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SAFETY ANALYSIS REPORT

231-Z BUILDING

CS Powers

CONTRACT

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EN Greenwell	"	"	LC Schwendiman	"	325 Bldg
GP Hanneman	"	"	WF Sheelv	"	324 Bldg
WS Hartnett	"	"	DH Stewart	"	RO Bldg
DD Hays	"	"	RW Stewart	"	231-Z Bldg
MM Hendrickson	"	Fed. Bldg	JW Taylor	"	"
JF Honsted	"	3702 Bldg	NG Wittenbrock (21)	"	Fed. Bldg
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PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

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The 231-Z Building, located in 200-West Area of the Hanford reservation, is utilized for metallurgical research on plutonium and its alloys, and for fabrication development work on plutonium components and reactor fuels containing plutonium or other alpha emitting materials. The laboratory is operated for the USAEC by Pacific Northwest Laboratories of the Battelle Memorial Institute. Large quantities of plutonium, from 100 to 200 kilograms, are routinely handled and stored. Nearly all operations involve plutonium metal in the dry or unmoderated state.

Plutonium research and development activity is conducted in categories of physical metallurgy, property determination, alloy development, and process development. Sponsorship is 80 - 85% USAEC Division of Military Application; 10% USAEC Division of Research; and 5 - 10% other, including service to PNL and other Hanford components.

The operations performed involve working with plutonium in quantities varying from small metallographic samples (fraction of a gram) to large parts weighing up to several kilograms. Research and development activities include melting, alloying, casting, machining, rolling, pressing, forging, electron beam welding, and vapor deposition of plutonium and plutonium alloys. Metallurgy research operations include metallography, electron microscopy, dilatometry, density determination, electron microprobe, x-ray diffraction, high temperature and high speed properties determination, and room temperature property determination.

Activities in the aforementioned categories are:

1. Physical Metallurgy--Mode and kinetics of phase transformation, modes of deformation, structure, phase stability, and metastability.
2. Property Determination--Customary static properties, property and property changes, and brief transient effects.
3. Alloy Development--Development of plutonium alloys having properties appropriate to highly complex uses in special environments.
4. Process Development--Devise new processes for the production of highly specialized metallic plutonium components.

NUCLEAR SAFETY LIMITS FOR THE 231-Z BUILDING

In this document only those limits stated in this section are regarded as binding. All other material presented is intended to be descriptive or to be justification for the nuclear safety limits.

1. Type and Quantity of Material--The quantity of fissile material handled as a batch in transfer, processing, or storage operations will not exceed 45% of the critical mass of that material.

Plutonium metal is the principle fissionable material processed and stored in the facility.

The material is normally dry and unmoderated; however, moderated material is also allowed consistent with the limits stated herein.

Small quantities of ^{233}U , ^{235}U , ^{237}Np , and ^{238}Pu are also handled in the facility. The criticality safety limits established for ^{239}Pu are enforced regardless of the fissionable material involved.

The total amount of fissionable material that may be processed and stored within the 231-Z Building is not specified. The potential limit considering storage space and number of glove boxes is approximately 500 kilograms.

2. Operational Limits--All operations, including transfer and storage, which involve fissionable materials are conducted within the limits defined by Criticality Safety Specifications (CSS). The CSS's are originated by the building criticality safety representative and are reviewed and approved by the Senior Specialist, Critical Mass Physics; the Manager, Nuclear Safety; and 231-Z Building management.

3. Limits on Flammable Gases--Flammable gases are permitted in the laboratory. Their use is limited to the following operations:

- a) Welding and brazing.
- b) Heating prior to bending or forming.

These operations are not performed on fissionable materials.

SUMMARY

An intensive review of the nuclear safety of the operation of the 231-Z Building has been made. For background information complete descriptions of the floor plan, building services, alarm systems, and glove box systems are included in this report. In addition, references are included to The Plutonium Laboratory Radiation Work Procedures, Safety Guides, 231-Z Operating Procedures Manual and Nuclear Materials Accountability Procedures. Engineered and administrative features contribute to the overall safety of personnel, the building, and environs.

The consequences of credible incidents were considered and are discussed. It is reasoned that the maximum hazard to personnel, the

building, and the building environs would result from a fire which would spread to the glove box ventilation system.

The probability of a criticality is extremely low since controls and procedures are added to design features so that one single accident, equipment failure, or procedure violation cannot cause criticality. The direct effects of a criticality incident involving approximately 5×10^{-17} fissions would be localized. If it occurred in a glove box it is not expected that the box would be breached. It is estimated in such a case that not more than three persons might be working in the vicinity near enough to receive possible lethal radiation.

SITE DESCRIPTION

The 231-Z Building is located in the 200-West Area of the Hanford complex. Orientation of the 231-Z Building with respect to other installation in the 200 areas is shown in Figure 1. Figure 2 shows the location of the 200 areas with respect to the Hanford site. Figure 3 shows the location of the Hanford site with respect to the Pacific Northwest. Further details concerning physical features and population distribution can be found in references 1 and 2.

FACILITY DESCRIPTION

The 231-Z Building consists of two storeis of reinforced concrete and concrete block construction. The second floor is essentially one large open bay with floor area of approximately 23,500 sq.ft. used for piping, ventilation ducts, filter cages, miscellaneous storage, and supporting facilities (vacuum pumps, hydraulic equipment, etc.) for equipment on the first floor. The first floor area is approximately 27,000 sq.ft. of which

Neg 35138-1

FIGURE 1. 200 Areas - Orientation Map

HANFORD
AREA MAP

Map 100-1

FIGURE 1. Features of Hanford Reach and Vicinity

100-100-1

100-100-1. Geographical Relationship of Pendleton, Oregon, to the Pacific Northwest

5,300 sq.ft. is used for building service machinery. The remaining 21,700 sq.ft. is laboratory area. In addition to the main laboratory structure there is a 3,000 sq.ft. office extension of concrete block construction. The office building is attached to the laboratory structure and isolated by air locks. The office building has refrigerated air conditioning completely separated from the laboratory ventilation system. A 231-Z first-floor plan and equipment location is shown on drawing No. H-2-3520 (fold-out following Page 8). The functional arrangement of the laboratory is shown in Figure 4. Building services are described below:

I. Ventilation

A. Room--There are four main fresh air supply systems with a total design capacity of approximately 60,000 cfm. Rooms serviced by these systems receive one air change every four minutes. The systems are each equipped with wet cell washers and filters. Room air can be heated as required, at the supply fan. There are also steam booster heaters in the duct work.

There are seven room exhaust fans with a total design capacity of approximately 40,000 cfm. All exhaust ducts are located inside laboratory rooms whereas a number of supply ducts are located in each corridor. With proper balancing air movement is from the corridors into each laboratory room. This type of air flow is indispensable for proper contamination control.

All room exhaust fans draw air from the rooms through HHS-7511-S high efficiency fire and moisture resistant Type A filters. These filters are provided to insure against contamination release to the

RM	ITEM	EQUIPMENT	REF
1	1	PRESS HOOD (1-1)	SK-2-2325
1	2	POWDER PKG GLOVE BOX (1-2)	N-2-3502 SHI
1	3	POWDER PREP GLOVE BOX (1-3)	N-2-32187
1	4	POWDER PRESS GLOVE BOX (1-4)	N-2-32185
2	5	FURNACE GLOVE BOX (2-1)	SK-2-2375
2	6	SAI-1 & BALANCE GLOVE BOX (22)	SK-2-2373

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BY			REVISED BY		
DATE			DATE		
NOTE			H-2-3580

FIGURE 4. 231 Building - Operations Locations

environs in case of an incident involving contamination release within one of the laboratory rooms. The pressure drop across filters is checked routinely by the building air-balance crew to determine need for change from clogging or bypassing.

None of the room supply fans are connected to the emergency power circuit. Only the room exhaust fan servicing Rooms 46, 47, 49, and 50 is connected to the emergency circuit. In the event of loss of normal building power, air movement within the building would change radically. All air movement would be towards the north side of the laboratory to the fan operated from the emergency power. This arrangement is intentional. The potentially contaminated air moves away from the change rooms and office area.

B. Glove Box--One electrically driven 20,000 cfm blower provides minus 6-inch water gage pressure for exhausting the entire laboratory glove box complex. The extracted air is filtered once at the glove box and once again in the duct level before being discharged through a 30-inch diameter 80-foot tall stack.

Filters provide the principle protection for prevention of release of radionuclides to the atmosphere. The inlet and exhaust filters used on glove boxes are the high efficiency fire and moisture resistant Type A filters described by Hanford Specification HWS-7511-S, which states in part that a maximum of 5% of the filter medium may be combustible. Also, the filter shall have a minimum efficiency of 99.97% at rated flow; i.e. the penetration of 0.3 micron diameter, homogeneous particles of dioctyl phthalate (DOP) shall not exceed 0.03% as determined by the specified test.

Glove boxes are designed to contain enough filter area so that a flow of 150 cfm is maintained if the largest glove or bag port becomes completely open. This prevents gross contamination of personnel and room in case of a glove or bag rupture during operation. All glove box effluent passes secondary filters (same quality) before entering the exhaust duct. Glove boxes which present special fire or vapor hazards are provided with a Hanford Standard HWS-10001-M-5-20 Stainless Steel Wire Mesh Mist Eliminator used primarily as a fire stop.

An air sampler is installed in the effluent duct just ahead of the exhaust fan. The filter from the sampler is changed and checked on a weekly basis. If the sample indicates a plutonium concentration over 2×10^{-12} $\mu\text{Ci/cc}$ of sample air, action is taken to trace the source and eliminate it. In the history of the building there has never been a release to the atmosphere equal to that allowed by AEC Manual Chapter RL-0510.

The methods used for maintaining operating pressures within glove boxes and for supplying the various atmospheres to glove boxes are described later.

A steam driven blower maintains negative glove box pressures during electrical power outages. The steam unit takeover is automatic. An alarm bell located in Corridor A indicates power loss at the electrically driven unit. This emergency blower is driven by a reciprocating, single cylinder, double acting steam engine. The engine is on continuously, running at idle speed. When electric power is lost, the slow-down of the electrically driven fan results in a loss of differential pressure between the exhaust duct and the room. The differential pressure controls

the diaphragm operating valve which runs the steam engine. When the differential pressure changes by 2 inches water pressure, the valve is activated and the steam driven fan takes over the load. The emergency exhaust system is tested once a week by dropping out the motor control relay on the electrical system, simulating a power outage.

II. Utilities

A. Electrical Power--The electrical service to the building consists of one 750 kVA, 480 V, 3 phase power circuit for equipment operation, and one 600 A, 240 V single phase circuit for lighting and room receptacles. Some scattered room lights and the room exhaust fan servicing Rooms 46, 47, 49, and 50 are operated on emergency power from the generator located in the 200-W Power House.

B. Water--Both sanitary and raw water are available in the building. Raw water is used for all process cooling lines.

C. Nitrogen--Nitrogen is available in every laboratory room. Its primary use is to provide an inert glove box atmosphere. A 2,500 gallon capacity liquid nitrogen tank is installed on the east side of the building. Bulk liquid nitrogen deliveries are made twice weekly.

D. Argon--A manifold consisting of ten 220 cubic feet capacity argon cylinders supplies argon to selected rooms in the building where the use of nitrogen is considered inadequate.

E. Vacuum--Two Nash-Hyton Model H-4 vacuum pumps provide a pressure of minus ten inches of mercury with a combined capacity of 150 ft³/min. The vacuum sample lines are used exclusively to draw room air through 4 x 8 inch filter paper which is subsequently counted to detect airborne

alpha activity. There are fifty operating air samplers in the building. Each laboratory room has between one and four air samplers depending on room area and type of operations performed.

F. Compressed Air--Two air compressors, one on standby, furnish 90 psi air to the laboratory. Six glove boxes have air operated exhaust control valves. Loss of compressed air allows the control valve to open completely reducing the glove box pressure to minus six inches water. Compressed air is also commonly used in the laboratory to operate vacuum system valves. These compressors are not on the emergency power circuit.

Two smaller air compressors operate the ventilation controls when normal power is lost. These compressors are on the emergency power circuit. Two other compressors supply fresh air to the four mask air stations located in the laboratory. These compressors are not on the emergency power circuit.

G. Drainage--The drainage system, like most of the other building services, was installed to accommodate a chemical separations process facility. It consists of three separate systems. A wrought iron system drains the cooling water used by all the building service equipment into an underground line that empties into the pond located south of the 234-5 Building. An earthenware drainage system in the laboratory is used for waste cooling water used on vacuum systems and furnaces. After the earthenware line leaves the building it empties into the same line as the wrought iron system. A stainless steel system from the laboratory empties into a ground disposal crib. The crib is described in ISO-633, "Design Criteria - Waste Disposal Crib 216-Z-16," and operation is

described in ISO-982, "Specifications and Standards for the Disposal of Battelle-Northwest Laboratory Liquid Wastes." Only cooling water which passes through glove boxes is routed to the crib. The waste water going to the crib is monitored by continuous fractional sampling. The sample is collected once a week, analyzed and activity reported for total liquid flow volume which is measured and recorded. In addition to these laboratory drainage systems a separate sanitary system services the lunchroom and change rooms.

H. Steam--Steam is supplied from the 200-West Power House. The four room air supply fans and the booster heaters in the duct work are supplied 15-pound steam for building heating. The building hot water tanks are supplied 55-lb steam. The steam driven emergency glove box exhaust fan is supplied 225 lb steam.

III. Alarm Systems

A. Automatic

1. Criticality--Four HAPO Critical Incident Alarms, Model I, are installed in the 231-Z Building; in addition, two remote horns are located in the duct level. The location of all audible alarms are shown on the floor plan, Figure 5. The instrument is designed to give an audible and visual (red light) alarm signal in the event of a critical incident. The instrument is an after-the-fact warning device, and offers no protection prior or leading up to a critical incident. The units are calibrated to alarm when the radiation level reaches 500 mr/hour gamma. The instruments are connected to the building emergency power, and are tested once a month. The four criticality detection instruments are interconnected and one signal will cause all to alarm. Prior to testing, the building occupants

FIGURE 5. 231 Z Building - Alarm Systems

are notified, over the building Public Address system, that a criticality test is about to take place. A five-second countdown is given and a gamma source is brought near the detector device. The same procedure is repeated at all four stations. Any malfunctions are reported and repaired immediately.

2. Fire--Fire sensing devices are installed in each laboratory room. There are no fire detectors in the duct level. There are nine fire bells located within the 231-Z Building and all will activate if any of the sensing devices are tripped. In addition, the signal will be received at the 200-West Fire Station via the area fire alarm system. The sensing devices are set to trip at 140°F and are routinely tested by the area fire department. The fire detection system is connected to the building emergency power.

3. Manual

1. Evacuation--The 231-Z Building is equipped with a siren alarm system. The alarm is activated by a switch located in the office reception area. Normal operation is a continuous alarm denoting immediate building evacuation. The alarm can also be switched to intermittent five seconds on, five seconds off operation to sound "take cover." A number of situations may arise where an organized withdrawal of personnel from the 231-Z Building is considered necessary. A strictly local radiation or contamination hazard may require that normal operations be discontinued and that personnel leave the building. When a Civil Defense Alert Signal is received over the Crash Alarm phone located in the Manager's office and Reception Area, the building is evacuated and personnel, utilizing evacuation buses maintained near the building, will relocate at a staging

area prearranged by Security Patrol. In case of a take-cover signal the 221-U Building tunnel area is regarded as the 231-Z Building underground shelter (ARHCO procedure for 200 Areas).

2. Telephone Crash Alarm--A crash alarm phone, part of the area-wide emergency communication system, is located in the Department Manager's office, and at the Receptionist's desk. Attention is obtained by continuous ringing of the telephone bell. The crash alarm phone network is tested weekly.

C. Security Alarm System

Every process area perimeter door and office area doors, including the doors from the men's and women's locker rooms, and also the doors on Vaults "A" and "B" are connected to the alarm system continuously monitored at the Z-plant badge house. The effect is to make the complete laboratory zone an alarmed vault. Microswitches are mounted on each door. An open door causes both visible and audible alarm signals at the badge house. An authorized signature list is maintained at the badge house that permits deactivation of the alarm for off-shift and weekend work.

IV. Glove Box Systems

A. General

Glove boxes used in the laboratory are individually designed enclosures that allow maximum utilization and versatility of the apparatus they contain. In general, a glove box will consist of 1) a formed stainless or carbon steel weldment constituting the frame, 2) transparent plastic panels sealed to the frame to form an essentially air-tight enclosure, and 3) a carbon steel structural support as required. A variety of accessories such as airlocks, glove ports, bag ports, sphincter seals, lights,

etc., are attached as required. Fabricated glove boxes must meet rigid inspection and test specifications.

1. Dynamic Type--Room air is continuously drawn into the glove box and exhausted at the rate of 50 to 100 ft³/min. Airlocks are commonly used. Fisher-Governor vacuum regulator valves are used for controlling the exhaust rate and maintaining the desired negative glove box pressure. This type of glove box is used for experiments of a nature not requiring the protection of an inert atmosphere. Some older glove boxes have Bristol controllers with air operated exhaust valves.

2. Inert Type--Some operations, particularly fabrication processes; i.e. machining, grinding, forging, etc., require a protective inert atmosphere. Nitrogen is generally used although argon is available. General construction features are similar to the dynamic type except room to glove box airlocks are not used. Inert gas is constantly bled through a rotometer into the glove box at a rate between two and ten ft³/hr depending on the operation and box volume. Also, the purge rate is dependent on the amount of oxygen permeating the gloves and minor leaks. In general, the oxygen content is maintained at less than 5% and is determined by sampling with a Fyrite oxygen analyzer. When oxygen content must be held at levels lower than 2% more sophisticated instruments are connected to the glove box for constant monitoring. Valving is available to purge the box at a very high rate if desired. Exhaust control techniques are similar to dynamic boxes. Inert boxes can be operated dynamically if desired.

3. Vacuum Type--Several completely evacuable glove boxes are used in the laboratory. These are of heavy walled steel construction with safety plate viewing windows and vacuum tight glove ports. The boxes can be

evacuated to 50 microns Hg and then backfilled with the desired atmosphere. Extremely pure atmospheres can be achieved and maintained. Except for the evacuable feature the exhaust supply, instrumentation, and operation are identical to inert type glove boxes.

4. Open Front Hood--Operations, such as decontamination, special packaging, and others not requiring full glove box protection are carried out in chemical fume hoods. These hoods are generally connected to the building glove box exhaust system, however, the exhaust is filtered only at the duct level.

ORGANIZATION AND ADMINISTRATIVE CONTROLS

The 231-Z Building is operated by the Metallurgy Development Department of the Chemistry and Metallurgy Division, Battelle-Northwest. The Department is divided into three R&D Sections--Plutonium Development, Plutonium Research, and Plutonium Product Development.

Assignment of Responsibilities

The Department Manager is responsible for the safety of every activity within the building. The Facility Manager represents the Department Manager and is responsible for the safe and continued operation of "facility services" such as electric power, building integrity, alarm systems, and management functions involving nuclear safety. He is also responsible for giving orientations to people unfamiliar with the building, to acquaint them with the criticality, radiation, and contamination potentials.

Laboratory monitors are assigned to each individual laboratory and are responsible for operations and safety in that laboratory. It is the

monitor's responsibility to comply with established safety practices and procedures. Section managers have the responsibility of assuring compliance with safety regulations by those reporting to them.

An engineer from the Metallurgy Development Department is assigned to the position of department representative to perform all liaison with Critical Mass Physics and Nuclear Safety Department with regard to criticality safety and Criticality Safety Specifications. He originates Criticality Safety Specifications (CSS) as needed, and checks to see that the specifications and their limits are read, understood, posted, and followed. Any design changes or process modifications which affect criticality potential are submitted for review by Critical Mass Physics.

Two radiation monitors are permanently assigned to the 231-Z Building. The monitors determine the radiation levels that exist in various parts of the building, and assist with all nonroutine activity in which radiation exposure and contamination are possible; such as shipping or receiving radioactive material, filter changes or moving contaminated equipment.

Administrative Controls

1. 231-Z Operating Procedures (BNWL-MA-13). This manual includes all aspects of nuclear, radiological, and personnel safety procedures common to the plutonium development operations performed in the 231-Z Building. A copy of this manual is assigned each exempt staff member and to each laboratory.
2. Formalized Nuclear Safety Procedures as set forth in BNWL Operating Guides and Criticality Safety Procedures (BNWL-MA-25).
3. Mandatory Criticality Safety Specifications which are independently reviewed by Nuclear Safety and Critical Mass Physics.

4. Periodic audits for criticality safety by operating personnel and by Nuclear Safety personnel. (See Item III--Criticality Controls and Limits).

5. Training program for operating personnel. This includes general orientation with all aspects of the Metallurgy Development Department work procedures and familiarization with the operating procedure manual. They are also made familiar with current safety guides applicable to radiological and criticality hazards, and glove box operations. They are then assigned to work with experienced personnel until they become proficient in their assigned work areas.

SAFETY ANALYSIS

I. Fissionable Material Description

Plutonium metal is the principal fissionable material processed and stored in the 231-Z Building. From time-to-time, as programs dictate, plutonium oxide, ^{233}U , ^{235}U , and ^{237}Np are also handled. Normally from 100 to 200 kilograms of plutonium are contained within the laboratories and vaults of the building.

II. Criticality Potential

The presence of large quantities of fissionable material in the facility allows the possibility that a critical mass could be inadvertently assembled, if proper safeguards are not provided.

III. Criticality Controls and Limits

All operations in the 231-Z Building involving fissile material are controlled by Criticality Safety Specifications (CSS). The CSS's are reviewed on a yearly basis and, if required, are modified.

They are usually based on batch control.*

From time-to-time new research or developmental processes are undertaken by the Metallurgy Development Department. The criticality safety is reviewed for any new work involving more than 15 grams fissionable material or if a significant change is made in an existing operation. If it is determined that the work is not covered by an existing specification a new specification is prepared. In the preparation of a CSS, adherence to the two-contingency policy** is always a prime consideration. Every CSS must contain this element of safety. Although neutron absorbing materials or poisons could be used, no credit is taken for them and the two-contingency policy is not dependent upon their use.

The Metallurgy Development Department's Criticality safety representative determines the basic amounts of fissile material necessary for the operation. He submits a criticality safety evaluation request to the Critical Mass Physics Department describing the process and asks for limits. He then prepares a Criticality Safety Specification from the recommended limits supplied by Critical Mass Physics.

The Department Manager reviews the specification and, if approved, it goes to the Nuclear Safety and Critical Mass Physics Departments for further

*Batch control of a fissionable material always limits the size of the batch to less than 0.45 of the critical mass of the material under specified conditions. Batch control also requires spacing between each batch and other fissile material sufficient to isolate the batch.

**The two-contingency policy states that at least two unlikely, independent and concurrent events must occur before a criticality is possible

approvals. The final specification is reviewed with building personnel before being put into use.

Internal nuclear safety audits are performed by the Facilities Manager, and bimonthly audits are performed by a representative of Nuclear Safety Department. Immediate action is taken on any suggestions or requests that will improve the criticality safety program.

IV. Contingencies Arising from Operations

The following description of operations and contingencies relate to specific areas of activity within the Department and are intended to describe the scope of the work performed in the 231-Z Building:

A. Receiving Fissionable Material--All fissionable material entering the 231-Z Building is received by the vault custodian through the southwest entrance of the building.

The following controls are enforced when a shipment of fissionable material is received:

- Spacing and stacking limitations applicable to the shipping containers are adhered to until the container is emptied.
- A label similar to the following is affixed to the container by the vault custodian. The label requires action by the person who empties or returns the containers.

OFFSITE SHIPPING CONTAINER STATUSH A P O
PLUTONIUM METALLURGY OPERATION

RECEIVED AT PMO:	DATE	BLDG.	RECEIVER
TO BE FILLED OUT BY PERSON REMOVING CONTENTS		TO BE FILLED OUT BY PERSON RETURNING CONTAINER	
BLDG. NO.	DATE	BLDG. NO.	DATE
		☐ CONTAINER EMPTY ☐ FASTENERS SECURE ☐ CORRECT ADDRESS	
REMOVED BY		INSP. BY	

BD-7500-046 (11-61) AEC-GE RICHLAND, WASH.

- As quickly as practical the contents of the containers are removed, repackaged if necessary, and placed in the vaults or in glove boxes.
- The spacing between fissionable material within the shipping containers and any other fissionable material must be at least 3 feet.
- Only one shipping container is unloaded at a time. This facilitates batch control of material during the act of storing it.
- Only personnel experienced in handling fissionable material and cognizant of the hazards involved are authorized to unload shipments.
- Inner shipping containers (in which the fissionable material is handled and stored) are necessarily airtight, and hence watertight.
- Radiation monitoring coverage is required whenever a shipping container is opened.

Contingencies--The amount of fissionable material received in one shipment may vary from a few grams to over 50 kg. These materials are received

in LLD-1, DOT 6M, and RFD Model 2030-1 shipping containers (Figures 6, 7 and 8). The containers are reusable and are maintained contamination-free. The greatest number of shipments involve unmoderated Pu metal buttons which are received in LLD-1 shipping containers, with two cans per container and 1 to 2-1/2 kg Pu per can. The dimensions of the button can are usually 4" dia. x 2-1/2" high. Abbey⁽¹³⁾ states that more than 30 such cans could not be made critical in a fully reflected, tight cubic array. Considering that the cans are unloaded and stored one at a time, the accumulation of large numbers of cans together is not credible.

There are no water supplies in the general area of the vaults where these cans are unloaded. Even if these cans were completely water flooded criticality is not possible if the controls listed in this section are exercised. The specified spacing between cans (and that afforded by shipping containers) is sufficient to keep any number of them subcritical when water flooded. Furthermore the cans are watertight, which precludes dispersal of fissionable material within the water.

B. Transportation and Storage of Fissionable Materials--Transportation and storage of fissionable material is covered by CSS which limit batches in storage or in transit to a maximum of 45% of a critical mass. Approved storage locations include glove boxes, refrigerators, cubicles, shelves, and shipping containers. The majority of work in the building involves unmoderated plutonium; separate storage is provided for moderated plutonium. There is no intermixing of moderated and unmoderated fissionable material in the same storage array.

Two storage vaults are in the building. They are constructed of 12-inch thick steel reinforced concrete with bank vault type combination lock doors. There are no water lines or drains in either of the vaults.

KKD-1 and LLD-1 Dot Permit SP-4960
(M-101 and M-102)

FIGURE 6. LLD-1 Shipping Container
26

FIGURE 7. DOT 6M Container - Model 1518
Exploded View

FIGURE 8. RFD Container - Model 2030-1

Floor plans of the vaults are shown in Figures 9 and 10. All fissionable material prepared for transfer or storage is packaged in watertight containers. Material is first placed in a metal can and the lid taped shut. Buttons are stored in the as-received condition (sealed in plastic and a mechanically crimped metal can).

Three types of storage arrays are shown in Figures 11 and 12. These storage arrays are attached to the wall, floor, or ceiling to provide stability. In all cases, the amount of plutonium in each storage location is limited to a maximum of 45% of a critical mass. The vault custodian is the only person allowed to enter or remove material into or from the vaults, and he is responsible for keeping the vault inventory. When a transfer is made, it is mandatory that the custodian enter the transaction and the transferee verify the transaction record. An inventory sheet used for this record is shown, Figure 13. This inventory sheet is also used wherever fissionable material is processed or stored.

Contingencies--If fissile material is stored properly in the vault, there is no credible cause of criticality. If flooding occurred, and cans remained as stored, criticality is not possible, since the cans are watertight and the batch of cans in each cubicle is limited to 45% of critical mass and is isolated from other fissile material. Collapse of the racks is not credible, since they are constructed of 16-gauge steel and able to withstand 100 lb per section.

Periodically, parts containing up to 2.6 kg of plutonium are processed and stored in the vaults and laboratory. The numbers of these parts may range up to a dozen. It is physically possible to stack such parts in storage and/or transportation. Although critical approach

FIGURE 9. Vault "A" 231-Z Building

FIGURE 10. Vault "B" 231-Z Building

FIGURE 11. Vault "A" Storage Racks

FIGURE 12. Vault "B" Storage Rack
33

[illegible]

FIGURE 13.

measurements have not been made, Stevenson⁽¹⁴⁾ has reported data that are pertinent. Based on his data and the assumption that full reflection might reduce the critical mass by a factor of 2, it is concluded that for a critical mass to be achieved, a stack of at least 12 parts would have to be assembled. However, a number of factors mitigate against achieving such an assembly. These are:

- No operation or program objective promotes such action.
- Criticality Safety Specifications prohibit such assembly.
- It is probably impossible to achieve this degree of stacking of such parts without assistance or special support.

A fire in the vault would be limited to a very small amount of exposed combustible material estimated at 100 pounds, not including painted surfaces. Storage of canned plutonium oxide in cardboard separator boxes is allowed in the vault. A maximum of 50 cartons (1.4 lbs/carton) is allowed.

If a fire were started in a vault the fire fighting procedure would be that recommended for any class D* location. In the unlikely event that the fire became too intense for entry, or if the fire occurred during off hours, the fire department would attempt to prevent all entry of air to the room, causing the fire to smother itself.

C. Rolling--A variety of rolling operations with fissionable materials are accomplished in the 231-Z Building. These include

*Fissile materials facility fire fighting category D, which allows the use of water only in the form of high expansion foam.

fabrication of fuel element plates, rolling stock for foils, phase stability studies, and general preparation of rolled sheet.

The mill is installed in a completely evacuable glove box. Other than being an evacuable chamber, the mill glove box is standard; it utilizes a 4-inch Fisher-Governor regulator valve for ventilation control. The rolls and feed tables may be heated for elevated temperature rolling. A recirculating oil system provides coolant and lubrication for the roll bearings. The rolls are reversing, which allows alternate rolling in both the forward and reverse direction.

Contingencies--A possibility for room or personnel contamination exists by either burning a glove on the heated feed table or by pulling a glove off during glove box evacuation. The glove box is equipped with special glove port covers to minimize the potential for either accident. These covers are put in place whenever the gloves are not in use or when the glove box is to be evacuated. The gloves are continually inspected during the pump-down operation. If a glove were accidentally pulled off or burned only minor room contamination would occur.

Approximately 5 gallons of hydrogenous liquid could enter the glove box if the roll bearing oil line were to rupture. The floor of the glove box would be covered with oil to a depth of approximately one-half inch. Dispersal of the fissionable material allowed in the glove box into this thickness of oil could not cause criticality. An oil thickness of at least 2.35 inches would be necessary.

D. Pressing--Numerous hydraulic presses are available in the facility. They range from a relatively small 50-ton capacity press to a massive 5000-ton capacity unit. Typical uses include part fabrication by forging, and

enhancement of properties by isostatic pressing. The presses are installed in or around glove boxes for work with fissionable materials. The pressing operations are similar to any die operation with nonradioactive materials.

A 100,000 psi isostatic facility is also available. The process uses high pressure oil to achieve isostatic conditions. In the operation, samples are placed in a die containing a special oil which remains liquid at the high pressures. The pressure vessel is heated to the desired temperature, closed and sealed, and oil is pumped into the vessel cavity until the desired pressure is reached. The pressure is maintained for a selected period of time then the cavity is decompressed through a throttling valve into a container inside the glove box. The samples are removed from the vessel and evaluated in other laboratory equipment.

Contingencies--The potential exists for dies or other equipment to fail and cause fragments of plutonium or contaminated material to penetrate the gloves or glove box panels. Shields are placed around dies and over glove ports to minimize this possibility of shrapnel penetration with the resultant contamination of rooms and personnel. If a fitting or valve in the high pressure line were to fail while the vessel was pressurized it is possible for the chamber to decompress and discharge the oil (contaminated) into the room. The equipment is designed with a minimum number of joints in the room. If possible, joints in the piping are made inside the glove box. Two pressure sensing recorders in the control panel would indicate a leak and alert the operators to the malfunction. If a failure were to occur inside the glove box and all the high pressure oil was pumped into the glove box, the resultant oil depth would not exceed one inch. The operators continuously monitor the system during the high

pressure cycle. Emergency controls are provided to instantly shut off all hydraulic equipment.

E. Gaging--Precision dimensional inspection of fabricated plutonium components are routinely made using a Sheffield rotary contour gage. The gaging glove box is connected to the central glove box conveyor system but is isolated from the conveyor system by hydraulically operated air lock doors. Isolation is required to allow the precise temperature control necessary to achieve accurate dimensional inspection. Parts to be inspected are placed on a precision manipulating fixture and the inspection process is controlled by a technician from outside the glove box.

Contingencies--The gaging process has no affect on geometry, moderation, or reflection. There are no internal sources of oil, water, or other moderating liquids. The potential for inadvertently assembling a critical mass is considered extremely low. In no case is more than 45% of a critical mass of plutonium in the form of fabricated components allowed in the glove box.

F. Radiography--Plutonium components are removed from glove boxes using standard plastic bag techniques and are transferred to a lead enclosure where they are radiographed using a Morelco 300 KV x-ray machine.

Contingencies--There are no credible criticality accidents that could occur during or because of radiographic inspection. Only one item at a time is removed from the glove box system for radiographic inspection. Standard spacing is maintained as the plutonium part is hand-carried from the glove box to the radiographic area. Any one component is a small fraction of a critical mass and there is no credible opportunity for a significant change in geometry, moderation, interaction, or reflection.

During handling or manipulation of the packaged plutonium the plastic bag may be punctured, the welded bag seam may fail, or the technician may drop the package to the floor rupturing the bag and releasing significant amounts of plutonium to the laboratory room. Similar accidents involving failure or rupture of a plastic bag have caused airborne plutonium concentrations in the range of 10^{-10} microcuries per cubic centimeter. While airborne plutonium concentrations of this magnitude are significant, the building ventilation system is designed to control these emergencies and no release of plutonium to the environs would be expected.

The dangers and hazards associated with operating x-ray equipment are recognized. Only a certified nondestructive testing technician is allowed to operate the equipment.

G. Plutonium Heat Treating and Quenching--Plutonium is heat treated by holding the metal at a desired temperature for prescribed times. The temperatures may be any temperature between room temperature and the melting temperature, and the heat treating times vary between a few seconds and many weeks. The metal may be heat treated in liquids, in vacuum, or in inert atmospheres. Liquids used for heat treating are nonflammable fluids that are subjected to either an inert atmosphere or to a vacuum. The vacuum heat treatments are performed either in a dynamic or a static vacuum. Heat treatment in a dynamic vacuum is performed in tube furnaces. Heat treatment in static vacuum is normally performed outside the glove boxes in salt baths after the specimens are sealed in quartz or glass. The samples are quenched by directly immersing the metal into a liquid, which may vary in temperature from -100°C to $+25^{\circ}\text{C}$.

Contingencies--The specimens are laboratory specimens so the amount of plutonium is generally much less than the glove box limits, which are established on the basis of 45% of a critical mass. Limits are placed on the amount of plutonium, the volume of liquid, and the size of the liquid containers.

Widespread contamination caused by fire or any other accident is remote because 1) nonflammable liquids are used, and 2) heat treatments using high temperature fluids employ temperature control systems in which at least two failures must occur before the temperature will exceed 300°C. The salt baths are limited to 600°C by the design of the equipment and they are under constant surveillance when in the glove boxes. The salt baths outside the glove boxes are kept in a restricted area prohibiting the presence of all organic materials.

H. Electron Beam Welding--The electron beam welding equipment is neither equipped nor intended to be used to directly join radioactive materials. However, the facility is designed to make EB weld closures on encapsulated radioactive materials.

A work chamber 53" x 36" x 36" is connected to a vacuum system consisting of a 10" diffusion pump backed by a 300 cfm roughing pump. The work chamber has doors on both ends for loading, unloading, and for installation of special jigs and fixtures. A precision work table that can be both electrically or manually driven allows X-Y manipulation of the work beneath the fixed position electron beam. Windows on both doors and on the front panel allow optical viewing of the workpiece during processing. The machine is rated at 6 KW (150 KV at 40 ma).

Items to be welded are placed within the work chamber and positioned on the work table. The chamber is evacuated and the welding operation is completed. Interlocks prevent the energizing of the EB gun until suitable pressures are attained. Welding parameters are established on materials which do not contain radioactive materials.

Contingencies--The final weld closure on encapsulated radioactive materials may be accomplished during a typical operation. However, the chances of achieving criticality are considered nil. Items are processed one at a time. The mass in the chamber is limited to 0.45 of a critical mass and neither geometry, moderation nor reflection are affected by the process. There are no internal water or hydraulic lines. The only source of moderating liquid is the vacuum pump oil and although the mechanism is not immediately apparent, if all the vacuum pump oil were vented to the work chamber, it would form a layer of oil approximately 2" thick on the chamber floor. A housekeeping mess to be sure, but of little consequence, otherwise.

If, during the welding process, the electron beam were to completely penetrate the encapsulation material and strike the radioactive material, gross contamination could occur to all surfaces within the chamber. This potential was considered during the design of the equipment and the chamber and vacuum system were connected to the building glove box exhaust system to safely contain and control whatever contamination may occur. Standard decontamination procedures would be followed to clean up the equipment.

The possibility of a fire or explosion occurring within the chamber during a welding operation is not considered credible. The operation

is performed under vacuum and even if the chamber were to suddenly vent to atmosphere, there would be nothing combustible available to burn.

There are some low level X-rays generated when the electron beam strikes the workpiece. These X-rays could present a hazard to operating personnel. Lead shielding built into the work chamber reduces the x-ray level to less than 2.5 mr/hr and the equipment is checked frequently by radiation monitors to assure safety.

I. Electrical Discharge Machining--Electrical discharge machining is used 1) as a damage-free method of trepanning samples from plates or other shapes, and 2) in conjunction with an ultrasonic thickness gauge as a method to achieve extremely accurate and uniform component thicknesses. Only equipment capable of item 1 above is presently in service; however, equipment capable of item 2 above will be put into service shortly and the following discussion assumes that the operation is, in fact, in place. A final review of the operation will be made prior to issuance of a CSS.

A plutonium part is held in a suitable manipulating fixture, partially submerged in oil, and an electric arc is used to remove metal. The cutting tool is generally brass or graphite and is hollow to allow oil to flush through the tool and onto the part. The oil cools the part and also sweeps away the metal fines that are produced in the operation. Both the amount and concentration of plutonium in the oil will be held to limits defined by a special CSS. Metal removal rates are low, normally less than 0.001 inch per pass, and the total metal removed in any one operation would be less than 100 grams. When the planned operation is completed, the oil is drained from the work chamber into a reservoir. During EDM operations the oil and plutonium fines are continuously slurped from the workpiece while

have to ignore the obvious change in the condition of the oil (all tanks and reservoirs are intentionally made of transparent materials to allow this observation). The minimum critical mass for the system (570) grams will be approximately 600% above the operating control limit and it is extremely unlikely that this mass could be accidentally accumulated.

The oil used as the dielectric has a flash point of 300 F and an ignition temperature of 332 F. The EDM operation involves very little power and the temperature rise in the work tank is almost undetectable. It is difficult to imagine an ignition source for the oil; however, if a fire did develop and could not be controlled by the use of the available dry chemical extinguishers, then gross contamination may occur within the room. If the fire spread through the ventilation duct work, then some discharge of plutonium to the environs could result. The consequences of this type of accident are described elsewhere in the report.

J. $^{238}\text{PuO}_2$ Sugar Mixtures--A special glove box has been prepared for working with plutonium oxide containing about 20 wt% $^{238}\text{PuO}_2$. This oxide, mixed with sugar and a small quantity of water, is heated and poured into special geometrically safe containers for eventual use by the Critical Mass Physics Dept.

Contingencies--If through error, 100% ^{239}Pu oxide was used in the process a critical mass could not be assembled because of limitations in the quantity of moderating material and the volume of mixing vessels.

The criticality controls for the operation take into consideration the moderating material (sugar), shape, and amount of plutonium oxide in the box. Limits are such that there is never more than 45% of a critical mass in the box at one time.

oil is supplied through the cutting tool. The oil may be either:

1) pumped through a 5-micron filter where the plutonium fines are removed, or 2) pumped into a high speed centrifuge where the fines accumulate as a cake, or 3) may be routed directly back through the tool.

Contingencies--The degree of criticality safety of this operation depends on the mass of plutonium in the work tank and the amount of plutonium in the form of fines which may accumulate in the oil. Conservative limits are placed on both so that under normal operating conditions there is less than 0.45 of a critical mass within the glove box. In addition, limits are placed on the quantity of oil in the glove box and on the total amount of plutonium that may be "assigned" to the oil recirculating system. Plutonium parts are weighed before and after the process and the difference is assigned to the oil system. Credit is taken (based on analytical results) when a filter is changed or when the centrifuge is cleaned. Analytical samples are regularly taken from the reservoir to determine the plutonium concentration that develops because of filter or centrifuge inefficiency.

The minimum critical concentration for a 30-liter vessel is 19 g/l.* The minimum critical mass would be 570 grams assuming the vessel were fully reflected. Even if the filter or centrifuge were to malfunction and allow all of the plutonium fines to be dumped back into the work tank a criticality hazard would not exist. Oil from the work tank that is not filtered or centrifuged becomes very black and opaque. The operator would

*HC Paxton, et al, Critical Dimensions of Systems Containing Uranium and Plutonium, TID-7028.

The additional radiological problems associated with ^{238}Pu were taken into consideration during the fabrication of the glove box (no rubber seals, special gloves, etc.); in addition, extra caution is taken with glove change, bagout, etc. to reduce the potential of a contamination incident.

K. Criticality Cubes--The Critical Mass Laboratory uses 2" cubes of plutonium oxide-polystyrene in some of their experiments. These blocks, containing various ratios of plutonium to hydrogen are fabricated in the 231-Z Building.

Plutonium oxide blended with polystyrene powder is heated, pressed and then cooled in a die to produce the 2" cubes.

To date, two ratios of hydrogen to plutonium have been used: 5 to 1 and 15 to 1. The calculated critical mass of these mixtures is 14.5 and 11.9 kg of plutonium respectively.

Contingencies--The working limit established for this glove box by a criticality safety specification takes into consideration the amount of moderating material, and the hazard from double batching. There are oil and water lines within the glove box. The hydraulic oil is contained in a recirculating system. The water, in a cooling coil, makes one pass and is piped to the 231-Z holding crib. The capacity of the hydraulic oil reservoir is limited so that in the event of a leak it would not flood the glove box floor to a depth of more than one inch. The glove box is equipped with a moisture detector connected to a fail-safe water valve to shut off the water supply in case of a leak. These administrative controls and engineered features provide assurance that a critical mass will not be accidentally assembled.

L. X-Ray Diffractometers--X-ray diffraction work is conducted in two separate locations in the 231-Z Building. Facilities for use with plutonium or plutonium-bearing materials consist of glove box enclosed commercial x-ray diffractometers and they are available in each location. One location is devoted primarily to room temperature phase identification work while the other is equipped for elevated temperature work, as well as room temperature investigations.

Contingencies--The criticality potential in either of these facilities is inconsequential because the number and size of the samples are small; the total amount of plutonium permitted in each glove box is limited to less than 230 grams. Fire is only a remote possibility because only limited amounts (less than 50 ml) of flammable liquids are permitted and then only under carefully controlled conditions, such as inert atmosphere and no source of ignition. Potential for persons receiving harmful dosage is low because 1) the energies of the X-rays are small, 2) the X-rays are directed through narrow slits, and 3) shielding is used.

M. Structure and Impurity Analyses--Plutonium structural analyses is performed using optical and electron microscopy and with x-ray diffraction cameras. Specialized impurity analysis is conducted by means of an electron microprobe. These instruments involved in the analyses are standard and typical of those used in the field. They are not enclosed in glove boxes.

The electron microscope is not involved directly with radioactive samples. The sample surfaces are prepared in the metallography glove box and they are examined by means of replicas, which are prepared in either a separate glove box or in an open-faced hood. Decontamination procedures

are necessary only on cellulose acetate replication tape which has been softened in acetone and applied to the sample surface; the amount of acetone is restricted to a few milliliters. At least two replicas are prepared and discarded to minimize contamination during subsequent replication. The final replica is cleaned in 0.5N hydrochloric acid and finally in distilled water, ultrasonically, until the smearable contamination activity was reduced to less than 500 D/M.

Contingencies--There is no possibility for criticality because of the very small laboratory samples used in the analyses. Widespread contamination is also not a possibility for either the microprobe analysis x-ray diffraction, or the metallograph because only a small amount of metal is handled at one time.

II. Vapor Degreasing-Ultrasonic Cleaning--The equipment for this operation consists of a double tank arrangement each with a 60-liter volume of fluid. The tanks are essentially equal in shape with dimensions of 13 x 14 x 20 inches. In addition, they are separated horizontally by a 4-inch air gap. One tank is used for degreasing, the other can be ultrasonically agitated. A part held in a tray designed to hold only one part, is immersed in the degreasing tank for a short period of time to remove various greasy residues. It is then transferred to the second tank and immersed in the ultrasonically agitated fluid. As an added precaution to prevent double batching in this operation there is only one suspension hook for handling the tray and only one tray is supplied for the glove box. At the present time Freon 113, a nonhydrogenous fluid, is in use. The parts normally cleaned in this facility can contain up to 2600 g of plutonium. None of the cleaning fluids contemplated for use have a gross corrosive or oxidizing affect on plutonium.

Contingencies--In order to achieve criticality it would be necessary for a substantial portion of the 2600 g of Pu to be oxidized and dispersed in a moderating fluid inadvertently put in one of the tanks. The inadvertent substitution of an unknown fluid in the tanks would be detected by the operator upon start-up of the degreaser prior to immersion of the part. The operating characteristics of the degreaser is quite dependent upon the fluid in use. Based on this analysis it is concluded that the occurrence of a criticality incident in this facility is not credible.

Barring the inadvertent introduction of a highly volatile and low flash point degreaser fluid the potential for release of radiological materials from this facility is considered comparable to that for normal glove box operation.

0. Arc Melting--The equipment involved in this operation consists of an evacuable chamber containing a water cooled hearth with five stations for producing up to 200 g buttons of plutonium alloys. The operation consists of positioning on the hearth up to five charges of solid plutonium metal and alloying element. The hearth is raised to close the chamber which is then evacuated and backfilled with argon. The charges are then arc melted individually, one per station on the hearth.

Contingencies--Flooding of the chamber with water during arc melting, plus complete oxidation of a 1000 g charge, would present the greatest potential for a criticality incident. Immersion of the five 200 g charges in any array in the water-flooded chamber is much less than 45% of a critical mass. The chamber has an ID of 15.5 inches, a height of 16 inches with a volume of 49 liters. The maximum amount of plutonium alloy involved would be 1000 g since each of the five hearth stations can only accommodate

a maximum of 200 g for successful arc fusion. Flooding of the chamber could result from a water leak in the hearth. Whether the chamber could fill or not is open to question since, during operation, the leak would be quickly observed by the operator and the water shut off. The water to the hearth is normally shut off at the end of the melting of a group of buttons or the end of the working day.

In view of the foregoing discussion, the possibility of a criticality incident involving the arc melting facility is not considered credible.

P. Downdraft Table--The downdraft table has two important functions, 1) to allow contamination-free assembly of plutonium components within a nonradioactive jacket, and 2) to allow the contamination-free loading and unloading of special shipping container inserts.

The downdraft facility is not a glove box but is a specially designed room containing a table built into a high velocity ventilation system. The table has a slightly recessed top area of approximately 3-1/2 square feet. The table top is a heavy gauge stainless steel wire mesh grid. Plutonium material may be transferred from the central glove box conveyor system directly to the downdraft table through hydraulically operated air lock doors. The key to the safe and successful operation of the downdraft table is the streamlined high velocity air movement through the table grill work. Plutonium parts must be handled over the grill work for the air stream to capture and contain the plutonium contamination.

During normal operations, 2000 cfm of air moves through the table top. The air is recirculated through two absolute filters before returning to the work room. Approximately 200 cfm of clean dry air is

continuously added to the stream. Air discharged from the system is directed to the building glove box exhaust system. During standby operations, the recirculating system is turned off and only the 200 cfm make-up system is in operation. This flow is necessary to keep contamination from the table top grill from spreading to other parts of the room.

A radiation monitor is present during all operations, and all personnel working in the room wear full assault masks. An intercom system allows communications with personnel outside the facility. The work room is maintained at a negative pressure ($1/2''$ H₂O) with respect to the surrounding laboratory.

Contingencies--neither of the primary functions of the downdraft facility present credible criticality situations. There is never more than 0.45 of a critical mass assembled at any time. As one would expect, a weapon assembly consists of precisely dimensioned and toleranced components. It is inconceivable that the wrong number of components or components of erroneous size and weight could be assembled. It is also not possible to comprehend the availability of components, or the sequence of events that could allow a critical mass to accumulate during any phase of the downdraft table operation.

Bare plutonium components are handled on the downdraft table. In some cases, the plutonium may have been stored in a shipping container for months and may be oxidized. Such problems are anticipated and full respiratory protection is required for all operations. If, during normal downdraft table operations, there was a power outage or some other malfunction in the ventilation system, gross contamination could occur in the work room. Personnel could evacuate through the air lock between the work

room and the laboratory. The work room is designed with vinyl coated walls and polished metal surfaces to simplify decontamination. The major contamination would be contained within the room.

If a fire occurred on the downdraft table, it could present one of the more serious radiological accidents in the facility. The potential for a fire is exceedingly small. There are no flammable gases or solvents used in the operation or available anywhere in the facility and all operations are performed at room temperature. There are at least two and generally three people working inside the room and at least one observer outside the room. A fire would be instantly detected. MgO sand and dry chemical extinguishers are available to control the fire. In certain cases (metal fires only) the material may be placed back in the inert atmosphere of the glove box conveyor system. In the worst case, the burning material may be drawn through the work table grill and into the ventilation system. Burning material could impinge on the first of a series of three 24" x 24" x 12" fire resistant high efficiency filters. If the fire could penetrate three successive filters, then plutonium could be discharged to the 200-West Area environs. This accident is considered credible but extremely unlikely because:

- A fire would have to develop in an area containing very little combustible matter.
- Fire control efforts would have to fail.
- The burning of a very limited quantity of combustible matter would have to damage and penetrate three successive fire resistant absolute filters.

Q. Vapor Deposition--Vapor deposition consists of the transfer of atoms and/or groups of atoms from a source across an ionized plasma or evacuated space to a substrate which retains the deposited material. The atoms or groups of atoms are obtained from the source by ejection as a consequence of ion bombardment or by evaporation. The plutonium source, because of its geometry, is always less than 45% of a critical mass. During any one operation up to 2.6 kg of plutonium may be transferred from the source to the substrate.

Equipment requirements for this operation include vacuum systems with 10^{-9} torr capability, power supplies with ratings ranging from 10 amp at 3000 V to 400 amp at 10 V, a pressure controller, and an evacuable cylindrical chamber equipped with water cooling and power feedthroughs.

Contingencies--The accidental oxidation of all of the plutonium metal to plutonium oxide in the event of a water leak presents the greatest potential for an incident. For the oxide generated to be critical in water a spherical volume of 4.5 liters would have to be exceeded. The design of the chamber prevents this in two ways. First, the unobstructed volume in the chamber is not spherical. Secondly, the volume is less than 3.5 liters. In addition, a water leak during deposition automatically causes loss of vacuum which terminates the operation. Filling of either the chamber or glove box with water is prevented by fail-safe switches which shut the water off. As an additional safety feature the operation is under continuous surveillance by the operator and/or process control computer. Deviation from normal operation is quickly determined and corrective action taken.

The possibility of double batching sources is eliminated by the size of the deposition chamber which can only accommodate one source at a time.

Based on the foregoing analysis it is concluded that the operation is critically safe under credible accident conditions.

Uncontrolled release of radioactive material from the glove box depends on the creation of large quantities of steam from a sustained hot plutonium source-water reaction. This is not considered credible for several reasons. First, the water is automatically shut off as a consequence of the water leak itself. Second, termination of the deposition causes the source to cool down thus restricting the heat available to sustain steam generation. Third, the components of the chamber are bolted together reducing the potential for release of even minor amounts of steam to the glove box. Although considered unlikely in view of the foregoing discussion, should the pressure in the chamber exceed ≈ 15 psi there is a possibility that the ion gage tube outside the glove box would rupture. This could cause the release of an unknown amount of alpha contamination. The rupture would immediately be detected by the operator and the room evacuated. No unusual problems would be expected to be encountered during the ensuing decontamination. Based on this discussion it is concluded that the operation is safe with respect to the uncontrolled release of radioactive materials from the glove box.

R. Sulfamic Acid Dissolution of up to 1.0 kg Plutonium--Periodically, it is necessary to remove up to 1.0 kg of plutonium from plutonium clad metal units by a sulfamic dissolution process. The process of

removing plutonium from base metals by sulfamic acid dissolution has been in routine use in the 231-Z Building for many years, but under a 230 g Pu glove box limit. Since the upper limit for this operation is over the minimum critical mass for the Pu-H₂O system (510 g), more extensive controls are required than for the standard dissolution process.

Sulfamic acid is received as a powder and mixed with water outside of the glove box prior to starting the dissolution process. This minimizes the possibility of substituting an acid which might react violently with the plutonium. Before the Pu-clad metal unit is immersed in acid the total Pu weight must be established by two independent weighings. The material is logged into the glove box on the standard double-signature inventory sheet used throughout the building. The amount of plutonium in the glove box is limited to 1.0 kg (max). No more than 5.0 liters of sulfamic acid is permitted in the glove box. An additional 1.0 liter of rinse water is permitted (6.0 liters solution total). Two dissolution of rinsing pans 12 in. dia. x 3 in. deep (max) are permitted in the glove box at one time. In addition, three 2-liter bottles for solution loadout are permitted. No water lines are permitted to the glove box. Only measured amounts of liquids may be introduced into the glove box. Sulfamic acid is the only acid approved for this operation (use of this acid chemically limits the concentration of plutonium in solution to 134 g/l).⁽¹⁵⁾

Contingencies--The criticality safety for this operation is based on the following critical parameters:

	Degree of Reflection		
	Bare	Nominal	Full
At 134 g/l Pu			
Minimum critical volume, liters	14.0	11.0	7.0
Minimum critical slab thickness, in.	4.3	3.2	2.0
For 1.0 kg Pu			
Minimum critical volume, liters	20.0	12.8	8.0
For 2.0 kg Pu			
Minimum critical volume, liters	14.0	10.1	6.2

In the extreme case, it is possible that 6.0 liters of plutonium solution could come together; however, based on the above table, it could not go critical without extra liquid and moderation.

The bottles with the plutonium-sulfamic acid solution are normally stored in the vault. These bottles are not stored for long period of time, normally about one week. As soon as a plutonium analysis is received the bottles are transferred to the ARHCO Recovery Unit. Should radiolytic decay cause evolution of gas, and if this gas pressure was enough to rupture a bottle no serious problems are expected other than the decontamination operation which would be necessary.

If another acid was accidentally substituted for sulfamic it is possible a violent reaction with the plutonium could occur. There is no criticality hazard because there is a maximum of 6.0 liters of liquid and 1.0 kg of plutonium. A homogeneous mixture of this concentration cannot go critical even with full reflection. There would be no pressurization or hydrogen concentration that would endanger the glove box because the glove box control system would remove and dilute the excess gas. There is a flow rate of approximately 50 cfm. It is inconceivable that any reaction would occur that would produce hydrogen fast enough to produce an explosive mixture.

S. Plutonium Casting--Plutonium is rarely, if ever, available in a form or shape that would allow direct use in a fabrication or research and development program. Melting and casting are used to achieve desired shape, purity, and metallurgical condition. Plutonium is a reactive metal and melting and casting must be done in a protective atmosphere. Most casting operations are performed under vacuum.

Induction melting equipment up to 30 kW rating is available for the operation. Oxidized tantalum crucibles are commonly used to hold the plutonium during melting although suitably protected graphite crucibles may be used. Melt temperatures of up to 1700°C may be necessary at times, but temperatures in the range 1000 - 1300 degrees centigrade are generally the case. Graphite is the best all around mold material for plutonium casting because it is inexpensive, easy to protect, easy to fabricate, light weight, and has adequate strength at casting temperatures. Graphite must be washed with a protective coating to prevent carbon pickup by the molten plutonium. In a typical casting operation, plutonium is placed in the melt crucible and a suitably prepared mold placed in proper position underneath. The bell jar is closed and evacuated to the micron range. Heat is applied to outgas the mold (resistance strip heaters are clamped to the mold for this purpose). The mold is heated to the necessary temperature to assure filling of the mold cavity. This is generally in the 500 to 650 degree centigrade range. The plutonium is heated to desired temperature and poured into the heated mold. The specific casting technique used depends upon such things as mold size, mold temperature, melt size and melt temperature.

Contingencies--The casting operation processes more plutonium than any other facility in the 231-Z Building. Hundred of kilograms are melted and cast each year. The object produced by casting may weigh from 60 grams each to approximately 6.5 kilograms each, which is less than 45% of a minimum critical mass in this operation. There are two basic operating modes--one for castings weighing up to 4.6 kilograms and the other for castings greater than 4.6 kilograms but less than 6.5 kilograms. The two modes of operations differ significantly only in two areas--melt crucible diameter and required review and approval of molds.

It may also be possible to cast the molten plutonium into a mold that is not safe by geometry or the mold may become damaged or partially disassembled and the plutonium could freeze in other than the desired location or shape. Every mold used for castings greater than 4.6 kg must be specifically approved by the Senior Specialist, Critical Mass Physics, with assurance that the two-contingency policy is not violated.

Heavy reliance for criticality safety is placed on administrative controls and on the sound judgment of highly skilled personnel. Certain mandatory rules are followed for all casting operations. Entry or removal of plutonium requires the standard witnessing and weight verification on the glove box inventory sheet. There is no more than 200 cubic centimeters of hydrogenous liquid permitted in the glove box. (This does not include hydrogenous liquids contained in the cooling coils). Only one crucible charge is permitted in the glove box at one time. This material must be melted, cast, and removed from the glove box before material for the next charge is brought in. The plutonium must be kept dry at all times. Whenever water is flowing in cooling

coils in the glove box, continuous operator surveillance is provided to assure quick shutoff in the event of a leak.

T. Machining--Conventional machine shop lathes are enclosed in glove boxes to allow machining of plutonium bearing materials. The objectives of the machining operation are to achieve specified dimensions and surface finish. Occasionally, useful components may be salvaged by machining the plutonium from them.

Items to be machined are securely positioned in the lathe chuck. Machining variables such as spindle speed, tool configuration, depth of cut, feed rate, and type of coolant or lubricant are selected based on the material to be processed. Because of the pyrophoric nature of plutonium, all machining operations are conducted in a nitrogen atmosphere. Turnings generated in the process are continuously collected and packaged in metal containers.

Contingencies--The change in geometry which occurs during machining is in the safe direction. A less concentrated metal system results. Hydrogenous liquids may be used as a lubricant during machining. On these occasions, the lubricant is manually applied to the part with a brush. The amount of hydrogenous liquid is limited; however, a large oil supply for operation of a hydraulic spindle is present for one of the lathes. If all of this oil were pumped into the glove box and all of the plutonium present was dispersed in this oil the minimum critical height under this condition would be 6.3 inches. The amount of oil available would only reach a maximum height of 4.9 inches. As an additional safety factor, the containers used to store turnings are limited to a volume of one liter or less. There is no combination of allowable liquid and 1-liter contain-

ers that could be assembled into a critical mass. There are, by design, no reservoirs where the liquid could accumulate in a shape other than a critically safe slab. To have the potential for a critical mass, double batching must occur, the material must be of favorable geometry, an oversize container must be available, and then the plutonium must be intentionally submerged in the hydrogenous liquid. This sequence of events is not considered credible.

Fires occasionally occur during machining operations. They are generally of little consequence because of housekeeping practice; such as minimizing accumulation of turnings in metal containers, use of oxygen lean atmospheres, availability of fire control materials, and the lack of flammable solvents and other combustible materials. However, because of the pyrophoric nature of plutonium, especially when in the form of chips or fine turnings, the danger of a glove box fire is ever present.

The most likely malfunction that could increase the potential for a fire would be loss of the inert glove box atmosphere. This could occur if a glove or plastic bag were accidentally punctured or if the building nitrogen supply system was exhausted (due to some unexpected high usage between scheduled fillings). Simply losing the glove box inert atmosphere would not necessarily in itself trigger a fire. There would also have to be a source of ignition. This could, admittedly, be a relatively minor act such as movement of a can of turnings. The consequences of a fire of this type are covered elsewhere in the report.

U. Metallography--Metallography is the examination of the structure of metals using the optical microscope. Metallographic preparation consists of 1) sectioning specimens, 2) mounting the specimens in plastic, 3) machining the metal surface, 4) grinding the metal surface, 5) polishing the surface to a mirror finish, 6) etching to delineate the microstructure--etching may be chemical, electrolytic, or cathodic etching, and 7) microscopic examination. Each of these seven operations are performed in a separate section of the glove box. Elevated temperature metallography is performed in a separate glove box facility.

Contingencies--The potential for criticality is remote because the operations are limited to a maximum of 45% of a critical mass. The amount of metal in each plastic mount, the size of the mounts, the volume of liquid, the type of liquid, the geometry of the liquid containers, and the total number of mounts are all carefully controlled using design and administrative controls so that the limit of 45% of a critical mass is not exceeded. Conservative assumptions are made in calculating the limits; for example, it is assumed that 1) the Pu metal-plastic system is equivalent to the Pu-H₂O system, and 2) the metal is dispersed instead of in lumps as in the actual situation, 3) spherical geometry, and 4) solid array of specimens. None of these conditions are ever met. The number of specimens in each compartment of the glove box is limited and it is carefully monitored to see that it is not exceeded. No water or hydraulic lines are connected to the glove box. The amount of moderating materials, including the plastic mounting material, is restricted and controlled.

Widespread contamination from fire is not likely because non-flammable liquids are used in all stages except in etching. Etchants may consist of a number of flammable liquids, such as alcohol, but the potential for a fire during etching is minimized by 1) using inert atmospheres, 2) constant surveillance, 3) using limited quantities of flammable liquids, and 4) keeping only a small amount of combustible materials in the etching compartment.

V. Mechanical Property Determinations--Mechanical property determinations of plutonium and plutonium alloys are conducted in a number of glove boxes in the 231-Z Building. Examples are tensile testing, compression testing, high strain rate testing, creep studies, biaxial stress testing, hardness measurements, and fatigue testing. The tests are performed with the plutonium in a number of environments. The material may be tested in either vacuum, air, inert atmosphere or liquids depending on the specific test being conducted. The materials are laboratory specimens that generally weigh less than 200 grams each.

Contingencies--Criticality is not likely because the amount of plutonium, specimen shape, vessel geometry, the volume of liquid, and type of liquid for each operation are controlled so that the glove box limits are less than 45% of a critical mass.

Widespread contamination is possible only if a large fire were to occur. Nonflammable fluids are utilized to preclude the possibility of a fire. Occasionally a flammable liquid is required for a specific experiment; however, no liquid is used that has a flash point below 300°C. To insure that the flash points are not exceeded, a temperature control system is incorporated into the tests; the temperature is monitored, a

maximum temperature is guaranteed by a second controller, and the amount of power input is restricted.

W. Density Determinations--Density measurements are made using a fluid buoyance technique based on Archimedes' principle. The weights of the specimen are first measured in the glove box atmosphere and then measured in a fluid. The density is calculated using these two measurements. Some examples of the displacement fluids are: carbon tetrachloride, Freon, and inert fluorochemicals. The equipment used is based on the size of the sample. The process can be divided conveniently into four weight classifications; that is 0 to 100 g, 0 to 200 g, 200 g to 1 kg, and up to 3 kg.

Contingencies--Criticality is avoided in the facilities that use balances having capacities up to 200 g by limiting the size of the liquid container to less than 3 liters. For density determinations of metal weighing more than 200 g, the fluid is limited to liquids such as carbon tetrachloride and Freon-113 that have low moderating characteristics. The hydrogenous fluids used for precision density measurements are quite expensive (\$150 to \$300 per gallon), are only available in one-gallon containers, and are well marked. It is extremely unlikely that the wrong fluid could be used, but even if water were substituted this error alone would not cause criticality.

Fire is avoided by using inert atmosphere in the glove box and by restricting the use of flammable liquids in the glove boxes.

X. Spallation Testing--In this operation a portion of the energy of a 5,600 joule capacitor bank is deposited in an approximately 1 g, 15 to 30 mil diameter plutonium wire approximately 2 inches in length. The 2 to 10

microsecond time for energy deposition causes the specimen to fracture when the energy deposit is large enough.

Contingencies--Since the specimen size is so small and their number generally less than 25 because of experimental requirements and material availability, the potential for a criticality incident is considered to be much lower than for most glove box operations involving plutonium. The containment of test specimens in teflon or ceramic tubes which are in addition surrounded by a protective shield during the test prevents the contact of specimen fragments with either the glove box walls or the gloves.

Y. Environmental Chamber--The environmental chamber provides a heat treatment cycle which alternately subjects a part to hot and cold temperature. The glove box contains a nitrogen atmosphere and has no hydrogenous liquid lines connected to it. The chamber atmosphere is continually recirculated through a heater and refrigerator section to adjust the temperature. The system is normally programmed to cycle between -65°F and +165°F. These temperatures are near the capacity of the chamber. The construction of the chamber does not add significantly to the reflection. The walls are made of stainless steel sheets with a layer of fiber glass insulating material between.

Contingencies--Because operations are limited to a maximum of 45% of a critical mass, the criticality potential from double batching is minimal. The maximum temperature of the chamber is below the melting point of plutonium, therefore the geometry of the part will not be affected if a controller sticks during the heating cycle. Fire hazards are minimal because of the nitrogen atmosphere. The contamination

which would result from tearing of a glove would provide no more than the usual decontamination problems.

2. Plutonium Burning--It is considered an unnecessary risk to store plutonium turnings or other pyrophoric scrap in the vaults or laboratory rooms. Material with a high potential for ignition is intentionally burned and the safe oxide is stored for eventual return to recovery operations.

Plutonium scheduled for burning is rinsed in a nonflammable, non-hydrogenous solvent to reduce the smoke and flame associated with the burning of oil soaked material. Turnings are placed in a heavy walled stainless steel skillet and are ignited with a soldering gun. The skillet is covered with a perforated lid. The lid prevents significant flame flare-up and allows reasonable slow, safe burning rates by restricting the access of air.

Contingencies--There are no water lines to the glove box. The oxide formed as a result of the operation is weighed and packaged for return to production recovery facilities. The combined weight of metal plus oxide allowed in the burning glove box is limited to 45% of a critical mass. Although the critical mass of oxide in the dry unmoderated state is many times that of solid metal, a limit of 1.5 kg of oxide is allowed to accumulate before removal from the glove box. This limit is imposed for personnel radiation protection rather than criticality consideration.

The heat generated from the burning of plutonium is dissipated through the normal glove box ventilation. The burning pan is always placed on a transite insulation pad to reduce heat transfer to the glove box floor. A criticality in this operation is not considered credible from either double batching or moderation.

If, through carelessness or neglect, the gloves attached to the front panel are not properly secured outside the glove box, they could be ignited by the burning plutonium. This could allow plutonium to escape from the glove box into the laboratory room. There could be severe contamination within the room but the building ventilation system is designed to handle this type of emergency. Release of plutonium, through the 99.97% efficient room filters, to the atmosphere would be well below established safe limits. However, if the burning gloves were to somehow cause damage to the glove box exhaust filter (which are protected with wire mesh prefilters which act as a flame trap and spark arrestor) then significant amounts of plutonium would be discharged into the main ventilation duct work. If the secondary filter were also somehow penetrated then this plutonium could be discharged to the 200-West Area.

V. Contingencies Arising from Environmental Conditions

No credible environmental conditions are apparent that could cause a criticality in the 231-Z Building.

A. Earthquake--The Uniform Building Code, 1955 edition, Pacific Coast Building Officials Conference, places the entire area east of the Cascade Mountains in Zone 2 of the Seismic Probability Map. This rating implies the possibility of moderately damaging earthquakes of intensity 7 or 8 (on the Modified Mercalli Scale of 1931) over a period of decades. The 231-Z Building structure and fixtures are designed to withstand earthquake shock of this intensity.

B. Flood--The elevation of the 231-Z Building is 675 feet above sea level. The Columbia River at the nearest point at 100-B Area is 400 feet elevation. Possibility of flooding of the 200-W Area from natural Columbia River floods or rain deluge is virtually nonexistent.

Hydrology of the general area showing river flow minimum and estimated maximum is given in reference 2.

C. Windstorm--The highest wind gust recorded at the 200-West Meteorological Station was 72 mph in the year 1950. The 231-Z Building was designed to withstand 100 mph wind loads. The building has suffered no damage from wind in the 24 years since it was built and none is anticipated.

The Pacific Northwest is one of the geographical areas of the country with a low frequency of tornadoes. To our knowledge, the first tornado ever photographed in this area occurred near Yakima on May 20, 1948. Between May 20 and June 16 of the same year, other tornadoes were observed near Yakima, Ephrata, and the Hanford Meteorology Station. The only one of these that reached the ground and did any damage occurred west of Yakima on May 29, 1948. This one destroyed an uninhabited mountain camp.

Twelve tornadoes have been reported within 100 miles of the Hanford area from 1916 to the present. Of these none have been observed occurring on the Hanford Reservation.

VI. Other Potential Accidents--Fires

The 231-Z Building is adequately equipped with extinguishers strategically placed to be used for extinguishing fires. All extinguishers in the laboratory are first aid dry chemical type. Some of the extinguishers are

equipped with quick-change couplings and piercing nozzles that may be used for glove piercing for extinguishing fires in glove boxes. Most glove boxes are equipped with coupling devices to receive dry chemical extinguishers. Couplings are installed according to Hanford Standard M-5-18.

All rooms and corridors within the laboratory are equipped with dry chemical extinguishers plainly marked and easily accessible.

Firemen are equipped on each engine with large 30-pound extinguishers which are compatible with the quick-couplings on 231-Z Building glove boxes, in addition they are equipped with quick coupling glove port plugs which aid in fire fighting and prevention of contamination spread where a glove has been burned or ruptured.

A pre-fire plan survey for 231-Z Building is current. This plan is reviewed by the Fire Department and, if necessary, revised every two years.

Routine guided familiarization tours of the 231-Z Building are made by all 200-W Area Fire Department personnel on a twice-a-year basis.

Fire Department supervision, in addition to directing weekly fire alarm and equipment tests, visit the building for familiarization on a more frequent schedule.

A. Fires within a Glove Box--General operating procedure prohibit large accumulations of combustibles in a glove box, i.e. accumulations which could burn long enough and with flame high enough to ignite bags, gloves, or plastic panels.

Where a potential ignition source exists (as in a glove box containing a frequently used furnace), the glove box is operated on an inert atmosphere, which inhibits oxidation of any sort.

Fires are most likely to happen in an area of high work activity and during a time when operators are present. The operators have MgO sand available in every glove box. Special connections are installed on glove boxes for the use of dry chemical fire extinguishers and a fire extinguisher is attached to the glove box.

B. Fires Outside a Glove Box--No fissile material is stored in the 231-Z laboratory in such a way that collapse of racks, shelving, etc. due to fire could lead to a criticality. Therefore, the major nuclear safety concern with a fire outside a glove box is whether the spread of flames could be large enough and prolonged enough to destroy a glove box or other means of contamination containment, and whether people might breathe any released contamination. Several controls make this unlikely:

- Combustibles are kept to a minimum near glove boxes or storage areas.

- A fire large enough to consume a glove box or release double-canned material would almost certainly set off the automatic alarm system if not first extinguished or at least detected by operating personnel. Trained firemen would be on the scene before extensive damage had been done. Fire station is located to allow 3-minute contact.

- Evacuation of the building would be prompt and certainly in advance of any significant contamination release; and no one would re-enter the building except in an assault mask (under established procedures), until it was assured that airborne contamination and surface contamination throughout the building were below permissible levels.

There would not be significant contamination release to the outside. No laboratory rooms have windows, and doors would remain shut. It is unlikely the filters between room air and the stacks would be destroyed by fire, since filters are quite distant from the exhaust intakes and are fire resistant (95% noncombustible).

VII. Summary

A summary of postulated incidents chosen for further evaluation, including those nonradiological, and their estimated qualitative effect on personnel, building and environs are shown in Table I. Accidents listed in this table were evaluated for credibility and, if considered credible, for quantitative consequences.

TABLE I
SUMMARY OF THE 231-Z BUILDING HAZARDS AND THEIR
EFFECT ON PERSONNEL, BUILDING, AND ENVIRONS

<u>Event*</u>	<u>Relative Hazard to Personnel</u>	<u>Relative Hazard to Building</u>	<u>Contamination Release to Environs</u>
<u>Criticality</u>			
in Storage	High	Low	Low
in Process	High	Possibly High	Possible
by Flooding	High	Low	Low
<u>Fire</u>			
Lab Room	Low	Possibly High	Low
Inside GB	Low	Low	Low
Breaching GB	Possibly High	Possibly High	Low
Vent. Sys.	High	High	Very High
Vault Storage	Possibly High	Possibly High	Possibly High
<u>Contamination</u>			
GB Malfunction	High	Possible	Low
Oper. Error	High	Low	Possible
<u>Explosions</u>	High	Possible	Low

*Several laboratory operations present special hazards to personnel (high pressure dies, high voltage, etc.), but do not represent a significant risk to the building or environs.

CONSEQUENCES OF ACCIDENTS

The consequences of accidents resulting from criticality, fires, alpha contamination spread, and explosions are discussed.

I. Nuclear Criticality

Since large quantities of dry plutonium and its alloys are routinely handled in the 231-Z Building, the potential exists for the occurrence of a prompt critical reaction. Considering the controls and Criticality Safety Specifications, it is conservatively estimated that a combination of errors, such as over-batching plus violation of spacing limits would be required to achieve a criticality incident. Such a combination of errors on the part of trained personnel who are thoroughly familiar with procedures, hazards, and safety rules is highly unlikely. Of a slightly greater, but still low, degree of credibility is the accidental addition of reflecting material around plutonium components. Water flooding from a broken cooling water line inside a glove box is an example. However, even under such a condition a nuclear reaction is unlikely since the plutonium would have to be homogeneously dissolved or dispersed in the water to effect a very large reduction in critical mass. The slab geometry of the water in a flooded glove box would be unfavorable for criticality to occur.

Even though the probability of a nuclear criticality is low, it is pertinent to consider the consequences.

An assumed criticality incident in a glove box probably would not exceed 5×10^{17} fissions, and would probably be limited to a single burst since it would involve fissile material in nonsolution form; thus the energy of the criticality would be expected to put the material in a non-

critical configuration. The consequences of such an incident would be the neutron and gamma radiation exposure to people within the building. Table II was adapted from Aspinall's report,⁽³⁾ showing results of a criticality involving 1×10^{17} fissions, which is within one order of magnitude of what might be expected. It gives an estimate of the dose a person could receive from external radiation, starting at various distances from the incident and evacuating after up to two seconds delay at a speed of 5 m/s. It is evident that anyone within a radius of 4 meters of the incident might receive from 400 - 500 Rem. This exposure would be fatal to half the persons receiving it.⁽⁴⁾ Prompt reaction, one second delay, and rapid evacuation would reduce the radiation dose considerably. Only those within two meters of the incident would receive probably fatal radiation. Normally no more than three persons would be within this distance. Other persons in the building would be warned to evacuate by the building criticality alarm system.

Mechanical damage to the glove box might include rupture of bags, gloves, and the glove box panels. 5×10^{17} fissions would provide 3850 kcal of heat which is sufficient to produce 350 cubic feet of steam if water is available. This would pressurize the average glove box (volume, 200 cubic feet) to 700 inches H₂O (300 in. H₂O above atmospheric pressure). Gloves and bags tend to fail at differential pressures above 20 in. H₂O. Water probably would be present if criticality did occur, since accidental water reflection is the most likely cause of a criticality in the 231-Z Building. Safeguards such as limited volume water systems, operator surveillance during cooling water usage,

and automatic water detection and shut-off systems nearly assure the prevention of accidental flooding.

TABLE II*
EXAMPLE OF EFFECT OF EVALUATION ON DOSES
RECEIVED FROM A CRITICALITY INCIDENT

Initial Distance from Incident (m)	Total Dose Received (Rems)				
	Without Evac.	Evacuation at 5 m/s after Initial Delay Times of			
		2s	1.5s	1s	0.5s
1	3100	2300	1900	1500	850
2	2300	620	510	400	260
3	1000	270	240	150	140
5	360	110	94	78	58
10	91	29	27	23	19

*The figures in this table are based on calculation and are presented for illustration only.

If serious damage to the glove box occurred, some plutonium release to the room would be expected. However, the dose in the vicinity of the criticality from inhalation of airborne plutonium or fission products would probably not be significant compared to the external dose from exposure to neutrons and gamma radiation.

In the environment a potentially significant exposure pathway would be via inhalation of iodine or plutonium. There would not be enough fission gases released to cause a significant offsite exposure from external radiation.

The quantity of several fission gases formed during a 5×10^{17} fission criticality is given in Table III.

TABLE III
RADIOACTIVE FISSION GASES FORMED IN A CRITICALITY
(5×10^{17} FISSIONS)

Isotope	Quantity (Curies)
^{131}I	0.5
^{133}I	6.7
^{135}I	22.5
^{133}Xe	1.4
^{135}Xe	20.9

Much of the iodine would be expected to remain in the plutonium-water mixture. Since a lack of data on release which, is felt, are surely applicable complete release of iodine is assumed. Also, complete release from the critical mixture of the noble gases is assumed. 50% plate-out of iodine prior to release to the environment is used but no credit is taken for filtration. There are high efficiency filters but no charcoal absorbers in the 231-Z ventilation system. With these assumptions the resultant release to the environment is: 1/2 the iodine and all the noble gases.

Airborne plutonium would be effectively filtered by the high-efficiency filters which remove at least 99.95% of particles of 0.3 micron minimum diameter. If all the plutonium involved in a criticality burned, the estimated Pu release to the environment would be 0.85 grams or 0.05 curies of ^{239}Pu .

As a consequence of this release of iodine and plutonium, the calculated consequences to individuals 1 mile downwind of the building, would be a dose of 0.3 Rem to the thyroid (based on ^{131}I), 15 Rems lifetime dose to bone and 1.2 Rems to the lung. If the plutonium was of mixed isotopic composition, 65% ^{239}Pu , 29% ^{240}Pu , 5% ^{241}Pu , and 1% ^{242}Pu ; the dose would be 55 Rems to bone and 2 Rems to lung tissue.

In the event of a criticality the airborne plutonium would be only a small fraction of the actual total involved and the dose to bone and lung tissue would be proportionally smaller than the values given in the preceding paragraph.

II. Fires

Plutonium and its alloys are pyrophoric necessitating extra care during handling and storing, especially of turnings and fines. Inert glove boxes are provided for all fabricating operations where there is danger of a fire. Although this minimizes the possibility of a fire, the hazard is always present. The occurrence of a fire would be rapidly detected by the automatic detection system in the building.

The consequences of fires, which are contained in a glove box or laboratory room, are considered relatively minor. However, in the event the fire spreads to the ventilation system the hazard to personnel, building, and environs are considered to be potentially very high. A possible explosion in the duct system could spread considerable alpha contamination throughout the building and possibly to the outside if control is not affected.

III. Alpha Contamination Spread

In normal operations the occasional accidental release of alpha contamination involves only small amounts and offers no serious radiological problem as the room exhaust system and respiratory protection devices are in place, proven, and frequently used. All Metallurgy Development Department personnel have received sufficient training and practical experience to cope with these situations.

All rooms within the laboratory are equipped with air samplers which operate from the building vacuum. The filters from the samplers are changed daily and immediately checked for contamination. This is a duty of the radiation monitors assigned to the building. In addition to the daily air sampling, there are three portable continuous alpha detectors which give an audible alarm as well as recording the level of contamination. These instruments are used at high risk locations.

An extremely hazardous situation would result from the rapid or explosive pressurization of a glove box. From one to three people could receive in excess of the maximum permissible body burden of plutonium as recommended by the National Council of Radiation Protection (NCRP). In the event injured personnel could not be promptly evacuated it is conceivable that doses exceeding maximum permissible body burden could occur.

IV. Explosions

The cause for an explosion of sufficient magnitude to breach the 231-Z Building is not apparent; however, explosions occurring within individual laboratories could present a serious hazard to personnel.

Explosions within a glove box could result from the accumulation of an explosive gas, such as the vapors from alcohol or benzene which are used conservatively in some operations. Another source could be a metal-water reaction occurring during a melting operation. A third but less likely cause would be a bottle of flammable gas being connected to an inert gas feedline to a glove box. In any of these events explosion would probably breach the glove box and severely injure and contaminate personnel in the room. It is unlikely that the confines of the room would be exceeded.

MAXIMUM CREDIBLE ACCIDENT

Based on the above discussion, it is concluded that a fire large enough to engulf a glove box would be the maximum credible accident in 231-Z Building. The fire protection and alarm systems described earlier make this sort of fire extremely unlikely, but it does remain credible. Further, it is postulated for the sake of this analysis that ignition of plutonium metal occurs.

Tests have been conducted by several investigators to estimate the extent of plutonium release from burning metal or during exposure of plutonium and its compounds to high temperatures and fires.

Hilliard⁽³⁾ estimated the maximum release of plutonium involved in a fire as 0.08 percent. He concluded that volatilization would not be a significant release mechanism at temperatures under about 1,600 C, a much higher temperature than would occur in a glove box fire.

In more recent work, Schwendiman,⁽⁵⁾ Mishima,^(9,10) and Kadasch have measured airborne release of plutonium from various compounds, solutions and from plutonium metal. Using small rods (1/4" diameter x 3/4" length) which were ignited in a stream of dry air they found up to 5×10^{-5} wt% released. By rapping the rods and drawing air through the oxide mass an additional amount of Pu was caused to be airborne, as much as 0.03 wt%. Using larger pieces of metal and causing ignition with an arc welding unit they measured releases of up to 0.032 wt% per hour.

K. Stewart⁽⁷⁾ conducted tests to determine the release of plutonium from metal exposed to a temperature of 850°C in a petroleum fire. About 1% of a 200-gram specimen was dispersed by the fire. Of this 1% only a small fraction was of a particle size small enough to remain airborne. As a result of his tests, Stewart suggests using a release value for plutonium metal exposed to petrol fires of 0.05%. He states, ". . . . value of 0.05% is clearly a satisfactory safe value to use in estimation of the airborne hazard downwind from a fire involving plutonium."

For estimating the consequences of a fire, 0.05% release of plutonium in an aerosol form which could be dispersed in the environment has been used. It has been assumed that the dispersed plutonium was of a respirable

size. Using this release value, if a glove box burned containing 6.5 kg of plutonium, 3.25 grams of aerosolized Pu oxide would be formed, and released to the glove box or room air. (The plutonium is considered to be ^{239}Pu). Any contaminated dust in the glove box might also become airborne during the fire; however, because of the frequency and care with which the glove boxes are cleaned, it is not expected that the amount of Pu in this airborne dust would exceed 2 grams. Thus, a total of 5 grams (0.31 Ci) of Pu could become airborne during the fire. If these 5 grams were spread out uniformly over a room with a volume of 10,000 ft^3 , the concentration of plutonium in the room air would be $10^{-3} \mu\text{Ci/cc}$. An individual breathing this aerosol without respiratory protection would receive many times the maximum permissible body burden.

High efficiency particulate filters are installed in both the glove box exhaust and in the room air exhaust. So glove box air is normally filtered twice and room air once prior to release to the environs. If the primary glove box is breached during a fire the room air will still be filtered prior to release from the building. This filter is 99.95% effective for removing particles of 0.3 microns diameter at design air flow. Applying this factor (passage of 0.05%) gives an estimated release of 2.5×10^{-3} grams or 152 μCi .

The release of 152 μCi of ^{239}Pu would not cause significant contamination of the environs.

Individuals exposed to the passing plume at downwind points would receive some internal body deposition of plutonium. The dose to bone tissue and to the lung is estimated in Table IV. In making the estimates of the lung dose the plutonium was considered insoluble. For the bone dose estimates it was considered soluble.

TABLE IV
LIFETIME DOSE TO LUNG AND BONE FROM PLUTONIUM INHALATION 152 μ Ci RELEASE

<u>Downwind Distance</u> <u>(miles)</u>	<u>Lifetime Dose</u> <u>to Lung</u> <u>(rem)</u>	<u>Lifetime Dose</u> <u>to Bone</u> <u>(rem)</u>
0.1	0.04	0.5
0.5	0.006	0.1
1.0	0.004	0.05
2.0	0.001	0.025

If the final filters were somehow breached, and assuming no plutonium was deposited in the ductwork, so that 5 grams of plutonium was released to the environs, the following consequences are estimated: The release of the 5 grams (0.31 Ci) of ^{239}Pu would be expected to result in a peak ground deposition (at 100 yards) of about 0.01 $\mu\text{Ci}/\text{m}^2$ and about 0.005 $\mu\text{Ci}/\text{m}^2$ at 1000 yards if the release occurred during unfavorable meteorological conditions. This level of contamination would not be detectable with field survey instruments. Contamination of this extent would be no greater than a nuisance level and resuspension of plutonium in air would not be great enough to constitute an inhalation hazard.⁽⁷⁾ The 234-5 Building is located about 350 yards from the 231-Z building.

The lung dose from Pu inhalation during cloud passage is given in Table V. Also, given in Table V is the lifetime dose to bone tissue with the plutonium considered to be soluble.

TABLE V
LIFETIME DOSE TO LUNG AND BONE FROM INHALATION OF PLUTONIUM

<u>Downwind Distance</u> <u>(miles)</u>	<u>Lifetime Dose*</u> <u>to Lung</u> <u>(rem)</u>	<u>Lifetime Dose*</u> <u>to Bone</u> <u>(rem)</u>
0.1	30	1000
0.5	10	300
1.0	3	80
2.0	3	50

*All values have been rounded off to 1 significant figure.

Should a serious accident occur in which both the glove box filter and final filter were breached it would appear important to evacuate personnel promptly from the immediate area, including 234-5, and to provide respiratory protection (face masks). If it were necessary for individuals to remain inside 234-5 protection could be afforded them by their using properly fitted and effective face masks.

Calculational methods used for the dose estimates are described in BNWL-SA-1616,⁽¹¹⁾ and BNWL-811.⁽¹²⁾

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