand filter. A manual override switch is provided to momentarily open the supply dampers and start the supply fan to clear the building of smoke, as required.

Upon a significant increase in pressure in the roof exhaust tunnel (from loss of stack exhaust fans or pressurization from Building 221-F), controls on room air supply and ventilation systems will initiate four different responses at pre-set pressure levels. If the tunnel pressure increases to -1.0 in. (H₂O), an alarm will sound to indicate a departure from the normal pressure of -1.5 in. (H₂O). If the tunnel pressure increases further

to -0.7 in. (H₂O), all air supply fans to Building 235-F stop automatically. If the pressure subsequently increases to -0.5 in. (H₂O), Damper D3 (building exhaust header) and the vent valve from the cold-feed preparation area close automatically. If the pressure finally increases to -0.3 in. (H₂O), the building and the cells are isolated automatically by the closure of Damper D4 and the pressure control valves (554 PV1 and PV2 in Figure 10) located between the building and process exhaust headers. In addition, all inert gas supplies are closed and vented (outside Building 235-F) and the purge lines to the recirculating gas system (V1 and V3) remain closed regardless of internal cell pressure. Other pumps and fans (vacuum systems and constant air monitors) exhausting into the process exhaust duct are stopped. These actions prevent pressurization of the building and cells and possible air reversals that could release contamination into the unregulated areas of Building 235-F.

Manual resets are required to return the ventilation systems to their normal operating condition following an abnormal condition. Manual control is also provided external to the building for the air supply system (fan and Dampers D1 and D2) and the building exhaust (Damper D3).

3.3.2.2 *Filters*

Wherever possible, filters will be tested with DOP (dioctyl-phthalate) each time they are replaced to confirm that they are properly seated and meet minimum efficiency standards. Because of their physical location, the filters in the process exhaust line will be tested as a unit (99.95% minimum efficiency) instead of testing each filter separately. Also, it is not feasible to test any of the three filter stages in the inert gas recirculation systems, since the DOP would contaminate the gas purifiers. Alternate provisions for testing are believed to be unnecessary because 1) the redundancy of filter stages (3 total) between the cells and the gas purifiers provide adequate assurance against the spread of contamination, and 2) any discharge from the recirculating system passes through the process exhaust filters which are tested adequately.

In addition to DOP testing, sample taps are installed between filter stages and in ducts for the detection of contamination resulting from a malfunction in the filtration system. Sensors to detect pressure differentials across filter stages are also installed to indicate excessive dust loading or breakthrough conditions.

3.3.3 Detection and Alarm Systems

3.3.3.1 Fire Alarm and Suppression Systems

As previously indicated, all cells and cabinets having air atmosphere are equipped with fire detectors set to alarm at a preset temperature of 140°F. These detectors will initiate operation of the automatic *Halon-1301* fire suppression systems installed in the air enclosures. All rooms of the facility on both floors, including the fan-filter room on the second floor, are separately equipped with similar fire detection and automatic Halon suppression systems. These systems are the "total flooding" type designed to achieve a maximum extinguishing agent concentration of 7% in 14 sec. This rate meets the NFPA standards of 5% in 10 sec.²⁶

Control panels for the fire alarm and extinguishing systems are located in the operating room and the building lobby (south entrance). Fire alarm signals, both audible and visual, will announce in the operating room, the building lobby, and the F-Area fire station. Communicator lights on the operating room and lobby panels indicate the location of the fire. Each extinguishing system has two manual actuating switches to provide backup to the automatic controls. One switch is located in the operating room and the other in a corridor adjacent to the affected area. Emergency power to each control unit is provided by batteries.

To maintain negative pressures in hazardous areas and to vent smoke in case of fire, exhaust air flow will continue under all circumstances. However, the fire detectors will initiate the shutdown of supply ventilation equipment and the closing of main supply dampers. This action will assure *Halon 1301* concentrations which are sufficient to extinguish potential fires within the facility.

In addition to the fire suppression capability, the facility is protected from a general fire by its compartmentalization and its isolation from surrounding areas of Building 235-F. Isolation is provided by fire doors and fire walls capable of withstanding a 2-hr fire. The building and the PuFF Facility, as far as practicable, are constructed with noncombustible materials.

Except for the *Halon* system in the Plutonium Experimental Facility (PEF), no general fire suppression system exists in other areas of Building 235-F. There is, however, an existing building fire alarm system which sounds simultaneously in the control room, building lobby, and the F-Area firehouse. The F-Area firehouse is located approximately one-half mile from Building 235-F and is manned 24 hr a day, 7 days a week.

3.3.3.2 Contamination Detectors and Alarms

Twenty high-volume, rapid-response continuous air monitors (CAM) are installed within the PuFF Facility to monitor airborne contamination and initiate alarms when activity is high. The air sampling system audits airborne alpha contamination levels in 13 critical areas within rooms of the facility and in the room air exhaust ducts. The sensitivity of the CAM samplers is ~ 1 to 2 MPC/hr [i.e., $2-4 \times 10^{-12}$ $\mu\text{Ci } ^{238}\text{Pu}/(\text{cc})(\text{hr})$]. CAM alarm levels are conservatively set at slightly above background. In the event of an alarm, operating personnel will leave the area immediately and wait for Health Physics personnel to respond. Operating personnel will not re-enter the area without Health Physics concurrence.

Detectors and annunciators for the CAM system are located strategically throughout the facility. In the operating area, detection heads are located in the exhaust duct and at each end of the room; local alarms consist of a horn, flashing light, and annunciator lights on the control panel. In the east maintenance area, detection heads are located in the exhaust duct and six positions behind the cell line; local alarms consist of three flashing lights and horn in the area plus annunciator lights and horn in the north corridor. In the west maintenance area, detection heads are located in the exhaust duct and five positions behind the cell line; local alarms consist of two flashing lights and horn plus annunciator lights and horn in the north corridor. On the second floor, detectors are located in the exhaust ducts of the inert-gas purification room, east and west line service rooms, and the metallographic room; local alarms consist of two flashing lights and horn in each room plus annunciator lights on a panel in the south corridor. In addition, annunciator lights on the control panels in the operating room and the Health Physics room identify the area in which a high activity concentration occurs.

In addition to the CAM system, eleven air samplers (filter paper) are located in the air locks servicing the process rooms to audit potentially very low levels of contamination leaking from the operating and maintenance areas. Room and process exhausts to the sand filter and effluent from the stack are sampled continuously and counted periodically (once each shift). As described in Section 3.3.2.2, sample taps are located between filter stages and in exhaust ducts to detect contamination resulting from filter malfunction. Samples will be taken routinely from the recirculating water systems and analyzed for contamination.

3.3.3.3 Other Detectors and Alarms

The inert gas cells are equipped with sensors, coupled with alarms located on the control panels in the operating room, to detect pressure variations (Section 3.3.2) and high oxygen and moisture contents in the cells. No water detectors are included within the cells because there are no internal sources of water. However, a high-moisture alarm on the inert gas system would signal the presence of any water. Water detectors are installed in the service trenches beneath each cell line for the unlikely event of a rupture of a cooling water line to a furnace or storage well.

Low-flow sensors, with alarms, are installed in the closed-loop cooling water system servicing the hot press and in the coolant lines servicing the in-cell furnaces (Section 3.1.7.3). Low-flow alarms to furnaces also initiate automatic shutdown of the affected furnace. The low-flow alarm in the hot press loop is interlocked with shutoff valves. The low-flow detectors have been installed in the systems where a water leak would either constitute a hazardous condition (induction coil leak in the hot press), or where it could adversely affect the product (furnaces).

3.3.4 Hot Press Controls and Interlocks

Because of its potentially hazardous nature (Section 3.4.4.3), the vacuum hot press is equipped with controls, interlocks, and alarms to assure its safe operation and to mitigate the consequences of abnormal conditions. These controls and alarms are located in the operating room on the first floor.

- Microswitches are installed on glove port covers to provide an interlock to interrupt power to the hydraulic and vacuum systems when the covers are out of position.
- Water-flow switches are installed in water circuits for interlock protection.
- Automatic shutdown of the induction heating system will occur if cooling coil temperature or temperatures in the furnace chamber become excessive, or the chamber pressure too high.
- Ground and surge detection circuits will shut down the motor-generator set if there is an electrical malfunction.
- No power will be supplied to any part of the system unless water pressures are within limits.
- Overload relays for all motors and time delays on generators will operate until motor speed is attained.

- Vacuum valve switching is arranged so that inert gas cannot be admitted into the furnace unless vacuum valves are closed.

3.3.5 Administrative Controls

Administrative control is vital to the safety of operating personnel, protection of equipment, and continuity of production. The administrative control system⁷ to be used in the PuFF Facility has evolved from more than 20 years of operating experience of nuclear facilities at the Savannah River Plant. This system has been effectively applied to nuclear facilities which are substantially more complex than the PuFF Facility. The system features independent controls by four Du Pont organizations: 1) the Separations Department of the Manufacturing Division is responsible for operating the facility; 2) the Separations Technology Department of the Manufacturing Division provides technical assistance for the process; 3) the Technical Division is responsible for the basic process technology; and 4) the Health Physics Department of the Manufacturing Division provides guidelines for and technical assistance in contamination and radiation control.

The administrative controls are implemented through Technical Standards and Operating Procedures. The Technical Standards limit the range of process parameters affecting product quality and define critical limits for safe operation. Operating Procedures provide the detailed operating limits for all the production processes and include emergency procedures. The limits specified in the Operating Procedures are sufficiently lower than those given in the Technical Standards to provide an adequate margin of control. Nonstandard or unusual operations must be reviewed in advance under this administrative system, and appropriate approvals obtained before such operations are executed. Operations expected to be outside of limits established by the Technical Standards require a Test Authorization, which must be approved by the first three organizations listed above. Operations which deviate from the Technical Standards, Operating Procedures, or Test Authorizations are considered to be unusual incidents and are individually investigated to determine the cause and to establish methods to prevent similar incidents in the future.

Health Physics concurrence is required for all procedures and controls related to contamination control and radiation exposure. The design and operating objectives are to limit all radiation exposures to as low as practicable in accordance with ERDAM 0524.¹⁵ Radiation exposures and assessments of assimilation for individual operating personnel are monitored routinely and recorded to avoid exceeding the guide values established by the ERDA and Du Pont.^{14, 16}

The PuFF Facility will be operated as a regulated area. Protective clothing and radiation badges will be required at all times. Personnel will normally enter and exit through the personnel corridor. Plutonium oxide will be brought into the building through the service entrance. It will be transported along service corridors between the service entrance, the cell line, and the vault.

3.3.6 Quality Assurance

The systems within the PuFF Facility that are critical to safe operation and subject to the Savannah River Plant Quality Assurance Program²⁷ are listed in Table 7. Specific details will be found in the Quality Assurance Plan for Production Operations in the PuFF Facility (to be issued).

TABLE 7

Safety-Related Systems

Emergency power supply

Fire suppression system

Building and Maintenance Exhaust header dampers (D-3 and D-4)

Cell maintenance exhaust valves (e.g. Valve 484WV in Cell 1)

Over-temperature interlocks on furnaces and hot press

Hot press blow-down line

Hot press ground detector

Seal pots

3.4 SAFETY EVALUATION

Hazards associated with the operation of the PuFF Facility and the consequences of potential accidents that might be initiated by these hazards are evaluated in this section. The evaluation is made to ensure that adequate safety features are available to: 1) prevent unacceptable releases of radioactivity outside the PuFF Facility; 2) control releases within the PuFF Facility to levels that do not result in significant uptakes to personnel or serious loss of equipment; and 3) minimize other causes of injury to personnel or damage to equipment. The release of contamination to the environment during normal operations is assessed in Section 3.5.

3.4.1 Scope and Summary

The safety of the PuFF Facility is evaluated primarily in terms of the risk to operating and off-site personnel of inhaling particulate $^{238}\text{PuO}_2$ after loss of containment by the process enclosures. The fine $^{238}\text{PuO}_2$ powder to be processed in this facility is the principal hazard (Section 3.2), and containment of the powder is the primary design factor in ensuring safe operation. Risk is defined as the product of the probability of occurrence of a release and the consequences of the release expressed as a radiation dose (rem) to personnel.

The risks to off-site personnel from events with a range of probabilities and consequences are summarized in Table 8. Best estimates of off-site doses indicate that the guide value of 75 rem (liver is critical organ; Appendix B) would be exceeded only in the event of an airplane crash; the risk of an airplane crash is acceptably small, 2×10^{-6} rem/yr.

The probabilities for occurrence of release events were evaluated using Fault Tree Methodology.²⁸ The fault tree analysis identified the sequences of events that could lead to the release of radioactivity, as summarized by four of the top events considered: above normal stack releases, excess activity to the sand filter, release to streams, and unfiltered releases (such as breach of the building by tornado or airplane crash). Portions of these four trees are shown in Figures 13 through 16, respectively; the complete set of fault trees is given in Appendix A. Each fault tree was developed in considerable detail to identify critical components of the facility (individual valves, instruments, etc.). Reasonable values for the probabilities of the top events could

TABLE 8

Summary of Risks from PuFF Operations

Event Description	Frequency (Events/yr)	Consequences		
		Release to Environment (Ci/event)	Dose at Nearest ^a Plant Boundary (rem/event)	Risk at Nearest Plant Boundary (rem/yr)
Moderate Frequency				
Routine cell entries	80	1×10^{-9}	2×10^{-10}	2×10^{-8}
Sand filter releases	11	7×10^{-10}	9×10^{-11}	1×10^{-9}
Untoward stack occurrences	1	7×10^{-10}	9×10^{-11}	9×10^{-11}
Low Frequency				
Release through building exhaust	7×10^{-3}	8×10^{-7}	1×10^{-7}	1×10^{-9}
Fire	3×10^{-3}	8×10^{-7}	1×10^{-7}	3×10^{-10}
Design-basis earthquake	5×10^{-5}	4×10^{-1}	0.1	5×10^{-6}
HEPA filters bypassed	1×10^{-5}	3×10^{-6}	3×10^{-7}	3×10^{-12}
Very Low Frequency				
Design-basis tornado	1×10^{-7}	1000	20	2×10^{-6}
Airplane crash	2×10^{-8}	550	100	2×10^{-6}
Explosion in hot press	4×10^{-10}	2×10^{-1}	6×10^{-3}	2×10^{-12}

a. Meteorological conditions used to calculate downwind concentrations are those which give doses equal to or greater than those which would occur 95% of the time (95 percentile meteorology).

FIGURE 13. Fault Tree for Above Normal Stack Release

FIGURE 14. Fault Tree for Excess Activity to Sand Filter from PuFF

FIGURE 15. Fault Tree for Release to Streams

FIGURE 16. Fault Tree for Unfiltered Release

then be estimated from failure statistics for these components based on actual SRP experience in the separations areas²⁹ and nuclear and chemical industries in general.³⁰⁻³²

The consequences of these events, or doses to operating and off-site personnel, were calculated from postulated quantities of PuO₂ powder released by the accident. These quantities were based, as appropriate, on general SRP experience, experience in similar facilities at other sites, or an engineering judgement of the operations to be performed. As discussed in Appendix B, the properties of ball-milled powder were used for nearly all calculations because this powder is three times more hazardous than feed powder on a unit weight basis. The downwind concentrations of activity resulting from a release to the environment were obtained using the results of Cooper and Crawford.³³ Doses to personnel were estimated using the New Lung Model¹⁹ instead of the Original Lung Model of the International Committee on Radiation Protection³⁴ because the original model neglects the important effect of particle size on inhalation and retention. (See Appendix B for discussion of the two models.)

3.4.2 Occurrences of Expected Moderate Frequency

Experience in 200-Area canyon operations and in facilities similar to PuFF indicates that releases from routine cell entries, perturbation of the sand filter, or untoward stack occurrences will probably occur several times during a year of continuous operation (Table 8). These releases are expected to be very small, confined to local areas, and represent a minimal hazard to operating personnel. They will not significantly delay production nor unduly compromise the capital investment. Experience indicates that less than 1 μ Ci of activity will escape primary containment per event, and $\sim 1 \times 10^{-3}$ μ Ci will be released to the environment per event. The total release to the environment for all such events in a year of operation is expected to be 0.1 μ Ci, or about one-tenth of the predicted annual release from all process exhausts (Section 3.5.2).

3.4.2.1 Sand Filter Releases

Both the building and process exhausts from the PuFF Facility pass through the sand filter before being released to the environment from the stack. Experience with the sand filters in the 200 Areas shows that above-normal stack releases can occur when there is a perturbation of the air flow through the sand filter.²⁹ The overall frequency of these events, from 200-Area experience, is 1×10^{-4} /hr.

The frequency of these events may be increased to 1×10^{-3} /hr as a result of PuFF operations, if it is conservatively assumed that relatively major changes in air flow from the two PuFF exhaust systems would initiate similar above-normal stack releases (see Appendix A). Difficulties in the building exhaust are expected to be encountered more frequently than difficulties in the process exhaust, 1×10^{-3} /hr compared to 8×10^{-5} /hr. The principal contributors to building exhaust difficulties are inadvertent closure of Damper D-3 or either of the valves connecting the building exhaust header and the maintenance exhaust header, 3.5×10^{-4} /hr each. Closure of these dampers can occur from either personnel errors (2×10^{-4} /hr) or malfunctions of the valves themselves due to electrical or instrument air difficulties (1 to 5×10^{-5} /hr).

The sand filter efficiency for alpha activity varies between 99.5 to 99.9% during normal operation.²⁹ Assuming for the present analysis that a perturbation in air flow produces a one-hour burst of activity five times a normal amount based on an average exhaust activity of 2×10^{-3} $\mu\text{Ci}/\text{ft}^3$ (see Section 3.5.2), the design air flows, and a sand filter efficiency of 99.5%, approximately 7×10^{-4} μCi would be released to the environment per event. The resultant risk to an individual at the nearest plant boundary is negligible, 8×10^{-10} rem/yr.

3.4.2.2 Routine Cell Entries

The most frequently occurring hazard (three per week) will be the potential release of low levels of contamination during routine insertion and removal of material from the cells and glove boxes. These temporary, controlled breaches of primary containment are required for a variety of reasons including product removal; replacement of equipment, filters, gloves, or manipulators; metallographic sample removal; or liquid waste handling. These cell entries will be performed by trained personnel wearing protective clothing and respiratory equipment according to operating procedures. Depending on the assessed contamination levels associated with a particular operation, a secondary enclosure (plastic "hut") may be constructed around the immediate work area. Such enclosures will be exhausted through a HEPA filter by the off-gas exhaust that discharges to the maintenance exhaust header. Should any release occur, contamination will be confined to small areas that can be cleaned within a few hours by wet scrubbing and wiping. Any airborne contamination will be exhausted ultimately through the sand filter.

The greatest hazard from these operations is the potential ingestion or inhalation of particulate $^{238}\text{PuO}_2$ by operating personnel. Extensive experience in similar facilities in both the Plant and the Laboratory indicates that <5% of such operations result in a measurable uptake by the workers involved in the cell entry. Personnel in adjacent areas of the building are protected by the Constant Air Monitor (CAM) system that will detect airborne contamination and alarm at conservatively low levels. Consequently, the expected frequency for an uptake by operating personnel during such operations is $9.0 \times 10^{-4}/\text{hr}$ and the frequency for an undetected release is $2 \times 10^{-6}/\text{hr}$ ($2 \times 10^{-3}/\text{demand}$ for malfunction of the CAM system).

The consequence to operating personnel is assumed to correspond to a nasal contamination of 250 dis/min, which is the median value for such incidents reported in the two 200 Areas. Correcting this value for the fraction deposited in parts of the body during inhalation,¹⁸ and assuming 4-hr exposure time, the consequence is 3×10^{-6} rem/event and the risk is 2×10^{-5} rem/yr. No individual has received a maximum uptake since plant startup.

The consequence to offsite personnel is negligible from such incidents, 2×10^{-10} rem/event. This value was calculated from the median airborne contamination observed during similar events and was corrected for air flow, sand filtration, and meteorological dispersion. Assuming that 80 events/yr (half of the anticipated cell entries) result in the median release, the risk is 2×10^{-8} rem/yr.

3.4.2.3 *Untoward Stack Occurrences*

Experience in the 200 Areas shows that above-normal stack releases, similar to those resulting from perturbations of air flow through the sand filter, can happen as a result of various events in the stack itself. These releases have occurred at a frequency of $7 \times 10^{-5}/\text{hr}$ as a result of spalling of particulate matter, deterioration from acid attack and natural phenomenon, stack flushing, and unplugging a sampler port. These events could also cause release of $^{238}\text{PuO}_2$ because PuFF exhausts through the stack. Analysis of stack emissions indicates the consequences of these occurrences is the same as for air flow perturbations (7×10^{-4} $\mu\text{Ci}/\text{event}$, see Section 3.4.2.1). Consequently, the risk to offsite personnel is also negligible, 9×10^{-11} rem/yr.

3.4.3 Occurrences of Expected Low Frequency

Occurrences such as release of activity through the building exhaust (no HEPA filtration), design-basis earthquakes, or HEPA filter difficulties are expected to occur at low frequencies (once in 10 yr or longer), but may result in significant releases of activity to the environment, Table 8. In most incidents the barriers and ventilation systems in the facility are considered adequate to retain the contamination, with only a few μCi being discharged to the environment. However, in the case of an earthquake, the release may be as high as 0.4 Ci, which corresponds to a 70-yr integrated liver dose at the plant boundary of 0.1 rem (guide value is 75 rem).

The alarms provided and established procedures will minimize the consequences to the operating personnel from these events. However, suspension of operations for decontamination of affected areas could result for extended periods of time (several weeks to several months). The area CAM's would detect such releases and signal the operating personnel. Operator training and emergency procedures will minimize the likelihood of a serious uptake of contamination by facility personnel. The consequences to onsite personnel outside the facility will be minimal.

3.4.3.1 Release of Activity Through Building Exhaust

Experience in the 200 Areas shows that above-normal releases of activity to the environment occur when there is an increase of activity in the input to the sand filter. High activity inputs from PuFF could occur when activity is introduced into the building exhaust header by either of the following four events (see Appendix A):

- Difficulties in maintenance and process exhaust ($1 \times 10^{-5}/\text{hr}$)
- Release from cells (primary containment breached) ($4.6 \times 10^{-6}/\text{hr}$)
- Cell-line annuli become contaminated ($1.2 \times 10^{-7}/\text{hr}$)
- Seal pot relieves pressure buildup in Cell 9 ($2 \times 10^{-9}/\text{hr}$)

As shown by the fault trees in Appendix A, release of contamination from cells can occur from various sequences of events, including cell pressurization, loss of a glove by mechanical rupture or fire, loss of a cell window, or flooding of the cell annuli. Table 9 summarizes the frequencies of occurrence for typical events.

TABLE 9

Typical Events Leading to Releases Inside Building^a

<i>Description of Event</i>	<i>Frequency^b (Events/hr)</i>
Direct releases	
Ruptured glove	1×10^{-7}
Broken window	5×10^{-9}
Cell pressurized	6×10^{-7}
Rupture of ventilation ducts	2×10^{-9}
Rupture of liquid transfer piping	5×10^{-15c}
Contributing events	
Fire in cell	3×10^{-7}
Sources of pressure	6×10^{-4}
Cell evacuated	1×10^{-8}
Insufficient exhaust	7×10^{-4}
Seal pot fails to relieve pressure	2×10^{-4}
Fire in cell annulus	9×10^{-4}

a. See Fault Trees in Appendix A for details.

b. Maximum frequency; some slight differences exist between cells because of their construction.

c. Applies to Cells 7 and 8 only.

Since each of these four events would produce an alarm, the consequences could be mitigated by closing Damper D-3 to block the building exhaust header and force flow through the HEPA filters in the process exhaust. If Damper D-4 is closed, the building would become isolated by closure of Damper D-3. This action should not present an immediate hazard to personnel inside the building; several hours would be available to correct the fault in Damper D-4 before pressure in the cells would come to equilibrium with the surrounding rooms, and activity could escape. (Design leak rate of cells is 0.02 vol %/hr at 2 in. (H₂O)). Additional protection is provided by the filters on the air inlets to the cell-line annuli and Cells 7 through 9. Since the expected frequency for failure to close Damper D-3 is 5×10^{-2} /demand, the frequency for a high sand filter input through the building exhaust is 8×10^{-7} /hr.

Of the four events leading to a release through the building exhaust, release of contamination from the cells results in the largest consequence to both offsite or operating personnel. The consequence from the majority of cell operations can be estimated by assuming that the airborne activity in the cell is 0.02 Ci [based on 4000 dis/(min)(ft³) in exhaust from HEPA filtered enclosures, see Section 3.5.2] and that the release event corresponds to a leak of 0.2 vol %/hr (10 times normal rate) for 4 hr. Under these conditions 1.5×10^{-4} Ci would be released inside the building from a typical cell (300 ft³). Assuming further that all of the activity is transported through the building exhaust to the sand filter and released to the environment, an individual at the plant boundary would receive 1×10^{-7} rem/event. Consequently, the risk to offsite personnel is 1×10^{-9} rem/yr.

Evaluation of the consequence to operating personnel assumes that the CAM is inoperative and that the effluent from the cell is diluted by air flow and settling before it is inhaled by the operator (see Appendix B). The resulting consequence is an intake of 2.5 rem/event, and the risk is 1×10^{-2} rem/yr.

The risk from handling the fine powders in Cell 1 is three orders of magnitude higher. These events can be represented by assuming that the release corresponds to the fraction of an 85-g batch of ball-milled powder that is sufficiently small to become airborne. As indicated by the tests described in Appendix B, this fraction is ~0.255 g, or 3.0 Ci. The consequences to offsite personnel would be 2×10^{-3} rem/event. However, the risk is only 4×10^{-7} rem/yr because the frequency of occurrence is reduced by the fraction of time that the powder is exposed in the cell (0.03).

3.4.3.2 Fires

Although fire is one of the mechanisms included in the analysis of release of contamination through the building exhaust (Section 3.4.3.1), the risk from fire is considered separately in this section because of the specific concern for fires in plutonium-handling facilities.

The occurrence and consequence of a fire in PuFF are minimized by the use of inert-gas atmospheres inside most of the cells and the extensive *Halon* fire suppression systems in the air-atmosphere cells and rooms of the facility (Section 3.3.3.1). A direct release of activity to the environment by a fire is not credible because of the building construction (Section 3.1.2). Any release inside the building would be exhausted through the sand filter, which, because of its remote location and construction, would not be damaged by the fire or affected by the smoke

loading (Section 3.1.4). As indicated in Appendix A, the expected frequency for fire in the cells or adjacent rooms is between 3×10^{-9} and 3×10^{-7} /hr (depending on location).

The consequences were evaluated by assuming releases similar to those used in evaluating release through the building exhaust (Section 3.4.3.1). For the majority of operations the release would correspond to a fraction of the activity normally exhausted from the cell, or 1.5×10^{-4} Ci. Since this activity would be transported to the sand filter before discharge to the environment, an individual at the plant boundary would receive 1×10^{-7} rem/event. Consequently, the risk would be 3×10^{-10} rem/yr.

The risk from handling the fine ball-milled powder in Cell 1 is slightly higher. If a fire were to occur during these operations, the consequence would be much higher, 6×10^{-4} rem/event for an individual at the plant boundary, but the risk would only be 5×10^{-8} rem/yr because the frequency is reduced by the fraction of the time that the powder is exposed in the cell (0.03).

3.4.3.3 Design Basis Earthquake (DBE)

No significant offsite release is expected to occur from the PuFF Facility as a result of a Design Basis (or Maximum Shutdown) Earthquake. Building 235-F is a massive Class I structure similar in construction, but smaller than the reactor buildings at SRP. Analyses have shown that the reactor building can resist a DBE with a horizontal acceleration of 0.2 g.^{35,36} Structural analyses to determine the effects of the DBE on Building 235-F, including the PuFF Facility and its systems, have not been performed. However, the information developed in earthquake studies and structural analyses of reactor buildings and equipment^{35,36} indicates that a DBE or smaller earthquake would not result in a catastrophic release of activity from the process enclosures.

The sand filter and connecting roof duct and underground exhaust air tunnel from Building 235-F are designed and constructed to withstand a DBE.^{9,10} Stiffening members have been applied to the containment cells and cabinets to minimize relative seismic motion between the building and the enclosures. The ventilation systems servicing the PuFF Facility and parts of Building 235-F (especially the room air exhaust and process exhaust) have not been specifically designed to withstand the horizontal and vertical loadings associated with a DBE. There are no plans to analyze the response of these systems to a DBE as required by the General Design Criteria.²

Studies of the geology of the region, the geologic formation underlying the area, and the history of tectonic activity show that the plant is located in a region where the probability of an earthquake occurring with a magnitude of the DBE or greater is estimated to be $1.5 \times 10^{-3}/\text{yr}$.³⁷ This probability is based upon analysis of the available earthquake data for the Georgia-South Carolina Seismic Region. Taking into account the fraction of time powder is exposed in a cell, the probability for the postulated accident is $5 \times 10^{-5}/\text{yr}$.

Although no significant releases are expected from a DBE, the following accident sequence is postulated to assess upper-limit consequences:

- The DBE occurs during the processing of either ball-milled or feed powders in Cell 1 and causes the release of 4 g of powder. [As can be seen from Appendix B, this amount is 10 to 15 times higher than dispersible amounts of feed (0.5 g) or ball-milled (0.26 g) powders.]
- The barriers of the facility remain intact, and the room air exhaust continues to operate.
- The sand filter suffers minor damage, retaining an efficiency of only 99%.
- The upper two-thirds of the 61-m stack is lost, so that the release to the atmosphere occurs at 20 m.

The resulting lifetime dose to an individual at the site boundary would be about 0.1 rem (75 rem guideline value⁶), assuming 95 percentile meteorology prevails during the accident. If it is further assumed that a crack is opened in the roof duct and 10% of the exhausted activity escapes through it (90% goes to the sand filter and stack), the dose at the site boundary would be about 1 rem.

3.4.3.4 HEPA Filters Bypassed

Excessive activity in the input to the sand filter would also result if the HEPA filters in the process exhaust were bypassed. Based on experience, the most probable cause of this event is improper installation during a scheduled filter change, or a frequency of $1 \times 10^{-9}/\text{hr}$.

The upper limit consequence of this event assumes no HEPA filtration. Assuming the exhaust from each cell and box contains 4000 d/m-ft³,^{38,39} and the design flow rates, 2.8×10^{-6}

Ci would be released per event if 10 hr were required to replace the filters. The corresponding risk to offsite personnel is negligible, 3×10^{-12} rem/yr.

3.4.4 Occurrences of Expected Very Low Frequency

Although accidents such as the design-basis tornado, airplane crash, and hot press explosion are expected to occur with very low frequencies, 10^{-7} /yr or less, large amounts of radioactivity could be released to the environment, Table 8. The tornado and airplane crash have the potential for direct release to the atmosphere. The release from the hot press explosion (considered to be the Maximum Process Accident) occurs within the building and the consequence to the environment is reduced by the sand filter. Results of the analyses indicate that the resulting offsite doses exceed the guideline value only for an airplane crash.

3.4.4.1 Design-Basis Tornado (DBT)

The PuFF Facility was originally expected to be installed in Building 235-F in a manner that would resist the Design Basis Tornado,* as required by the General Design Criteria.² However, subsequent analyses⁴⁰⁻⁴² indicate that the facility as designed does not meet all of the requirements of the criteria. The following exceptions were found:

- Tensile cracking of the 8-in. reinforced concrete roof slab is likely for a 3-psi negative pressure gradient, although the roof panel as a whole should remain intact.
- Exterior doors and interior walls of the facility would fail well below the 3-psi design pressure.
- Breach of building containment at the east wall penetrations for supply air ducts and sanitary openings is possible.
- A differential pressure of 3 psi would likely breach the cells and cabinets, probably through the glove ports and/or window seals.

* The DBT defined in the General Design Criteria² corresponds to a class F6 tornado⁴³ (3-psi negative pressure gradient and up to 360 mph tornadic winds).

The effects of certain tornado-generated missiles, as proposed in Reference 44 were also evaluated.⁴² The results indicate that penetration of the roof slab by Type 1⁴⁴ missiles would occur; however, breaching of the first floor confinement barriers would be unlikely for the missiles considered.

Although the DBT would probably cause the breaching of the confinement barriers (e.g., failed doors, roof cracks, window cracking, and glove port leaks), gross failure of the massive building structure or process enclosures should not occur. Very likely some fraction of the exposed $^{238}\text{PuO}_2$ powder in Cell 1 would escape through failed window seals or glove ports and be forced through openings in the building into the vortex of the tornado. The activity would be lifted by the vortex and either carried into the accompanying thunder cloud or expelled at a lower altitude.⁴⁵ No tested dispersion models exist for transport and diffusion during or immediately following a tornado. However, these two alternatives were examined to estimate the offsite doses that might result from the dispersion of $^{238}\text{PuO}_2$ by a tornado.

Based on tornado statistics for a 21-yr period in the Georgia-South Carolina region,⁴⁶ the probability of a tornado of the F3 class or greater striking Building 235-F is about 1.4×10^{-4} per year. Existing data reveal that no tornadoes of the F5 or F6 (DBT) class have occurred in this two-state region. The probability of an F6 class tornado (DBT) occurring within the eastern section of the United States (Region 1 of the General Design Criteria) has been estimated to be $\sim 10^{-7}$ per year.⁴⁶

The ranges of consequences to onsite and offsite personnel, assuming the models of Reference 45, are less than the guideline value of 75 rem, as shown in Figure 17. These values assume that 85 g of ball-milled powder are released from PuFF and subsequently expelled by the tornado vortex at heights of 75 to 400 m above ground with wind speeds of 7.5 to 22.5 m/sec. These meteorological conditions represent the worst expected cases; if the quantity released remains within the cloud for the lifetime of the associated thunderstorm and then diffusion occurs, the resulting doses are up to 100 times smaller than indicated in Figure 17. Assuming the worst conditions the consequence to an individual at the northeast plant boundary (expected direction of tornado travel) is 6 rem/event and increases to only 20 rem/event at the nearest plant boundary. The resulting risk is 2×10^{-6} rem/event.

The consequences to operating personnel, both radiological and physical, are obviously expected to be very severe. However, the potential early warning of a tornado provided by both National and plant weather monitoring stations, and the extensive training of personnel in emergency shutdown procedures, will minimize the consequences to both operating and offsite personnel.

FIGURE 17. Integrated Doses for Airplane Crash and Tornadoes

3.4.4.2 Airplane Crash

This very damaging, but highly improbable, accident is postulated to evaluate the limiting potential consequences of conceivable accidents that might render protective engineered safety features ineffective and breach all containment barriers.

The accident assumed is the direct hit of Building 235-F by an airplane having a 10,000-lb fuel load. Based on the annual expected number of overflights*, the remoteness of the plant from airfields, and U. S. statistics on crash probabilities, the probability of an aircraft crash on the plantsite is $2.2 \times 10^{-5}/(\text{yr-mi}^2)$.⁴⁷ Taking the target area of the building as $8 \times 10^{-4} \text{ mi}^2$, the probability of a direct hit on Building 235-F is only $1.8 \times 10^{-8}/\text{yr}$.

To estimate maximum offsite doses, the aircraft is assumed to penetrate both the reinforced concrete roof slab and the second floor before the fuel tank ignites and demolishes Cell 1. Approximately 50 g of $^{238}\text{PuO}_2$ (assumed to be ball-milled powder, see Appendix B) is assumed to escape the building and be lifted to the top of the resulting 35-m fireball.⁴⁹ To calculate ground-level concentrations, the radioactive particulates are assumed to be dispersed into the atmosphere from a point source at an effective height of 45 m (includes 10 m building height). The resulting offsite integrated liver doses are shown in Figure 17. Although these doses exceed by a wide margin the guideline value of 75 rem,^{2,6} the small probability for this accident makes the risk small, $2 \times 10^{-6} \text{ rem/yr}$.

3.4.4.3 Explosion in Hot Press

An explosion in the hot press is considered the Maximum Process Accident because it has the potential for the largest release of $^{238}\text{PuO}_2$ inside the facility (up to 25 g in the postulated event). However, the engineered safety features and extensive interlocks and controls (Section 3.3.4) combine to give an expected small frequency for the accident ($10^{-10}/\text{yr}$).

The vacuum furnace chamber surrounding the hot press die is the primary containment for the hot press operation. It consists of two thicknesses of 3/16-in. stainless steel enclosing 4-in. of water shielding with penetrations for induction power, viewing windows, vacuum lines, and glove ports with evacuable covers.

* Estimated flights from Bush Field, Augusta, Georgia, assuming no restrictions on air space over plantsite.⁴⁸

Design of the chamber walls and the use of window shields and glove port covers during operation make penetration by internally generated missiles (die fragments) almost impossible.

However, a rupture of the hot press induction coil with the concomitant spraying of water on the hot graphite dies might cause sufficient steam generation to pressurize the hot press chamber and cause sudden loss of containment. Such a failure could be caused by arcing or loss of coolant flow, but is very unlikely because the induction coil is made of heavy-gage copper and is similar in design to those developed and used at LASL to minimize this hazard. The hot press interlocks are designed to prevent high temperatures and arcing, which could initiate a coil rupture. A blow-down line permits the steam generated to be released through a pressure-relief system into the adjacent vacuum pump cabinet and the Process Exhaust Header. This pressure relief will significantly reduce the driving force for this accident and cause most of the contamination to be exhausted through the Process Exhaust Header to two HEPA filters and the sand filter before release to the environment. As indicated in Appendix A, the expected frequency for an explosion, based in this sequence of events, is 4×10^{-14} /hr.

To evaluate the consequences, the explosion is assumed to occur at the beginning of the pressing operation and ejects 25 g of oxide (10% of the die contents) into the maintenance room. Although the oxide is composed of relatively nondispersable shards or sphere pieces it is further assumed that the impact pulverizes these shards so that 10% of that ejected becomes airborne and dispersed similar to feed powder (Appendix B). An operator in the room realizes the accident, either visually or from the CAM alarm, but breathes the contaminated air for the minute required to leave the room. The consequence is 3 rem/event, but the risk is only 1×10^{-9} rem/yr.

Since the airborne activity in the maintenance room would be exhausted through the building exhaust to the sand filter, the consequence to off-site personnel would result from the release of 0.15 Ci to the environment, and at the nearest plant boundary the risk is 2×10^{-12} rem/yr.

3.4.5 Other Untoward Events

The Fault Tree Analysis described in Appendix A provides the basis for evaluating the probabilities of other events that would not directly result in the release of activity but could result in either a radiation or physical hazard to operating personnel or a loss of production. Although the consequences and corresponding risks were not evaluated quantitatively, the very low expected frequency indicates that these risks would be acceptably small. In most cases these events result only from the simultaneous occurrence of two other events. Typical events in this category include the following:

- Fire in operating, service or maintenance rooms — 6×10^{-9} /hr. Requires occurrence of fire (3×10^{-4} /hr, based on 200-Area experience) and simultaneous failure of both primary and backup Halon systems (2×10^{-5} /demand).
- Loss of electrical power to critical equipment — 2×10^{-5} /hr. Requires loss of normal power (1×10^{-4} /hr) and loss of emergency power (4×10^{-2} /demand), or faults in wiring (1×10^{-5} /hr).
- High concentration of inert gas in operating or service rooms — 3×10^{-9} /hr. Requires rupture of piping (1×10^{-6} /hr based on 1×10^{-9} /hr-ft given in Reference 30) and either inattention by operating personnel (3×10^{-3} /demand) or an instrument malfunction (3×10^{-4} /demand).
- Natural phenomenon — 6×10^{-4} /hr. Extreme weather conditions can cause a variety of fault conditions such as localized flooding from heavy rains or stuck valves from low temperatures.
- Loss of cooling water — 1×10^{-4} /hr. Requires loss of supply to building (1×10^{-6} /hr, based on 200-Area experience) or difficulties within the facility (1×10^{-4} /hr).
- High radiation levels — 3×10^{-8} /hr. Requires procedural violations by both operating personnel (1×10^{-5} /hr) and supervision (3×10^{-3} /demand), or rupture of shielding tank (1×10^{-14} /hr) and concurrent operator inattention.
- Criticality (cell or vault operations) — 1×10^{-10} /hr. Requires procedural violations by three organizations, operating personnel, Health Physics personnel, and supervision.
- Combustible or explosive mixture in 4% H₂-Ar supply — 7×10^{-7} /hr. Requires error by vendor (assumed to be 1×10^{-5} /hr) and malfunction of analyzer (7×10^{-2} /demand) or operator inattention to alarm (3×10^{-3} /demand).

3.5 Environmental Impact of Normal Operations

3.5.1 General Features

The only significant incremental environmental impact of anticipated operations in the PuFF Facility are the emissions of minute quantities of ^{238}Pu and ^{239}Pu from the 61-m F-Area sand filter stack and the relatively small volumes of solid and liquid waste removed from the building. These features are described below and summarized in Table 10.

The environmental impact described in the Environmental Statement³ for the PuFF Facility is adhered to with minor exceptions which are described in Appendix D. There are no significant chemical or thermal emissions from the building. The building will continue to be isolated in the 200-F exclusion area encompassing a 148-acre tract separated from the surrounding pine forests by a chain link fence. Increased traffic and material transport will be accommodated by existing roads and parking areas.

TABLE 10

Anticipated Environmental Effluents from PuFF Facility

<i>Effluent</i>	<i>Amount/year</i>	^{238}Pu , Ci/yr	<i>Disposition</i>
Economically non-recoverable solid wastes	25 drums	800	Burial Ground (retrievable)
Low level liquid wastes	100 gal	.01	F-Area Waste-Handling
Sanitary waste	-	0	F-Area Sanitary Waste Treatment
Filtered gases			
Air	$2 \times 10^{10} \text{ ft}^3$	5×10^{-8}	Sand Filter Stack
Argon	$5 \times 10^6 \text{ ft}^3$		
Helium	$1 \times 10^6 \text{ ft}^3$		
4% H ₂ /A	$5 \times 10^4 \text{ ft}^3$		
Oxygen 16	$1 \times 10^3 \text{ ft}^3$		

Recoverable Waste from PuFF Facility

Solids			
"dry" recycle	50 packages	4,000	HB Recovery
"wet" recycle	15 packages	50,000	HB Recovery
High-Level Liquids	100 gal	150	HB Recovery

Operations in the PuFF Facility will have no adverse impact on the rest of the presently existing manufacturing activities in the 200-F Area. The room air and process gases exhausted from the facility will undergo final filtration in the underground sand filter which also serves several other production operations in the area. If economically recoverable, liquid and solid wastes from PuFF operations will be processed in H-Area B-Line; otherwise they will be placed in retrievable containers and sent to the SRP burial ground. Plutonium-238 oxide feed will be produced, stored, and transported from the H-Area B-Line as is presently done. Products from the PuFF Facility will be stored in Building 235-F until shipped offsite.

3.5.2 Stack Releases

Routine operations in the process cells and wing cabinet will release activity to the atmosphere at rates several orders of magnitude lower than the 5 mCi/yr predicted in the Environmental Statement.³ The reason for the decrease in predicted release rate is the design change made from purged to recirculating inert gas ventilation for enclosures having powder and shard operations.

During normal operations, cover gases from cells and wing cabinets are given either three (purged) or five (recirculated) stages of HEPA filtration plus one stage of sand filtration before stack discharge to the environment (see Figure 10, Section 3.1.7.1). The double HEPA filters in the recirculators and those in the process exhaust duct are too closely spaced to be adequately tested individually; DOP tests will only be performed on the double-stage unit. Therefore, credit is taken for only a single-stage of filtration for each multiple-stage unit in estimating stack emissions. The following conservative assumptions were made in calculating routine activity releases to the environment:

- The $^{238}\text{PuO}_2$ activity level in exhaust gases after one stage of filtration (99.997%) is taken to be $4000 \alpha \text{ dis}/(\text{min}\cdot\text{ft}^3)$. (This is the maximum value of the range of cabinet exhaust activities measured at LASL³⁸ and SRP.³⁹)
- Only the recirculating argon cells and cabinets in which powder and shard operations are performed contribute significantly to the released activity.
- The expected bleed-off exhaust rate of recirculating argon and helium is $10 \text{ ft}^3/\text{min}$.
- HEPA filter efficiency (double unit) is 99.95%; sand filter is 99.5% (Appendix A).

The results of the calculation indicate that, for the above filter efficiencies about 0.05 $\mu\text{Ci}/\text{yr}$ of $^{238}\text{PuO}_2$ contamination will be discharged from the stack during normal operations within the PuFF Facility. This release corresponds to a dose of 1×10^{-7} rem/yr to an individual at the nearest plant boundary.

Periodic maintenance operations within the cells, for which an individual cell is purged to the process exhaust duct, will not affect the above result significantly. Assuming that one cell or another is being purged 10% of the time, the release would be increased to 0.06 $\mu\text{Ci}/\text{yr}$.

3.5.3 Solid Wastes

All dry wastes from the PuFF Facility are treated as if they contained ^{238}Pu and are disposed of according to normal procedures.⁵⁰ Solid wastes from operations in the PuFF Facility include: box gloves, manipulator boots, HEPA filters, tools, small pieces of equipment, wipes, die parts, filter beds, metallographic sludge, metal waste cans, metal product containers, detergent powders, metallographic mounts, grinding and polishing papers, plastic bottles, and milling balls. These are bagged and sealed into non-flammable polyvinyl chloride bags attached to the back of the cells or wing cabinets in the maintenance areas. Based on radiation measurements (gamma-pulse height analysis), a judgment is made whether there is a recoverable amount of ^{238}Pu present. Recoverable waste is packaged and sent to H-Area B-Line for recovery. Other waste is sent to the burial ground in accordance with AEC Immediate Action Directive (IAD 0511-21).

Nonrecoverable waste containing less than 10 nCi/g will be packaged in cardboard boxes for burial in earthen trenches. Waste having activities greater than this will be placed in designated containers (steel drums). The sealed drum is then sent to the burial ground and placed in retrievable storage. Most of the solid waste volume will be disposed of in this manner. This waste is estimated to contain about 50 g (~ 800 Ci) of $^{238}\text{Pu}/\text{yr}$.

The drums are stored above grade within a specially constructed earthen mound.⁵¹ The drums are placed on a concrete pad that is sloped and ribbed to minimize exposure of the drums to standing water. Drainage ditches are provided to prevent flooding during a heavy rain. Drums containing >0.5 Ci of waste are sealed in a concrete culvert for storage. The containers are stored vertically and one-high beneath at least 4 ft of soil. The location and nature of the waste is documented for future recovery. The area surrounding the burial ground is continuously monitored.

The risk from long-term storage of solid wastes from PuFF has not been included in this Safety Analysis Report, but will be in the systems analysis of Burial Ground Operation (DPSTSY-200-6) and the 200-Area Safety Analysis Report scheduled for completion in December 1978.

Recoverable ^{238}Pu (reject fuel pieces, oxide pieces from the metallographic line, dust sweepings, etc.) will normally be placed in Type 2R or HB-Line primary containers before removal from the cabinet. The Type 2R containers will be bagged out, and the HB-Line containers will be removed through the breechlock (Wing Cabinet 1) into the shipping cask in which oxide feed was originally sent from HB-Line. These containers will be monitored, labeled, and documented before being sent to HB-Line for recovery. It is anticipated that about 4000 Ci of solid ^{238}Pu and 150 Ci as high-level liquid waste per year will be recycled in this manner. If reject and analytical spheres require recovery by dissolution ("wet" recycle), rather than the currently planned mechanical ("dry") recycle, then the amount could be increased by about 50,000 Ci/yr.

The risk from recovery of the 54,150 Ci/yr (max) in HB-Line has not been included in this Safety Analysis Report, but will be included in the HB-Line Systems Analysis and the 200-Area Safety Analysis Report scheduled for completion in December 1978.

3.5.4 Liquid Wastes

Liquid volumes exposed to contamination in the PuFF Facility will be small. Liquid waste will consist of: decontamination acids and detergents, metallographic etchants, recycled process water from metallographic operations, and bottled pump oils. Disposition of these wastes will be covered by specific operating procedures, written and approved in accordance with Reference 7. All transfers will be monitored and documented.

The facilities and procedures for bottling liquid wastes generated in the process enclosures and the metallographic facility were described in Section 3.1.7.6. Waste liquids in polyethylene bottles are placed into stainless steel drums containing vermiculite and transferred to either HB-Recovery, if recoverable quantities of ^{238}Pu are contained, or to the 200-Area radioactive waste handling system for transfer to the underground waste tanks.

The volume of the liquid wastes generated per year will be about 200 gal and will contain approximately 10 g of ^{238}Pu (~150 Ci).

The risk from long-term storage of these liquid wastes is not included in this Safety Analysis Report, but will be included in the safety analysis of the Radioactive Waste Handling and Storage Facilities scheduled for completion in September 1977.

3.5.5 Building and Process Services

Building services have little environmental impact. Domestic and cooling water and steam will be supplied to the building. Chilled water is provided for air conditioners, heat exchangers, and three closed-loop water systems. Steam condensate and domestic water drain to the building sanitary system which is pumped to the existing 200-Area sanitary sewer system. The existing facilities process the sanitary wastes produced and provide monitoring. No activity is expected to be released through this system.

Water cooling for process equipment is provided by three closed-loop recirculating water systems entirely contained within the facility (see Section 3.1.7.3 for description). Main cooling water for these closed-loop systems is supplied by and returned to the 200-Area cooling tower. All systems are routinely monitored for α -activity. No contamination is expected to enter the cooling tower water system.

Additional air conditioning, refrigeration equipment, air intake fans, and ducts were added to Building 235-F to service the PuFF Facility. A new exhaust duct, 614 ft long, is installed on top of the building and underground to the sand filter to exhaust all process enclosures and rooms of the facility. The air from clean sections of the building is exhausted without filtration through vents on top of the building.

A new unenclosed substation east of Building 235-F supplies the normal electrical power requirements of the PuFF Facility. The new emergency diesel for critical equipment within PuFF Facility is located in a tornado-proof concrete structure adjacent to the building.

Liquid argon tanks and helium, 4% hydrogen in argon, and $^{16}\text{O}_2$ gas cylinders are installed outside Building 235-F on a pad adjacent to the north wall.

All of these systems were installed in compliance with the Du Pont engineering standards and ERDA and Du Pont safety requirements.

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5. APPENDIX A — FAULT TREE ANALYSIS

Fault Tree Analysis (FTA) is a technique that organizes systematically and represents pictorially the events that can lead to a specified, undesired event.²⁸ The objectives of the analysis are: 1) to identify by deductive reasoning all possible modes by which the undesired event could occur; 2) to provide a clear and demonstrable record of the analytical reasoning; and 3) to provide a basis for design and procedural alternatives.

5.1 Fault Tree Construction

The basic part of the analysis is the construction of the fault tree, which is the graphical representation of the Boolean logic that relates the occurrence of the undesired, or top, event to a series of primary failures. These primary failures can be either events such as the malfunctions of a component in the system (valve stuck, pipe leaks) or errors by operating personnel (pushed wrong button, ignored operating procedure). The completed tree identifies the events that individually can cause the top event (connected by an OR gate), as well as the events that must occur simultaneously to cause the top event (connected by an AND gate).

The symbols used in the construction of the fault tree, shown in Figure 18, fall into three categories; event symbols, logic gates, and transfer symbols. The rectangle identifies an event that results from the combination of one or more basic events through a logic gate. The circle identifies an independent failure of a component in the system; these events are the basic events that ultimately lead to the top event. The diamond identifies an independent event that is not developed further in the tree because either sufficient information is available from other sources, the event has a low probability of occurrence, or there is insufficient information available.

Two basic logic gates are used; the AND gate and the OR gate. The AND gate provides an output only if all input events occur simultaneously. The OR gate provides an output if one or more of the input events occur. Occasionally an INHIBIT gate is used; identified by a hexagon. In this case the input produces the output only if a conditional input, identified by an oval, is also satisfied.

EVENT SYMBOLS

RECTANGLE - A fault event resulting from the combination of more basic events acting through a logic gate.

CIRCLE - An independent failure of a system component.

DIAMOND - A fault event not developed further to its basic causes.

LOGIC GATES

AND GATE - All input events must occur simultaneously to produce output event.

OR GATE - One or more input events must occur to produce output event.

INHIBIT GATE - Output is produced only if condition (stated in oval) is met.

TRANSFER SYMBOLS

TRANSFER IN - Identifies Branch A of the complete fault tree.

TRANSFER OUT - Indicates fault tree is continued on Branch B.

FIGURE 18. Fault Tree Symbols

Transfers between branches of the fault tree are identified by a triangle. A triangle connected from its side to a rectangle identifies that branch of the tree by the number or letter within the triangle. A rectangle connected to the apex of the triangle indicates a transfer to that part of the tree identified by the number or letter within the triangle.

5.2 Fault Tree Evaluation

The fault tree can be analyzed both qualitatively and quantitatively. Qualitative evaluation consists of determining the minimal cut sets. A minimal cut set is the smallest set of failures that must occur in order for the top event to occur. A complete list of minimal cut sets identifies all of the failure modes for the system and therefore identifies the weakest link in the system. Frequently common modes of failure can be identified from the analysis, but the fault tree does not inherently identify such modes.

The fault tree is evaluated quantitatively by combining the failure rate data for the primary events (circles and diamonds) to give the probability of occurrence of the top event. Failure rate data are usually obtained from experience with components similar to those used in the system being analyzed. If such data are not available then engineering judgment must be used. The probability of occurrence of an event that is the output of an AND gate is the product of the probabilities of all the input events. The probability of an event that is the output of an OR gate is the sum of the input probabilities. Wherever failures/demand were required (AND gates), values were obtained by multiplying the failure/hr by the estimated sum of the repair time, test frequency, and test duration (usually small).

5.3 PuFF Fault Trees

The fault trees constructed to analyze the safety of the PuFF Facility are listed in Table 11 and shown on pages 100 to 185 in terms of a single top event, *Release of $^{238}\text{PuO}_2$ to the Environment.** The events listed by frequency of occurrence in Section 3.4 are the minimal cut sets with the highest probabilities. Appropriate portions of this tree were used as required to evaluate separately the risks to operating personnel and the risks from specified design basis accidents.

* Refer to Figure 10 for location of dampers, valves, etc., that are identified in Fault Trees.

The PuFF fault trees are similar to those developed in the Systems Analysis of 200-Area Canyon Operations (Reference 29 because of the many areas of similarity (sand filter, electrical distribution, etc.). Many of the fault probabilities, particularly for personnel errors, were also taken from the data that form the basis for Reference 29. Other failure data were taken from experience with similar operations in other facilities located throughout the Plant and Laboratory and from Reference 30 (Rasmussen Report).

TABLE 11

Index to Fault Trees

<i>Number</i>	<i>Title</i>	<i>Used in Fault Tree</i>
A	Release of $^{238}\text{PuO}_2$ to Environment	-
1	Unfiltered Release	A
2	Above Normal Stack Releases	A
3	Release from Cells	A, 11
4	Malfunction of Constant Air Monitors	A, 11
5	Deleted	-
6	Fire Inside Building	27, 30, 67, 84, 85, 86
7	Deleted	-
8	Natural Phenomena	67, 87
9	Cooling Tower Water Contaminated	A
10	Sand Filter Perturbed	2
11	Excess Activity to Sand Filter from PuFF	2
12	Difficulties in Process Exhaust System	10, 27, 31, 33, 34, 35, 46, 65
13	Difficulties in Building Exhaust System	10, 35, 64
14	Building 235-F Exhaust Fans Inoperable	11, 12
15	Instrument Difficulties	4, 33, 34, 35, 46, 49, 52, 59, 60, 61, 72, 75, 76, 77, 78, 79, 80, 81, 82
16	Instrument Air Failure	81
17	Personnel Difficulties	11, 13, 14, 33, 34, 35, 40, 41, 42, 46, 52, 57, 58, 59, 66, 71, 72, 73, 75, 76, 77, 78, 79, 80, 81
18	Release of Contamination from Cell 1	3
19	Release of Contamination from Cell 2	3
20	Release of Contamination from Cell 3	3
21	Release of Contamination from Cell 4	3
22	Release of Contamination from Cell 5	3
23	Release of Contamination from Cell 6	3
24	Release of Contamination from Cell 7	3
25	Release of Contamination from Cell 8	3
26	Release of Contamination from Cell 9	3
27	Release from Metallography (Liquid-Handling) Box	3
28	Difficulties in Ventilation System	88, 89, 90
29	Release of Contamination During Cell Entries	11
30	Contamination Release Through Ruptured Glove (Bag)	18, 19, 20, 21, 22, 23, 24, 25, 26
31	Release Through Broken Window	18, 19, 20, 21, 22, 23, 24, 25, 26
32	Deleted	-

TABLE 11 (Continued)

<i>Number</i>	<i>Title</i>	<i>Used in Fault Tree</i>
33	Difficulties in Cell 1-6 Exhaust	18, 19, 20, 21, 22, 23, 30, 31
34	Insufficient Exhaust from Cells 7-9	24, 25, 30, 31
35	Difficulties in Cell 9 Exhaust	26, 30, 31
36	Sources of Pressure in Argon-Atmosphere Cells (1-5)	18, 19, 20, 21, 22, 30, 31, 62, 64
37	Sources of Pressure in Helium-Atmosphere Cell (6)	23, 30, 31, 63, 64
38	Sources of Pressure in Air-Atmosphere Cells (7-9)	11, 24, 25, 26, 27, 30, 31, 63, 64
39	Mechanical Fan (Blower) Failure	4, 14, 58, 59, 73, 87
40	Loss of Electrical Power to Fan A	14
41	Loss of Electrical Power to Fan B	14
42	Loss of Electrical Power Through ATS-5	40, 41
43	Loss of Electrical Power to MCC's (PDP's)	42, 84, 85
44	Faults in MCC's or PDP's	42, 84, 85, 86
45	Emergency Power System Fails	42, 84, 85
46	Seal Pot Fails to Relieve at 0.0" W.C.	33
47	Fire in Cells 1-5	30, 36, 89
48	Explosion in Hot Press	30, 31
49	Recirculating Argon Overheated	36, 73
50	Fire in Cell 6	30, 37, 89
51	CWS Water Contaminated	9, 73
52	Helium Overheated	37
53	Building 235-F Pressurized	1
54	Fire in Air-Atmosphere Cell (Box)	27, 30, 38, 39
55	Deleted	-
56	General Fuel	47, 50, 54, 68, 69, 83
57	Malfunction of Halon Supply	54, 88, 89, 90
58	Oxidizing Agents in Argon Supplied to Cell	47
59	Oxidizing Agents in Helium Supplied to Cell	50
60	Release from Cell 1-5 Annulus	3
61	Release from Cell 6-9 Annulus	3
62	Cell 1-5 Annulus Contaminated	9, 11, 60
63	Cell 6-9 Annulus Contaminated	9, 11, 61
64	Annulus Pressure > Operating Area Pressure	60, 61
65	Insufficient Exhaust from Inert Gas Cells	30
66	Difficulties in Valving	11, 33, 34, 35, 65
67	Cell (Box) Window Broken	27, 31, 47, 50

TABLE 11 (Continued)

<i>Number</i>	<i>Title</i>	<i>Used in Fault Tree</i>
68	Fire in Cell 6-9 Annulus	64, 89
69	Fire	88, 89, 90
70	Gas Fuels	56
71	Loss of Cooling Water (CW or PCW)	48, 49, 52, 58, 59, 68, 82, 83
72	Argon System Open to Malfunctioning Dryer Regenerator	49
73	Blowers in Gas Purifiers Inoperable	65
74	Deleted	-
75	Cell (Box) 1-6 Evacuated	67
76	Seal Pot Fails to Relieve at -4.0" W.C.	75
77	Difficulties in Inert Gas Supply/Exhaust	75
78	Difficulties in Inert Gas Supply	77
79	Air-Atmosphere Cells (7-8) Evacuated	67, 80
80	Cell 9 Evacuated	67
81	Valve Open (Closed)	11, 12, 13, 27, 28, 31, 36, 37, 49, 53, 58, 65, 66, 73, 77, 78, 79, 80
82	Furnace Overheated	83
83	Fire in Cell 1-5 Annulus	64, 89
84	Loss of Electrical Power to Equipment on MCC-2	15, 16
85	Loss of Electrical Power to Equipment on MCC-E1 (-E2)	4, 15, 58, 71, 73, 86
86	Loss of Electrical Power to Equipment on Emergency Power Panel	15, 59, 81
87	Stack Exhaust Fan System Inoperable (292-F)	13
88	Fire Associated with Halon Systems 44-1-5 and 44-1-6	6
89	Fire Associated with Halon Systems 44-1-1 and 44-1-2	6
90	Fire Associated with Halon Systems 44-1-3 and 44-1-4	6

* Based on estimated flights from Bush Field, Augusta, Georgia and no restrictions on flights over Plant site.

1. Unfiltered Release

2. Above Normal Stack Releases

3. Release from Cells

4. Malfunction of Constant Air Monitors

Halon System
Number

Areas Covered

44-1-1	East Maintenance Room
44-1-2	West Maintenance Room
44-1-3	Fan-Filter Room
44-1-4	East Line Service, West Line Service, Gas Purification, Cold Feed Preparation, and Hot Press Equipment Rooms
44-1-5	Operating Room
44-1-6	Regulated Storage Rooms and Metallography Laboratory

6. Fire Inside Building

8. Natural Phenomena

9. Cooling Tower Water Contaminated

10. Sand Filter Perturbed

11. Excess Activity to Sand Filter from PUFF

12. Difficulties in Process Exhaust System

13. Difficulties in Building Exhaust System

14. Bldg. 235-F Exhaust Fans Inoperable

15. Instrument Difficulties

16. Instrument Air Failure

17. Personnel Difficulties

18. Release of Contamination from Cell 1

19. Release of Contamination from Cell 2

20. Release of Contamination from Cell 3

21. Release of Contamination from Cell 4

22. Release of Contamination from Cell 5

23. Release of Contamination from Cell 6

24. Release of Contamination from Cell 7

25. Release of Contamination from Cell 8

26. Release of Contamination from Cell 9

27. Release from Metallography (Liquid-Handling) Box

28. Difficulties in Ventilation System

29. Release of Contamination During Cell Entries

*Applicable to Cell 4 only.

30. Contamination Release Through Ruptured Glove (Bag)

* Applicable to Cell 4 only.

31. Release Through Broken Window

33. Difficulties in Cell 1-6 Exhaust

35. Difficulties in Cell 9 Exhaust

37. Sources of Pressure in Helium-Atmosphere Cell (6)

38. Sources of Pressure in Air-Atmosphere Cells

39. Mechanical Fan (Blower) Failure

40. Loss of Electric Power to Fan A

41. Loss of Electrical Power to Fan B

42. Loss of Electrical Power Through ATS-5

* Panel No.	CB No.	Trans. No.	Emer. Power ATS
MCC-1	1C	750	-
MCC-2	1B		1
MCC-3	1A		-
MCC-E1	2B	1000	2
MCC-E2	3B		3
EPP	E1		2,3,4
MCC-N1	2C		-
MCC-N2	3C		-
MCC-N3	3D		-
PDP	2D		-
PDP-3	2A		-

43. Loss of Electrical Power to MCC's (PDP's)

44. Faults in MCC's or PDP's

45. Emergency Power System Fails

46. Seal Pot Fails to Relieve at 0.0" WC

47. Fire in Cells 1-5

48. Explosion in Hot Press

49. Recirculating Argon Overheated

50. Fire in Cell 6

51. CWS Water Contaminated

52. Helium Overheated

53. Building 235-F Pressurized

54. Fire in Air-Atmosphere Cell (Box)

56. General Fuel

57. Malfunction of Halon Supply

58. Oxidizing Agents in Argon Supplied to Cell

59. Oxidizing Agents in Helium Supplied to Cell

60. Release From Cell 1-5 Annulus

61. Release from Cell 6-9 Annulus

62. Cell 1-5 Annulus Contaminated

63. Cell 6-9 Annulus Contaminated

64. Annulus Pressure > Operating Area Pressure

65. Insufficient Exhaust from Inert Gas-Cells

66. Difficulties in Valving

67. Cell (Box) Window Broken

68. Fire in Cell 6-9 Annulus

70. Gas Fuels

71. Loss of Cooling Water (CW or PCW)

72. Argon System Open to Malfunctioning Dryer Regenerator

73. Blowers in Gas Purifiers Inoperable

• Applicable to cells 1-4 only.

+ Applicable to Cells 5-6 only.

75. Cell (Box) 1-6 Evacuated

76. Seal Pot Fails to Relieve at -4.0" WC

77. Difficulties in Inert Gas Supply/Exhaust

78. Difficulties in Inert Gas Supply

79. Air-Atmosphere Cells (7-8) Evacuated

80. Cell 9 Evacuated

* Depending on the type of valve and its use, probability given in other parts of the fault tree will be a combination of one or more of the indicated events expressed as either failure/hr or failure/demand.

81. Valve Open (Closed)

82. Furnace Overheated

83. Fire in Cell 1-5 Annulus

84. Loss of Electrical Power to Equipment on MCC-2

85. Loss of Electrical Power to Equipment on MCC-E1 (-E2)

86. Loss of Electrical Power to Equipment on Emergency Power Panel (EPP)

87. Stack Exhaust Fan System Inoperable (292-F)

88. Fire Associated with Halon Systems 44-1-5 & 44-1-6

89. Fire Associated with Halon Systems 44-1-1 & 44-1-2

90. Fire Associated with Halon Systems 44-1-3 & 44-1-4

6. APPENDIX B

COMPUTATION OF DOSES

The methods used to compute doses to offsite and operating personnel are discussed in this appendix. An integrated air concentration was defined based on process conditions, type of accident, and mixing conditions either within the facility or in the environment. Doses to the critical organ were calculated from this concentration using a lung model that considers the effects of particle size on the inhalation and retention (New Lung Model).

6.1 INTEGRATED AIR CONCENTRATION

The integrated air concentration resulting from any accident depends on the quantity and particle size distribution of the powder released from primary containment and the extent of dispersion before inhalation by personnel. For operating personnel, the dispersion depends on the particle size distribution, assumed duration of the accident, and the volume of air in which the operator is exposed (assumed to be 2000 ft³ or about one-third of the Operating Area). For offsite personnel, the quantity released is reduced by the effectiveness of the sand filter (no change in particle sizes) and the dispersion is affected by the assumed meteorological conditions.

6.1.1 Quantity of PuO₂ Released

The basic assumption of the safety evaluation of the PuFF operation is that the accident occurs when either an 85-g batch of ball-milled powder or a 510-g batch of feed powder is exposed in the cell. The accident releases some fraction of these amounts but does not alter the particle size distribution significantly. Although the actual inventory of different forms of PuO₂ is considerably larger (see Section 3.1.6), contributions to the release from the additional inventory can be neglected. This material will be stored in containers* inside storage wells beneath

* The containers are cylindrical, stainless steel cans with screw-top lids that are similar to the "2R Containers" described in the Code of Federal Regulations, 49CFR178.34.

the cell floors. Shards and other dense forms are too large to become dispersed, and the accidents are not expected to pulverize these forms to powders as fine as the ball-milled batch.

6.1.2 Particle Size Distributions

The particle size distributions of ball-milled and feed powders, as measured with a Coulter Counter, are shown in Figures 19 and 20. These distributions follow approximately a log-normal relationship, except for the limited resolution of this technique at both very small and very large particles. Extrapolation of this relationship was used to estimate the weight fraction of particles $<1 \mu\text{m}$ (data given in Table 12). Respective mass median diameters are 2 and 5 μm . The weight fraction of ball-milled powder in the range of respirable particle sizes ($<3 \mu\text{m}$) is 0.75, or three times that of the feed powder.

6.1.3 Dispersibility

During an accidental release, the fraction of $^{238}\text{PuO}_2$ particles escaping primary containment, mixing with the room air, and being transported through the exhaust system and the sand filter will depend mainly on the dispersion and inertial deposition (sedimentation and impaction) characteristics of the particles. Dispersibility is generally considered to be inversely related to the aerodynamic equivalent diameter (d_p^*) of the particles, while $d^2\rho$ is the controlling parameter for sedimentation and impaction.⁵²

For example, the settling velocity of a spherical particle in a medium of viscosity η is given by⁵²

$$V_s = \frac{d^2 \rho g C}{18\eta}$$

where g is the gravitational acceleration constant and C is the Cunningham slip coefficient, Figure 21.

The fraction of particles of a given size that could be dispersed was estimated from Figure 21. The settling velocity is essentially constant at 3×10^{-4} cm/sec for particles less than 0.01 μm . If particles 0.01 μm , or less, are assumed to be fully dispersed (suspended in air), the relative dispersability of larger particles can be estimated by the ratio of the settling velocities: for 1- μm particles, $3 \times 10^{-4} / 3 \times 10^{-2}$, or 0.01 (see data in Table 12).

* d is the diameter, and ρ is the density of the particle.

FIGURE 19. Particle Size Distribution of Ball-Milled $^{238}\text{PuO}_2$

FIGURE 20. Particle Size Distribution of Calcined $^{238}\text{PuO}_2$

FIGURE 21. Settling Velocities for PuO_2 in Air

TABLE 12

Data Used in Dose Calculations

Particle Size, μm	Dose Value $D(70)$, ^a rem/ μCi			Size Fraction ^b		Dispersible Fraction ^c
	Lung	Bone	Liver	Ball- Milled	Feed	
0.3	307.4	585.9	382.7	0.001	0.001	0.075
0.5	231.5	454.5	304.9	0.004	0.006	0.03
1.0	160.9	357.1	238.9	0.085	0.033	0.01
2.0	97.7	270.8	182.0	0.420	0.090	0.003
3.0	67.3	229.4	153.1	0.250	0.120	0.0015

a. Calculated from data given in Reference 60.

b. From data used for Figures 19 and 20.

c. From Figure 21.

Combining this estimated dispersability with the measured particle size distributions indicates that ball-milled powder is three times more hazardous than feed powder. Approximately 0.3% of a ball-milled batch is dispersable.

6.1.4 Filtration

The sand filter efficiency of 99.5%, reported for 200-Area experience,²⁹ was used in calculating concentrations of radio-activity released to the environment from abnormal (Section 3.4) and normal operations (Section 3.5). This value is lower than the DOP efficiencies (99.9 to 99.95%) measured for operating sand filters at SRP,^{11,53} or the 99.98% measured under "burst" conditions. Efficiency tests using PuO_2 have not been conducted, but are being considered by Los Alamos Scientific Laboratory personnel.⁵⁴

HEPA filters have been demonstrated to have the following efficiencies for milled PuO_2 :³⁸ 99.9973, 99.9970, and 99.865% for the first, second, and third stages, respectively. However, one engineering study of installed HEPA filters indicates that four stages are required to achieve a transmission factor of 1×10^{-7} .⁵⁵ The efficiency of first stage (in-cell) filters is assumed to be 99.997%. Since the double exhaust filters (combined second and third stages) will be DOP tested as a unit, a transmission factor of 5×10^{-4} (99.95% efficiency) is assumed. The combined HEPA and sand filter transmission factor is then 7.5×10^{-11} .

6.1.5 Atmospheric Dispersion

The integral ground-level air concentrations of $^{238}\text{PuO}_2$ following a short-term release of activity were obtained from the Gaussian Plume model⁵⁶ using atmospheric dispersion properties derived from a statistical analysis of measured meteorological data (SRL 2-yr data base).^{4,5,57}

Relative concentrations, defined as the ratio of the integral ground level air concentration to the total source emission, are given by:⁵⁷

$$\frac{\chi}{Q} = \frac{1}{\alpha \pi \bar{u} \sigma_x \sigma_y} \exp \left[-\frac{1}{2} \frac{\left(H - \frac{x v_s}{\bar{u}} \right)^2}{\sigma_y^2} \right] \quad (1)$$

where:

$\frac{\chi}{Q}$ = relative concentration on the plume centerline, sec/m³

σ_x, σ_y = Horizontal and vertical dispersion coefficients, m

H = release height, m

x = downwind distance, m

$\bar{u}$ = effective wind speed, m/sec

v_s = gravitational settling velocity (set equal to zero), m/sec

α = unity for $V_s = 0$, and 2 for $V_s > 0$.

The parameters $\bar{u}$, σ_x , and σ_y in the above equation were calculated for the range of meteorological conditions in the 2-yr data base. Of the corresponding χ/Q values obtained, only concentrations that were equal to or greater than those occurring 95% of the time (95th percentile concentrations) were used to compute downwind doses.³³

6.2 DOSIMETRY

6.2.1 Critical Exposure Pathway

Inhalation of airborne plutonium is the critical exposure pathway for atmospheric releases from the PuFF Facility. The vegetation uptake-ingestion pathway is of negligible concern in comparison, because of the large discrimination against plutonium

in the uptake by plants and the small absorption of plutonium by the gastrointestinal tract of man.⁵⁸ The total discrimination factor against plutonium for this pathway is estimated to be in the range of 10^7 to 10^9 .¹⁷

The internal radiation exposure resulting from the inhalation of plutonium depends in a complex way on its deposition and retention in the respiratory system and its metabolic clearance to and from critical body organs. These in turn depend on the chemical form, mass, and particle size of the plutonium. There are three distinct deposition sites within the respiratory system:¹⁹ the nasopharynx (N-P), tracheobronchial tree (T-B) and pulmonary region (P) or lower lung. The multiplicity of deposition sites leads to a multiplicity of clearance pathways; GI tract, liver, and blood.

Clearance (pathway and kinetics) depends strongly upon the chemical nature or solubility of the compound inhaled. Chemical compounds are separated into three classes according to their retention in the respiratory system: Class D (retained for days), Class W (retained for weeks), and Class Y (retained for years). Because PuO_2 is a Class Y compound, only 2 to 5% of the fraction originally inhaled (depending upon particle size) enters the circulatory system, the remainder is rapidly cleared via the GI tract where absorption into the blood is small.

6.2.2 Dose Model

Exposure doses to critical organs from the inhalation of $^{238}\text{PuO}_2$ were calculated using the recently proposed New Lung Model of the Task Group on Lung Dynamics.^{19,59} The Original Lung Model of the International Committee on Radiation Protection³⁴ is considered too conservative because it does not treat realistically (1) the effect of particle size on deposition and (2) the effect of chemical form on clearance from the respiratory tract. The new model is particularly applicable for analysis of accidents in PuFF Facility because the chemical form is known (PuO_2) and the particle sizes have been characterized (Section 6.1.2).

In calculating the absorbed dose to various body organs, the following assumptions were made:⁶⁰

- Release during accidents is short term.
- The PuO_2 contains 80% ^{238}Pu and 20% ^{239}Pu (see Table 4).
- Inhalation is the only process by which PuO_2 is taken into the body.

- Parameters for deposition and clearance were taken from Reference 61; these supersede previously published values.¹⁹
- Exposure was integrated over a 70-yr lifetime.

The resulting doses, $D(70)$, in rem/ μCi for an exposure of 70 years following an acute inhalation are shown in Table 12 as a function of particle size. The measured size fractions for ball-milled and feed powders (Section 6.1.2) and the estimated dispersible fractions (Section 6.1.3) are also shown in Table 12.

The relative hazards of ball-milled and feed powders are shown in Table 13 in terms of the dose commitment factor, $D_c(70)$, which was used in the calculations of doses resulting from accidents, and the Maximum Permissible Intake (MPI). The values for offsite personnel were obtained by weighting the dose values $D(70)$, with respect to the observed weight fractions. The values for operating personnel were obtained by weighting the dose values with respect to both the weight and dispersible fractions. The dispersible fraction was not used for offsite personnel because dispersion is accounted for by the atmospheric dispersion model.

The data in Table 13 show that the liver is the critical organ for exposures to the PuO_2 from the PuFF Facility. The organ with the lowest MPI value is always considered the critical organ, and the dose commitment factor for the critical organ is used in evaluating the dose calculations. In contrast, the Original Lung Model indicates that the bone is the critical organ.

The data in Table 13 also show that ball-milled powder is more hazardous than feed powder by a factor of 2 to 3. For offsite personnel, 85 g of ball-milled powder is equivalent to 255 g of feed powder. Consequently, the values for ball-milled powder were used in the dose calculations for all accidents. The 510-g batch size for feed powder is not considered to be a significantly greater hazard. If the airplane crash is used as an example, because it produces the largest offsite doses, and if a 100% release of a batch of each of the two powders is assumed, the offsite doses are 334 rem for feed powder and 147 rem for ball-milled powder.

TABLE 13

COMPARISON OF DOSES FROM BALL-MILLED AND FEED POWDERS

Power Type	Offsite Personnel			Operating Personnel		
	Weighted Dose Value, ^a rem/ μ Ci	MPI, ^b μ Ci	Dose Commitment ^c $D_C(70) \times 10^2$, $\frac{\text{rem-m}^3}{\mu\text{Ci-sec}}$	Weighted Dose Value, rem/ μ Ci	MPI, μ Ci	Dose Commitment $D_C(70) \times 10^2$, $\frac{\text{rem-m}^3}{\mu\text{Ci-sec}}$
Ball-Milled						
Lung	72.8	1.03	2.5	0.336	223	0.012
Bone	203.8	0.74	7.1	0.829	181	0.029
Liver	136.6	0.55	4.8	0.555	135	0.019
Feed						
Lung	23.9	3.15	0.8	0.156	481	0.006
Bone	67.0	2.24	2.3	0.358	419	0.012
Liver	44.9	1.67	1.6	0.240	312	0.008

a. Calculated from data in Table 12.

b. Ratio of guide values (150 rem for bone, 75 rem for lung and liver) to weighted dose values.

c. Weighted dose values times breathing rate (3.5×10^{-4} m³/sec).

7. APPENDIX C

DEVIATIONS FROM THE GENERAL DESIGN CRITERIA — PLUTONIUM FACILITIES

The design intent has been to meet, where practical, the design and operational requirements of the *General Design Criteria - Plutonium Facilities*,² hereafter referred to as *Criteria*. Except for resistance to a Design Basis Tornado, there is, for the most part, general compliance with the requirements of the *Criteria*.

Nonmandatory recommendations of the *Criteria* have been followed as far as practical. Major deviations from these recommendations and exceptions to mandatory requirements are discussed in this Appendix in the order in which the requirements appear in *Criteria*. The titles used are from the appropriate sections of the *Criteria*.

7.1 FACILITY DESIGN

7.1.1 Tornado and Other Storm Design Requirements

Requirement: *The geographical intensity regions, and the associated design basis tornado characteristics shall be used in designing for tornado resistance . . . (p. 73)*

Calculations indicate that Building 235-F is capable of withstanding winds resulting from the combined rotational and translational speeds of the Design Basis Tornado. However, the building does not provide adequate resistance to the associated pressure drop and some missiles (see Section 3.4.4.1).

7.1.2 Seismic Design Requirements

Requirement: *The adequacy of critical items shall be verified using a suitable dynamic analysis technique . . . (p. 75)*

Detailed analysis of the response of Building 235-F to a Design Basis Earthquake (DBE) at the Savannah River Plant was not made.⁹ The building probably provides a high degree of seismic protection since it is similar in construction to, and

has a lower profile than the SRP reactor buildings, which have been extensively analyzed and found to be capable of withstanding a DBE.³⁵ Thus, by analogy, the structure of the building housing the PuFF Facility should provide adequate earthquake resistance. The sand filter and connecting roof duct and underground exhaust tunnel from the facility are designed to withstand the DBE.^{9,10}

7.2 FIRE PROTECTION

Requirement: Minimum requirements shall provide complete automatic sprinkler or equivalent coverage throughout the facility with the provision of special hazard fire control measures where particular hazards exist. (p. 77)

Air-atmosphere enclosures and all PuFF Facility rooms are equipped with automatic *Halon 1301* fire suppression systems that meet NFPA specifications and are considered at least equivalent to automatic sprinklers. Fire suppression systems are unnecessary in enclosures with recirculating inert gas atmospheres.

7.3 RADIATION PROTECTION

7.3.1 Criticality Alarm System

Requirement: A criticality alarm system (gamma or neutron) shall be provided to meet, as a minimum, ANSI Standard N.16.2-1969. . . (p. 79)

No criticality alarm is planned for the PuFF Facility because: 1) the in-cell inventory limit will be one-half the calculated critical mass for the PuO_2 product, and 2) the isotope will be distributed throughout the cell line. An appropriate criticality detector and alarm system is installed in the storage vault. The criticality control procedures and the vault alarm meet the requirements of ERDAM 0530.²⁴

7.4 CONTAMINATION CONFINEMENT

The building barriers for the PuFF Facility consist of: 1) cells and cabinets, 2) operating and maintenance rooms, 3) airlocks and corridors, and 4) adjoining nonregulated areas of Building 235-F. The exhaust systems for these nonregulated areas are not filtered. If an incident threatens to release contamination into these areas, the exhaust systems will be shut down.

7.4.1 Integrity of Operating Area Compartments

Requirement: *The design of the operating area compartments and the critical structure shall provide confinement during normal operations and DBA conditions. (p. 80)*

Operating and maintenance compartments are not adequately protected against the pressure drop associated with a DBT.

7.4.2 Water Collection System

Requirement: *Collection systems should be provided for water runoff from the plutonium handling area, such as from firefighting activities. (p. 80)*

Water collection systems described in the ERDA design criteria are considered unnecessary because only a small amount of water will be used in the facility. The major potential source of water, the automatic sprinkler system, was not included in the design. A Halon suppression system, portable dry chemical extinguishers, and if needed, fire truck foam systems will be used.

7.5 UTILITIES

7.5.1 Electrical Utilities

7.5.1.1 Alternative Primary Feeder

Requirement: *This source of power is for the same overall purpose as that of the preferred primary feeder and shall be in ready standby for use by automatic transfer in the event of a forced outage or planned maintenance of the preferred primary feeder. (p. 82)*

An alternate primary feeder is not provided for the facility, because for a significant increase in cost, it would not increase reliability of the electrical system substantially. Emergency power is available from a diesel generator.

7.6 CONSTRUCTION OF ENCLOSURES

Requirement: *Noncombustible or fire resistive and corrosion resistant materials shall be used for enclosures and any required radiation shielding. (p. 83)*

Although the primary material is stainless steel, certain flammable materials were required for the construction of enclosures. Examples are seals, gloves, bags, manipulator boots, and electrical insulation.

8. APPENDIX D

DEVIATIONS FROM THE ENVIRONMENTAL STATEMENT

The Environmental Impact Statement³ (EIS) was prepared in 1972 prior to completing the design of the facility. Several design alternatives were eventually selected that differed from those set forth in the EIS. These deviations were made after consideration of the benefits, risks, and cost incentives. In relation to both public and onsite personnel risks, the changes are of minimal significance.

The major deviations are the inability of Building 235-F to resist a Design Basis Tornado (Section 3.4.4.2) and the deviations from the "Design Criteria for Plutonium Facilities" (see Appendix C). Other differences do not materially affect the conclusions of the Environmental Statement, and in some instances enhance the safety of the facility. These deviations are summarized in the order in which they appear in the Environmental Statement.

8.1 VENTILATION SYSTEM

Statement: The air in rooms immediately surrounding the process cabinets would be ventilated through at least one stage of HEPA filters to diminish the likelihood of plutonium release even if the cabinets were accidentally breached. (pp. 7, 8)

The air in the rooms immediately surrounding the process cabinets is exhausted directly through the F-Area sand filter instead of the single-stage HEPA filter indicated in the Environmental Statement.³ The sand filter should provide much greater resistance to smoke loading than HEPA filters under the adverse conditions associated with a fire. As discussed in Section 3.4, the sand filter more than adequately reduces any abnormal activity releases.

8.2 FIRE DETECTION AND SUPPRESSION

Statement: A system would be provided for the automatic detection and suppression of fire within the process cells and cabinets using a vapor phase extinguishant, Halon 1301, . . . (p. 12)

No automatic fire suppression systems are installed in the inert gas cells because the inert atmospheres do not support combustion. *Halon 1301* automatic extinguishing systems are installed in air atmosphere cells and cabinets, while general automatic *Halon* systems are installed in all rooms of the PuFF Facility.

8.3 WATER COLLECTION SYSTEM

Statement: *The drainage would contain no radioactive materials because sills at all process room entrances would prevent water entry and exit. (p. 13)*

Sills at entrances to process rooms to prevent entry and exit of potentially contaminated water are not provided because large volumes of water are not used in process or fire fighting (*Halon* or foam).

8.4 ENVIRONMENTAL IMPACT

8.4.1 Probable Environmental Effects

Statement: *^{238}Pu released to the environment from normal operation would not exceed 5×10^{-3} Ci/yr. (p. 19)*

The normal operating release from the facility will be lower than anticipated, 5×10^{-8} Ci/yr, primarily because of the sand filter.

8.4.2 Extraordinary Adverse Environmental Effects

8.4.2.1 Fire

Statement: *No combustible materials are used in the construction of the cabinets and PuO_2 is not combustible. (p. 23)*

Although stainless steel is the primary construction material, certain combustibles, such as seals, acrylic plastic shield windows, gloves, bags, manipulator boots, and electrical insulation, are required in the construction of the cells and cabinets, while certain other flammables will be required in the process. All such flammables will be used in controlled amounts. Examples are solvents and mounting plastics in the metallography facility, graphite dies in the hot pressing operation, and cotton and paper wipes used for decontamination and general housekeeping.

8.4.2.2 Gross Contamination Release

Statement: The plutonium oxide used in the PuFF process would always contain less than 20% fissile plutonium (^{239}Pu); no danger of criticality would exist for the amount of materials to be handled. (p. 24)

Quantities of PuO_2 exceeding the criticality limit for the ^{238}Pu - $^{239}\text{PuO}_2$ mixture will be stored in the vault of Building 235-F. Storage will be in safe arrays with a criticality detector and alarm present.

Statement: Radiation doses received at the plant perimeter as a result of postulated accidents will be several orders of magnitude less than the concentration guides given in ERDAM 0524.¹⁶ (p 22)

A much wider range of accidents was analyzed in this Safety Analysis Report. The maximum dose to an individual at the Plant boundary is 100 rem to the liver (critical organ) resulting from an airplane crash. However, the risk from this incident is low, 2×10^{-6} rem/yr. The cumulative risks from other accidents are also 5×10^{-6} rem/yr or lower.

8.5 RELATIONSHIP BETWEEN SHORT-TERM USES AND LONG-TERM PRODUCTIVITY

Statement: The only auxiliary structures to be built would be an air filter system and an air exhaust stack. (p. 27)

In addition to the installation of the sand filter, use of the existing 235-F Building required the construction of certain auxiliary external structures not indicated in the Environmental Statement.³ These include a new power substation and an enclosed emergency diesel generator.