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An Increment of Analysis

ESTIMATED AIRBORNE RELEASE OF PLUTONIUM FROM THE EXXON NUCLEAR MIXED OXIDE FUEL PLANT AT RICHLAND, WASHINGTON AS A RESULT OF POSTULATED DAMAGE FROM SEVERE WIND AND EARTHQUAKE HAZARD

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ABSTRACT

The potential airborne releases of plutonium from postulated damage sustained by the Exxon Nuclear Company's Mixed Oxide Fabrication Plant at Richland, Washington, as a result of various levels of wind and earthquake hazard, are estimated. The releases are based on damage scenarios that range up to 250 mph for wind hazard and in excess of 1.0 g ground acceleration for seismic hazard, which were developed by other specialists. The approaches and factors used to estimate the releases (inventories of dispersible materials at risk, damage levels and ratios, fractional airborne releases of dispersible materials under stress, atmosphere exchange rates, and source term ranges) are discussed. Release estimates range from less than 10^{-7} g to greater than 14 g of plutonium over a four-day period.

SUMMARY AND CONCLUSIONS

The potential mass of airborne releases of plutonium (source term) that could a result from wind and seismic damage is estimated for the Exxon Nuclear Company's Mixed Oxide Fabrication Plant in Richland, Washington. The postulated source terms will be useful as the basis for estimating potential dose to the "maximum" individual by inhalation and to the total population living within a prescribed radius of the site. The respirable fraction of airborne particles is thus the principal concern.

The estimated source terms are based upon the damage ratio, i.e., the fraction of enclosures crushed or punctured during events of varying severity and the potential airborne releases if all enclosures suffer particular levels of damage. In an attempt to provide a realistic range of potential source terms that include most of the normal processing conditions, a "best estimate" bounded by upper and lower limits is provided. The range of source terms is calculated by combining a high, best estimate, and low damage ratio based upon a fraction of enclosures suffering crush or perforation, with the airborne release from enclosures based upon an upper limit, average, and lower limit inventory of dispersible materials at risk. Two throughput levels are considered. Factors used to evaluate the fractional airborne release of materials and the exchange rates between enclosed and exterior atmospheres are discussed.

The postulated damage and source terms are discussed for wind and earthquake hazard scenarios in order of increasing severity.

The largest postulated airborne releases from the building are for the maximum wind hazard (maximum velocity of 250 mph) and for seismic hazard greater than 1.0 g ground acceleration. Both hazard scenarios postulate virtually complete destruction of the facility. Wind hazard at higher air velocities and earthquakes with higher ground accelerations should not result in significantly greater source terms. The source terms are expressed as the mass of plutonium airborne particles 10 μm Aerodynamic Equivalent Diameter[a] (AED) or less released with time (up to 4 days). From 0.5% to 91% of the source term is generated from 2 hours to 4 days after the event. The overall source terms for the damage scenarios evaluated are shown in Table 1 in order of increasing severity of wind and earthquake hazard.

(a) See footnote on page 2 for definition.

TABLE 1. Source Term Estimates for the Exxon Nuclear MOFP as a Result of Wind and Seismic Hazard

Event	Mass Release of Plutonium in Respirable Size Range,[a] g					
	Case 1[b]			Case 2[c]		
	Upper Limit	Best Estimate	Lower Limit	Upper Limit	Best Estimate	Lower Limit
Wind Hazard						
Maximum Wind Speed 95 mph (42.5 m/s), 6×10^{-3} per Year Probability of Occurrence						
Instantaneous	---	---	less than 10^{-7}		---	---
Additional mass released in next 2 hours	---	---			---	---
Additional mass released in next 6 hours	---	---			---	---
Additional mass released in next 16 hours	---	---			---	---
Additional mass released in next 3 days	---	---			---	---
Maximum Wind Speed 150 mph (67 m/s), 3×10^{-6} per Year Probability of Occurrence						
Instantaneous		0.01	4×10^{-5}	0.1	0.08	6×10^{-6}
Additional mass in next 2 hours		4×10^{-6}	3×10^{-6}	1×10^{-5}	8×10^{-6}	4×10^{-6}
Additional mass in next 6 hours		1×10^{-5}	1×10^{-5}	3×10^{-5}	2×10^{-5}	1×10^{-5}
Additional mass in next 16 hours		3×10^{-5}	3×10^{-5}	8×10^{-5}	6×10^{-5}	4×10^{-5}
Additional mass in next 3 days		1×10^{-4}	1×10^{-4}	4×10^{-4}	3×10^{-4}	2×10^{-4}
Maximum Wind Speed 190 mph (85 m/s), 6×10^{-8} per Year Probability of Occurrence						
Instantaneous	0.3 (0.3)[d]	0.2 (0.2)[d]	0.02	0.9 (1)[d]	0.6 (0.8)[d]	0.06
Additional mass in next 2 hours	0.1	0.06	6×10^{-4}	0.3	0.1	2×10^{-3}
Additional mass in next 6 hours	1	0.5	5×10^{-3}	2	1	0.01
Additional mass in next 16 hours	0.4	0.2	2×10^{-3}	0.8	0.4	5×10^{-3}
Additional mass in next 3 days	5	2	0.02	10	5	0.06
Maximum Windspeed 250 mph (112 m/s), 3×10^{-9} per Year Probability of Occurrence						
Instantaneous	1 (2)[d]	1 (1)[d]	0.1	2 (3)[d]	2 (3)[d]	0.3
Additional mass in next 2 hours	0.2	0.1	0.01	0.4	0.3	0.02
Additional mass in next 6 hours	0.6	0.4	0.03	1	0.8	0.1
Additional mass in next 16 hours	2	1	0.08	3	2	0.2
Additional mass in next 3 days	7	5	0.4	14	9	0.7
Seismic Hazard						
Ground Shaking of 0.3 to 1.0 g, 1×10^{-5} per Year Probability of Occurrence at 0.3 g	No significant structural damage postulated					
Ground Shaking of Greater than 1.0 g						
Instantaneous	1 (2)[d]	1 (1)[d]	0.1	2 (3)[d]	2 (3)[d]	0.3
Additional mass in next 2 hours	0.2	0.1	0.01	0.4	0.3	0.02
Additional mass in next 6 hours	0.6	0.4	0.03	1	0.8	0.1
Additional mass in next 16 hours	2	1	0.08	3	2	0.2
Additional mass in next 3 days	7	5	0.4	14	9	0.7

(a) Particles 10 μm and less aerodynamic equivalent diameter.
(b) 36 kg MO per day throughput.
(c) 72 kg MO per day throughput.
(d) Total mass of plutonium airborne.

CONTENTS

FIGURES

INTRODUCTION

A potential radiological hazard to the general population could result from the impact of natural phenomena upon licensed commercial mixed oxide fabrication plants. This report presents estimates of the potential release of plutonium from the Exxon Nuclear Company's Mixed Oxide Fabrication Plant (MOFP) at Richland, Washington, as a result of wind and earthquake hazards.

The plutonium release estimates were developed by identifying damages sustained by hazard situations of varying severity. The Pacific Northwest Laboratory[a] staff gathered facility and hazard probability information from several sources. The Engineering Decision Analysis Company (EDAC) provided the description and condition of the facility (EDAC 1978). Features whose failure might have a significant effect on the release of radioactive material were identified (Mishima, Schwendiman, and Ayer 1978). The probability of various levels of wind hazard at the site was assessed by Fujita (1977), while Teknekron Energy Resource Analysis Corporation (TERA) provided the same services for the earthquake hazard (1978). Mehta, McDonald and Smith (1979) provided the potential responses of the structure and contained equipment to various degrees of wind hazard, and EDAC (1979) provided the analysis for the response to seismic events. These last two analyses provided the "damage scenarios" upon which the estimates of the potential airborne releases of the contained radioactive material from the facility (source terms) were based. For each damage scenario developed, the amount of plutonium released was estimated at five time intervals after the accident for the two levels of processing throughput. The estimates are given as a range of values: upper limit, an average estimate, and a lower limit.

This report is a portion of an interdisciplinary study sponsored by the United States Nuclear Regulatory Commission (NRC) and coordinated by the Division of Environmental Impact Studies of the Argonne National Laboratory (ANL). The estimated airborne releases of contained radioactive material

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute.

presented here form the basis for calculating dose, which is one component of the overall risk analysis, NRC'S objective in the entire study. The primary concern in the calculation of downwind dose for this study is inhalation (McPherson and Watson 1978, p.3), and in this increment the primary emphasis is the release of plutonium particulate material of a size range that can be carried downwind and inhaled. Particles 10 μm Aerodynamic Equivalent Diameter (AED)[a] or less are conservatively assumed to be the respirable fraction. Such an assumption overstates the potential effect by a factor of 1.5 to greater than an order of magnitude, depending upon the lung deposition model chosen (Mercer 1977, Figure 1). The behavior of the structure and equipment in accident situations is not precisely understood. With such uncertainties, the estimates of airborne releases tend to be conservative, that is, estimates are probably greater than the releases that would actually be experienced.

(a) Aerodynamic Equivalent Diameter: particles exhibiting the aerodynamic behavior of a unit density sphere of the stated size.

BUILDING AND PROCESS DESCRIPTION

To develop estimates of potential releases from the Exxon MOFP, we begin by identifying the facility features and plant operations that may have an effect on the quantity of material released. The information was gathered from documents issued by EDAC and the U.S. Atomic Energy Commission (USAEC). Included in this information are engineered safeguards that may detect and prevent certain conditions such as fires, or that may mitigate some airborne releases. The locations where powdered plutonium may be accumulated, the quantity present, and the dimensions of the volumes into which the plutonium may be injected are used to estimate the amount of particulate materials that may be released during severe wind or seismic events.

BUILDING DESCRIPTION (EDAC 1978)

The Exxon MOFP is a combination pre-cast/cast-in-place concrete building 100 ft in the east-west direction, 114 ft in the north-south direction, with 28-ft high walls. Figure 1 is an isometric sketch of the facility as it is currently arranged. The mixed oxide fuel is prepared in the east portion of the high-bay area, which has plan dimensions of 76 ft in the north-south direction and 100 ft in the east-west direction.

The exterior walls are pre-cast, tilt-up reinforced concrete panels, 6 in. thick by 9 ft wide by 28.2 ft high, joined to 13-in. by 14-in. cast-in-place columns. A cast-in-place roof edge beam 12 in. by 14 in. (called a parapet beam) joins the columns and panels around the entire periphery of the building. The roof is metal decking with built-up roofing. Support is provided by a long-span open web joist, supported by the north, center, and south walls, that spans the high-bay and office areas.

The storage vault is located in the northeast corner of the facility and is cast in place. The exterior walls are 18 in. thick and the interior walls are 24 in. thick. The roof is an 8-in. thick reinforced concrete slab with wide flange steel beams.

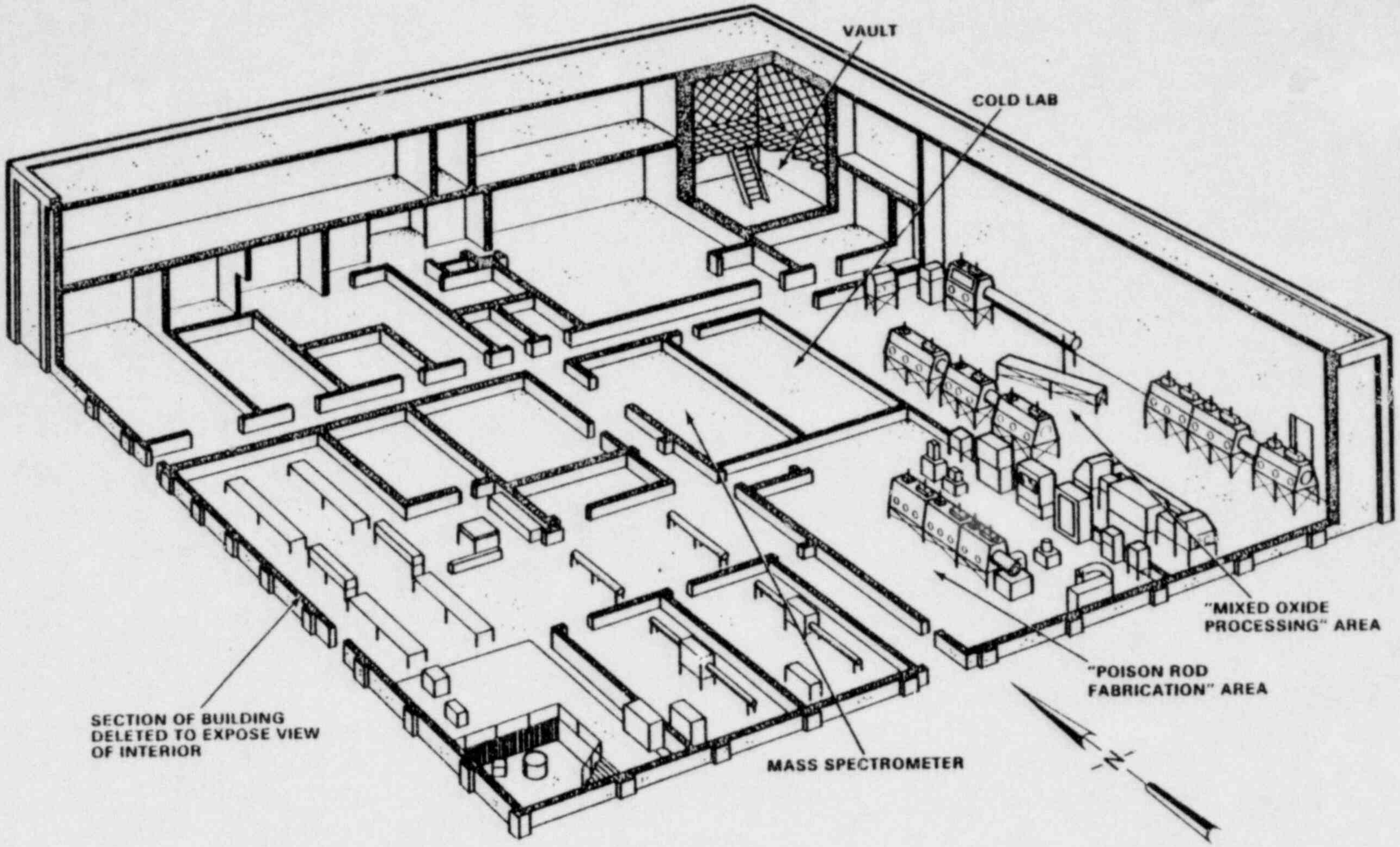


FIGURE 1. Exxon MOFP Building Arrangement for 36 kg per Day Design Throughput

PROCESS DESCRIPTION (USAEC 1974, pp. III-3 and 4)

The MOFP manufactures light water reactor mixed oxide (MO) fuel assemblies with a nominal composition of 4% PuO_2 in UO_2. The PuO_2 content has been as high as 5.5% but routinely is near 3%. The possession limit is 100 kg Pu. The current design production rate is 1/4 metric ton per day with a current actual processing rate of 1/20 metric ton per day.

The SNM license for the MOFP includes a limit of 10 kg of unencapsulated plutonium. The plutonium, for license purposes, is considered dispersible until it is loaded into fuel rods. Operating data indicate that, at maximum plant throughput, the 10 kg limit is approached and inventories in the various process stations are approximately as shown in Table 2 under case 1. Table 2 also indicates the form of the material present.

Experience with plant operations indicates that a maximum of 36 kg of mixed oxide fuel can be processed per 24 hour day using the current equipment arrangement. It is the throughput, not the quantity of plutonium, that controls plant capacity. Thus case 2 in Table 2 (72 kg/day throughput) is double case 1 (36 kg/day throughput) and assumes use of two mirror-image, parallel glove box lines. The arrangement is shown in Figure 2.

The PuO_2 is trucked to the facility in 5 kg packages in approved containers and stored before use in a safe configuration in the vault. The PuO_2 from the vault and UO_2 from the Uranium Oxide Fuel Plant next door are blended in glove box (glbx) 2a, which is located in the MO processing area (the east end of the high-bay section; see Figure 1). The MO is slugged in glbx 2b and pelletized in glbx 2c. The green pellets are placed in boats in glbx 3a and sintered in the sintering furnace (glbx 3c) at 1650 to 1700 F in a 15% hydrogen-85% nitrogen gas mixture. This gas is mixed outside the building and piped into the building through the south wall.

The sintered pellets are brought to final dimensions by a dry, centerless grinder equipped with a vaccum system to trap the airborne particulate material generated in glbx 4a. Inspection, rod loading, and cleaning are performed in glbx 4b and 4c. Rods are welded shut in the special helium-filled

TABLE 2. Exxon Nuclear Mixed Oxide Plant Material At Risk And Duty Cycle[a]

Glove Box	Process Step	Material (Form)	Inventory, g Pu Case 1	Inventory, g Pu Case 2[b]
2a	Blend, Mix, Granulate	PuO_2	{2,150}	{4,300}
2b	Blend, Mix, Granulate	MO		
2c	Pelletize	MO (Green Pellets)	400	800
3a	Feed Sintering Furnace	MO (Green Pellets)	200	400
3b	Exit Sintering Furnace	MO (Sintered Pellets)	200	400
3c	Sintering Furnace	MO (Sintered Pellets)	3,750	7,500
4a	Grind/Outgas Pellets	MO (1% Grinder Swarf) MO (99% Sintered Pellets)	{750}	{1,500}
4b	Rod Loading	MO (Sintered Pellets)	2,150	4,300
Vault	Storage	All forms including rods and bundles	90,000	180,000

(a) The duty cycle in the existing plant requires operation 24 hours/day, 7 days/week to obtain a throughput of 36 kg/day of mixed oxide. During such a campaign the inventories on Table 2 would be approximated. Experience with this and similar plants indicates that a yearly plant availability of about 65 percent is achievable; the remainder of the year is devoted to maintenance, cleanouts, and inventories.

(b) Half of each amount in ide[illegible]cal stations, except for vault when total 180 kg out-of-process inventory i[illegible] in a single hardened vault.

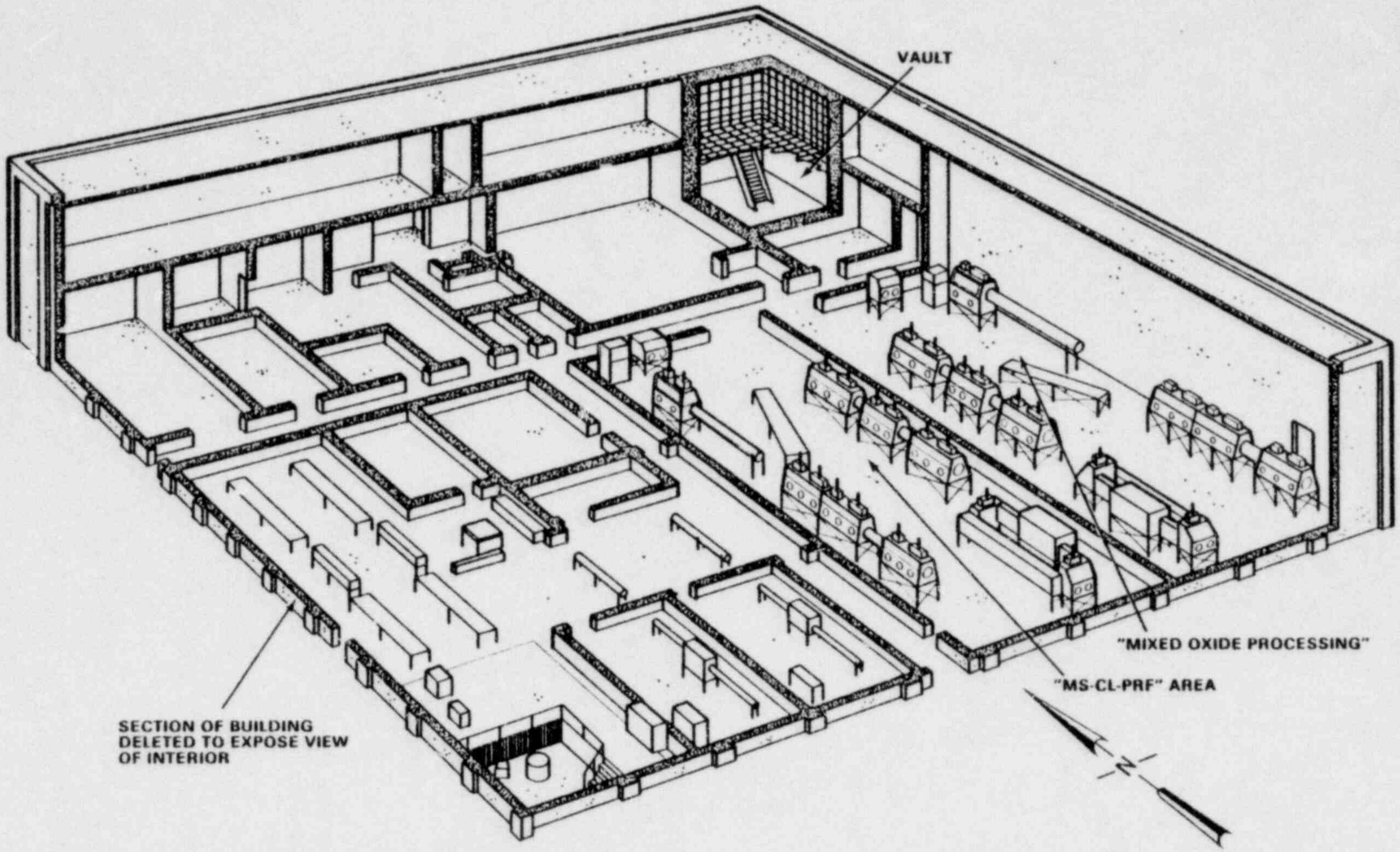


FIGURE 2. Exxon MOFP Building Arrangement for 72 kg per Day Design Throughput.

glove box in the northeast corner of the MO area; decontamination of the welded areas occurs in the open-faced enclosure along the north wall. There is no dry or wet scrap recycle.

ENGINEERED SAFEGUARDS (USAEC 1974)

Directional airflow is utilized in the facility to aid in the control of airborne particulate material (see Figure 3). Ambient air, filtered through high efficiency particulate air (HEPA) filters, enters the MO processing area via distributors located in the ceiling and exhausts through HEPA filter-sealed floor registers at a rate of at least ten air changes per hour. HEPA-filtered air is supplied to all glove boxes that use an air atmosphere and is exhausted via HEPA filters. Exhaust from the glove boxes is again filtered before it is combined with room exhaust. These combined gases are filtered again by two banks of HEPA filters located in another area before exiting from the plant. Approximately half of the room air from the processing areas is recycled.

Gas from the sintering furnaces is discharged to the building exhaust system through a duct equipped with an explosive gas detector. Explosive gas detectors are also situated around the sintering furnace to detect uncontrolled leaks of the cover gas. The exhaust ducts feeding the final filter bank are equipped with heat detectors; if the gas temperature exceeds 160°F, a spray is activated in the duct upstream of the final filter banks.

Rate-of-rise heat detectors are located in all processing hoods and on the ceiling of the processing area. The detectors in the ceiling activate an alarm. The detectors in glbx lines 2, 3, and 4 also activate Halon extinguishment systems.

AREAS OF CONCERN (MISHIMA, SCHWENDIMAN, AND AYER 1978a)

The amount of plutonium available for release in the event of severe winds and earthquakes depends not only upon the plutonium normally available as a part of process operations but also on the amounts accumulated on surface areas of process hoods and exhaust filters.

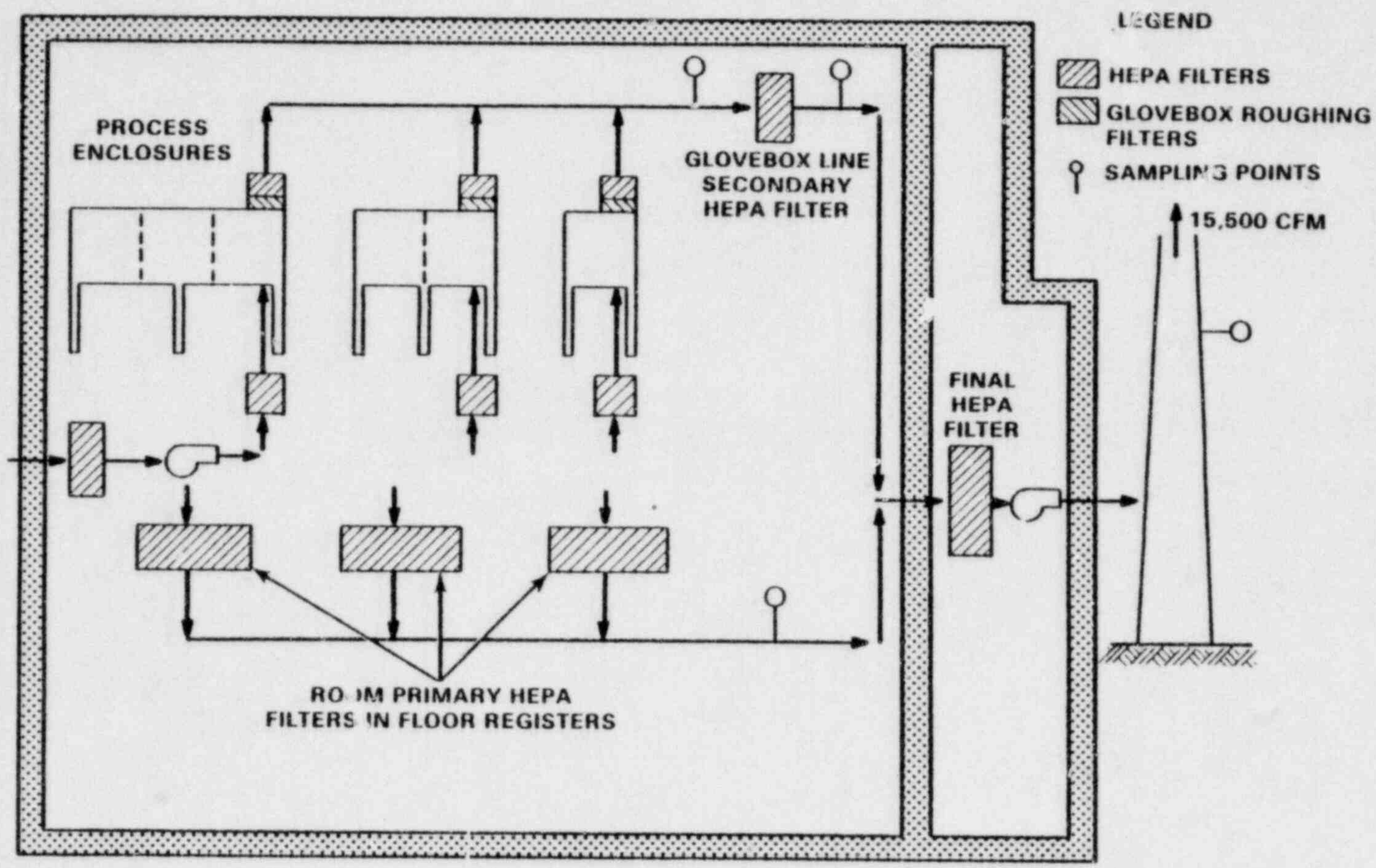


FIGURE 3. Schematic Representation of the MOFP Fabrication Area Ventilation System

Furthermore, the radiological significance and ease with which a material form can be made airborne help prioritize the concern over materials. The radiological significance of plutonium is greater than that of uranium used in the process. The downwind dose is dependent upon the injection into and the airborne transport of radioactive particulate material by the ambient atmosphere. Given the same level of force, more preformed particles of the size range that can remain suspended and be transported (powder) will be made airborne than will solids (pellets). This is because, in the latter case, some of the force is required to subdivide the solid and appreciable forces may be required to reduce a significant fraction of the solid to the size range of the powder.

Thus plutonium powders are of the greatest concern followed by MO powder. The PuO_2 powder in glbx 2a is the greatest concern followed by MO powder in glbx 2b and 4a (centerless grinder swarf). The remaining MO is present as pellets or encapsulated pellets. Neither form appears to be susceptible to the generation of significant quantities of particles in the size range that can be inhaled under the level and type of stresses considered in this study.

Two other sources of fine particulate materials are surface contamination and airborne materials collected in filters. Even in glove boxes handling pellets, the long-term buildup of the compounds handled in the glove box may result in the accumulation of significant quantities of material. Although there are indications that a significant portion of the material accumulated over long periods of time is tightly bound to surfaces, a conservative value of 7.5 g of powder/m^2 (this amount corresponds to a coating of powder visible to the unaided eye) is used (Mishima, Schwendiman, and Ayer 1979, p. 44).

PuO_2, MO, or unencapsulated pellets are handled in all of the boxes listed in Table 2. Five glove boxes (2a, 2b, 2c, 4a, and 4b) are each approximately 36 in. high by 72 in. long. by 36 in. deep (EDAC 1978, p. 5-14, Figure 5-6) and are estimated to have a total of 16.7 m^2 of contaminated interior surface area. PuO_2 is processed in glbx 2a and MO is processed in the other four glove boxes. The estimated Pu inventory involved with surface contamination for the 5 boxes is estimated to be:

in glbx 2a--16.7 m^2 x 7.5 g PuO_2/m^2 x 0.88 = 110 g Pu

in glbx 2b, 2c, 4a, and 4b--16.7 m^2 x 7.5 g MO/m^2 x 0.44 x 0.88 = 4.4 g Pu.

The furnace inlet and exit boxes (glbx 3a and 3b) have the approximate dimensions of 48 in. high by 48 in. long by 30 in. deep (EDAC 1978, p. 5-11, Figure 5-3) and an estimated 13.4 m^2 of contaminated surface area. MO is the material handled in these enclosures and the Pu inventory due to surface contamination is 3.5 g Pu per box.

The boat return conveyor is housed in an enclosure approximately 24 in. wide by 168 in. long by 24 in. high. Although no MO material is handled, some material may be available as dust from pellets. This enclosure is assumed to be contaminated to the same level as the other process enclosures. The estimated total internal contaminated surface area is 20.7 m^2 and the Pu inventory due to surface contamination is 5.5 g at a production rate of 36 kg MO/day. At a production rate of 72 kg MO/day, the Pu inventory for surface contamination in the glove box is 11 g.

An inventory of 1 g Pu is assumed for exhaust HEPA filters on glove boxes, 100 mg Pu per filter for the first stage of the final HEPA filter banks, and a loading of 0.05 mg per filter for the final stage (Mishima, Schwendiman, and Ayer 1979, p. 35). Each glove box listed in Table 2 is assumed to have a filter loaded with 1 g Pu. The filtration system is complex. The system normally operates with partial recycle but has full single pass capability. All Exhaust emitted to the ambient atmosphere passes through 3 stages of filtration. Although the exact number has not been ascertained, it is assumed that there are sufficient filters (30) to treat all exhausts at the rated flow of the filters. The total Pu inventory on filters at a production rate of 36 kg MO/day is 11 g; at a production rate of 72 kg MO/day the Pu inventory is 19 g Pu.

Other items not directly involved with containment of radioactive materials are also of concern since they may generate situations that can lead to the loss of containment of radioactive materials. Cylinders filled with gases under high pressure may become missiles if the valve is catastrophically lost. The 15% H_2-85% N_2 could be flammable if mixed with air and would fuel a pre-exsisting fire. High flash point hydraulic fluid reserviors are found at two locations in the current MO processing area: along the west wall of the area near glbx 2c and under the northeast corner of glbx 4a.

DAMAGE SCENARIOS

The responses of the MOFP building and equipment to severe wind or seismic events were developed by Mehta, McDonald, and Smith (1979; for wind) and EDAC (1979; for earthquake). The wind-induced damage ranges from the failure of a door in the MOP area, with little significant damage to glove boxes and filters or other processing areas, to collapse of the walls in the high bay area and roof, crushing essentially all the equipment in the processing areas. The earthquake damage is postulated to range from insignificant to collapse of the high bay area crushing up to seven-eighths of the glove boxes and filters. Estimates of specific hazard conditions and postulated damage are described below.

WIND HAZARD (MEHTA, McDONALD, and SMITH 1979, pp 30-33)

The results of winds ranging from 95 mph (42.5 m/s) to 250 mph (112 m/s) are postulated to range from loss of a standard door in a processing area to collapse of interior and exterior walls and the roof.

- Nominal Wind Speed 95 mph (42.5 m/s), 6×10^{-3}/yr probability of occurrence
  - Mixed Oxide Preparation (MOP) Area: Standard-size door in east wall fails outwards. Exterior filters on glbx 4a are damaged. There is no significant damage to remaining glove boxes or filters.
  - Cold Lab-Mass Spectrometry Poison Rod Fabrication (CL-MS-PRF) Area: No significant damage.
  - Vault: No significant damage.
- Nominal Wind Speed 150 mph (67 m/s), 3×10^{-6}/yr probability of occurrence
  - MOP Area: Same amount of damage occurs as for 95 mph wind.

- CL-MS-PRF Area: Double door in south wall fails. Portion of west interior wall fails crushing one third of the equipment (upper and lower bound are one-half and one-fifth respectively) within 15 ft of the wall.
- Vault: No significant damage

- Nominal Wind Speed 190 mph (85 m/s), 6 x 10^{-8}/yr probability of occurrence
  - MOP Area: A 20-ft section of south wall at southeast corner fails and a 20-ft section of roof collapses as a unit. Three-quarters of the glove boxes (upper and lower bound are one and one-half respectively) under the collapsed section of the roof are crushed. Half of the glove boxes (upper and lower bounds are three-quarters and one-fifth respectively) in the remaining area are perforated.
  - Cl-MS-PRF Area: Portions of the east and west interior walls collapse crushing one half of the glove boxes within 15 ft of the walls (upper and lower bounds are three-quarters and one-half respectively).
  - Vault: No significant damage.

- Nominal Wind Speed 250 mph (112 m/s), 3 x 10^{-9}/yr probability of occurrence
  - MOP AREA: Portions of outside walls collapse. Interior wall between MOP and CL-MS-PRF areas collapses. Roof collapses downward as a single unit crushing all glove boxes and filters.
  - CL-MS-PRF Area: The south wall collapses. The roof collapses as a single unit crushing all glove boxes and filters in area.
  - Vault: No significant damage occurs.

EARTHQUAKE HAZARD (EDAC 1979, p. 5-2)

The results of earthquakes ranging from 0.3 to greater than 1.0 g ground acceleration range from minimal to roof and wall collapse.

- Ground Shaking of 0.3 to 1.00 g, 1 x 10^{-5}/ yr probability of occurrence

  Damage does not lead to loss of component; therefore, no unfiltered release of contained radioactive material occurs.

- Gr[illegible]nd Shaking of 1.0 g and Greater, less than 10^{-5}/yr probability [illegible]rence

  Be[illegible], south wall fails and roof collapses as a single unit. Approximately three-quarters of the glove boxes and filters (upper and lower bounds are seven-eighths and one-half respectively) are crushed. The vault remains intact in excess of 1.87 g.

APPROACH AND FACTORS USED IN ESTIMATING SOURCE TERMS

Source terms are estimated to provide data for the calculation of potential radiation dose to the general population from the MOFP. A principal concern is that fraction of the airborne particulate material that can be transported downwind, inhaled by humans, and deposited in the deep lung (alveolar region). In addition, the remaining fraction of airborne particulate material (on the order of 100 to 200 μm AED) that is redistributed beyond the area of the facility is also considered in this study since it poses a potential surface-contamination and long-term resuspension problem.

Answers to several questions are required to arrive at a source term estimate. How much material can be affected by the event? What is the size distribution of the airborne material? What is the behavior of the airborne material in the time span required for release? What are the release rates and characteristics of the airborne material released to the ambient atmosphere? The factors and considerations used to answer these questions fall into two broad categories: fractional airborne release of materials and, if the material is injected into a constrained volume, the exchange rate. The factors involved in these categories are discussed below. A description of the upper and lower bounds placed upon the estimates is also presented.

FRACTIONAL AIRBORNE RELEASE OF PARTICULATE MATERIAL

The various factors applied to estimate the airborne release of plutonium as a result of the damage scenarios are listed in Table 3. Some considerations that influence the applicability of these factors for the six damage situations described are noted in the following paragraphs.

- Crush of a Glove Box Containing Powders: Crush is defined as a complete loss of containment such as rupture of the metal shell or loss of one or more of the large viewing windows. The glove box is subjected to stress that results in damage and provides the force to inject the powder into the air. Bouncing the powder into the air does not appear to provide as much dispersion of the powder as

TABLE 3. Fractional Airborne Release Factors Used To Estimate Consequences of Damage Due to Wind and Earthquake Hazard From Exxon MOFP

Event	Factor
Crush of glove box containing powder	Volume of glove box x 300 mg powder/m^3
Crush of glove box containing surface contamination.	10^{-2}/m of contamination airborne
Crush of fully loaded glove box filter	10^{-1} of contamination airborne
Perforation of glove box containing powder.	Volume of glove box x 300 mg powder/m^3
Perforation of glove box containing surface contamination	10^{-4}/m of contamination airborne
Perforation of fully loaded filter	10^{-2} of contamination airborne
Aerodynamic entrainment of powders, air velocity less than 5 mph	10^{-10}/s
Aerodynamic entrainment of powders, air velocity greater than 5 mph	10^{-8}/s

tumbling. An airborne mass concentration indicated by experimental data for powder remaining airborne in a volume after tumbling is used. (Mishima, Schwendiman, and Ayer 1978b, p. 30).

- Crush of HEPA Filter. Filters attached to glove boxes are enclosed in a metal container whose strength appears comparable to the glove box itself. Building filters are also enclosed in metal housings. Thus it is assumed that the filters suffer the same level of damage as the glove boxes to which they are attached. The filter frame and media are much more fragile than the metal housing but the plutonium-bearing material accumulated in the media (along with other components such as condensed organic vapors and lint) may not readily be dislodged. A conservative value of 10% of the accumulated material released is assumed in the absence of experimental data. (Mishima, Schwendiman, and Ayer 1979, p. 46).
- Crush of A Glove Box Containing Surface Contamination. Surface contamination can range from powder adhering to surfaces to material

mixed into the matrices of the surface. Mechanical entrainment appears to be an effective method for removing particles from surfaces (Fish et al. 1976, pp. 75-82) and a resuspension factor determined using a combination of mechanical and aerodynamic suspension is applied (Mishima, Schwendiman, and Ayer 1979, p. 44).

- Perforation of a Glove Box Containing Powder. Perforation is defined as a partial loss of containment that allows air to circulate through the glove box. Depending on the size of the opening and velocity of the air striking the opening, the particulate materials airborne within the volume are released from the glove box with time. Release of greater than 99% of the airborne particulate material within 30 min. is considered instantaneous. A mass airborne concentration found approximately 1 min. after tumbling a fine powder and considered quasi-stable, 100 mg/m^3, is considered to represent the airborne particulate material in a portion of the glove box (Mishima, Schwendiman, and Ayer 1979, p. 39).

- Perforation of a Glove Box Containing Surface Contamination. The stress imposed upon the glove box by perforation appears to be substantially less than the stress imposed by crushing. A factor substantially less, 10^{-4}/m, is applied (Mishima, Schwendiman, and Ayer 1979, p. 44).

- Perforation of HEPA Filters. Perforation of the filters can occur not only through penetration of the filter but also through damage caused by displacement of the enclosure. A factor of 10^{-2} is applied for the instantaneous airborne release of accumulated material to reflect the reduced level of stress required for this level of damage (Mishima, Schwendiman, and Ayer 1979, p. 47).

ATMOSPHERIC EXCHANGE RATE

The two principal areas of concern for atmospheric exchange are the MOP area for the current design throughput (see Figure 1) and the MOP and

CL-MS-PRF areas for twice the current design throughput (see Figure 2). Both areas are approximately 25 ft wide by 76 ft long by 28 ft high (53,200 ft^3 or 1507 m^3). The airflow through the significant items during the six events is described below.

- Nominal Wind Speed 95 mph. Air enters the area through a 28 in. by 76 in. opening (standard size door). Air velocity striking glbx 4a is sufficient to damage the filters outside the glove box. The inlet and exhaust openings are at least 8 in. by 16 in. The nominal calculated air velocity in the area is approximately 0.8 mph but it is assumed that air at 5 times the nominal velocity enters the glove box through a 0.9-ft^2 opening. Calculated airflow through the box under pessimistic conditions (air flows into one opening and out the other adjacent opening) is approximately 9 m^3 per minute and the volume of the glove box is displaced each 11 seconds. Under these flow conditions, particulate materials airborne in the glove box are considered to be released to the room instantaneously.

- Nominal Wind Speed 150 mph. In addition to the damage inflicted at 95 mph, the double doors in the south wall are lost. The calculated average air velocity through the MOP area is approximately 1 mph and airborne release from the damaged glove box 4a is essentially instantaneous.

  Air entering from the south wall causes a collapse of part of the west interior wall of the CL-MS-PRF area. The calculated average air velocity through the area is approximately 2.5 mph.

- Nominal Wind Speed 195 mph. A 20-ft section of the south wall collapses and causes the collapse of a 20-ft by 76-ft strip of the roof over the MOP area. The existing wind field is assumed to flow through the area. Particulate material from crushed and perforated boxes (although they may be partially buried) is assumed to be instantaneously released.

  Portions of both walls of the CL-MS-PRF area are postulated to collapse allowing air at essentially the existing velocity to pass through the area. Particulate material airborne in glove boxes (which may be under wind-generated debris) is conservatively assumed to be instantaneously released.

- Nominal Wind Speed 250 mph. The roof over the entire high bay area (which includes the MOP and CL-MS-PRF area) and most of the supporting walls collapse. Although much of the equipment in the facility may be buried by the debris, it is conservatively assumed that the material is exposed to the existing wind field.

- Ground Shaking of 1.0 g or Greater (EDAC 1979, p. 5-2). Beyond 1.37 g the south wall is unsupported and initiates collapse. It is assumed that all areas except the vault (which remains unaffected in excess of 1.85 g) suffer some degree of structural damage. An average wind speed of 10 mph (4.5 m/s) is assumed for calculating the atmosphere exchange rates for the earthquake damage scenario.

  One of the mechanisms for crushing gloveboxes is rupture by impact of a falling roof section. If it is assumed that the volume of a glove box decreases at the same speed as the roof falls, air could be ejected at a velocity of 48 mph. The release of particulate material made airborne by the damage is thus considered to be instantaneous.

SOURCE TERM RANGES

In order to provide some quasi-realistic bounds to the quantity of plutonium estimated to be released from the damage scenarios, three estimates are provided: upper bound, average, and lower bound. The assumptions under which the estimates are made are:

- Upper Bound:
  - The upper bound damage occurs.
  - The stated inventory that can be present is found at each location.

- All areas have a maximum loading, on the average, of surface contamination.
- All exhaust filters are fully loaded.

- Average:
  - The best estimate damage occurs.
  - The stated inventory at each location is reduced by the fraction of time it is normally found at that location.
  - All locations have a maximum loading, on the average, of surface contamination.
  - All exhaust filters are fully loaded.
- Lower bound:
  - The lower bound damage occurs
  - No process material is present and the maximum loading, on the average, of surface contamination is found at each location.
  - All exhaust filters are clean.

SOURCE TERM ESTIMATES

In the previous sections of this document, inventories of dispersible materials in various areas, damage levels, fractional airborne releases, and atmospheric exchange rates required to estimate the source terms for the postulated damage scenarios were described. These components are combined in this section with the specific conditions postulated for each hazard to arrive at three source term estimates for each scenario--an upper limit, a best estimate, and a lower limit.

The estimates are divided into the mass of airborne plutonium particulate material in the respirable size fraction released during five time intervals covering a four-day period. The quantity designated as instantaneous is the mass released from the facility within a few minutes following the hazardous event. The mass estimated in the remaining four time periods comes from two sources--the delayed release of material airborne in enclosures and the resuspension of dispersible materials exposed to the ambient wind field.

Drawings are used to illustrate the type and range of damage that could result in key areas from the scenarios described. The illustrations are not an attempt to show what actually happens--the data available and the state-of-the-art are not sufficient to predict the precise levels of damage that would be inflicted upon each item. Certain details of the facility have been omitted for clarity in the drawings.

The discussion is divided into wind and earthquake hazard in order of increasing severity.

SOURCE TERM ESTIMATES FROM WIND HAZARD

- Nominal Wind Speed 95 mph, 6×10^{-3}/yr probability of occurrence. The only significant structural damage inflicted upon the MOP at this wind speed is the loss of the standard-sized door in the east exterior wall of the area. Air circulating in the vicinity of glbx a damages the exterior filters. The situation is illustrated in Figure 4.

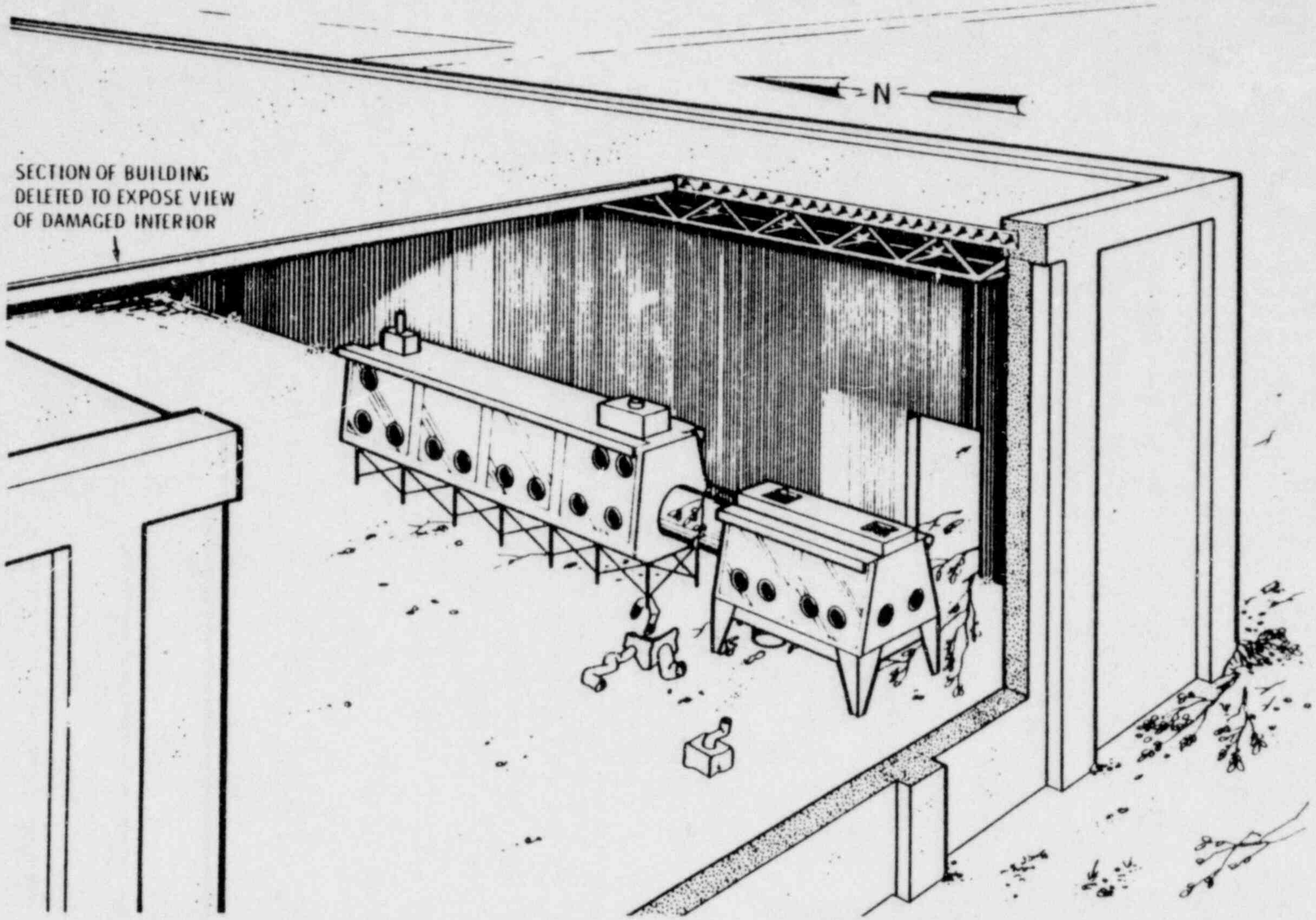


FIGURE 4. Range and Type of Damage Postulated in the MOP Area at a Nominal Wind Speed of 95 mph

The exhaust filter is assumed to be damaged (perforated) and instantaneously releases 1% of the collected particulate material to the area. The remainder of the material accumulated on the filter is entrained at the rate of 10^{-10}/s.

Air enters the glove box through the 8-in. by 16-in. openings for the inlet and exhaust air. The calculated velocity of air circulating through the glove box is less than 0.1 mph. Most of the inventory at this location is in the form of sintered MO pellets, which are not considered dispersible. The powder present is grindings in a vacuum cleaner receptacle and is assumed to be unaffected by the occurrence.

The interior contaminated surface area in the glove box is 16.7 m^2 and is assumed to be contaminated to a level of 7.5 g powder/m^2. The total calculated mass of the contamination is 125 g containing 4.4 g Pu. It is assumed that the disturbance to the glove box is equal that incurred during perforation; a resuspension factor of 10^{-4}/m is applied and 4×10^{-5} g Pu are made airborne in the glove box. Airborne material is released instantaneously to the area. The remaining Pu is assumed to be entrained at rate of 10^{-10}/s by the air circulating through the glove box and released into the air. All released material is assumed to be in the respirable size range.

Air enters the MOP area at the rate of approximately 14,600 cfm and does not appear to overload the exhaust system. Thus the particulate material released to the ambient atmosphere around the facility is assumed to pass through a functional exhaust system and is reduced by a factor of 2.5×10^{-7}.

The estimated releases from the facility (see Table 1) range from 10^{-9} to 10^{-12} g Pu over the four-day period and are reported as less than 10^{-7} g Pu.

- Nominal Wind Speed 150 mph, 3×10^{-6}/yr probability of occurrence.
  In addition to the damage described for a nominal windspeed of

of 95 mph, the double doors in the south exterior wall fail and approximately 462,000 cfm of air enters the corridor west of the CL-MS-PRF area. A portion of the interior wall is postulated to collapse, crushing one-third of the glove boxes (upper and lower bounds for damage are one-half and one-fifth respectively) within 15 ft of the wall. The calculated average air velocity in the area is approximately 2.5 mph. The situation is illustrated in Figure 5.

Since significant damage is postulated for the CL-MS-PRF, the throughput is important because the CL-MS-PRF area is not used for MO processing under the current process scheme. Furthermore it is postulated that the addition of 480,000 cfm of air exceeds the capacity of the exhaust system. It is thus assumed for the sake of conservatism that particulate material released to either area is released to the ambient atmosphere around the facility unfiltered.

The release of particulate material from the MOP area is the same as at 95 mph except that it is not passed through the exhaust system. The instantaneous release is based upon the release of 1% of the material accumulated on the filter from glbx 4a and the surface contamination shaken from interior surfaces during the incident. The time-dependent release is a result of the aerodynamic suspension of particulate materials--accumulated on the surface and contaminated surfaces inside glbx 4a--exposed by the incident.

At a design throughput of 72 kg MO/day, the CL-MS-PRF is assumed to be a single area with an equipment arrangement that is a mirror image of the MOP area. Equipment holding dispersible forms of plutonium that could be affected by the collapse of the west interior wall includes:

- glbx 4'a, which contains 7.5 g Pu in 213 g MO (swarf) grindings, MO accumulated on the exhaust filter and present as surface contamination.
- glbx 4'b, which contains MO accumulated on the exhaust filter and as surface contamination.

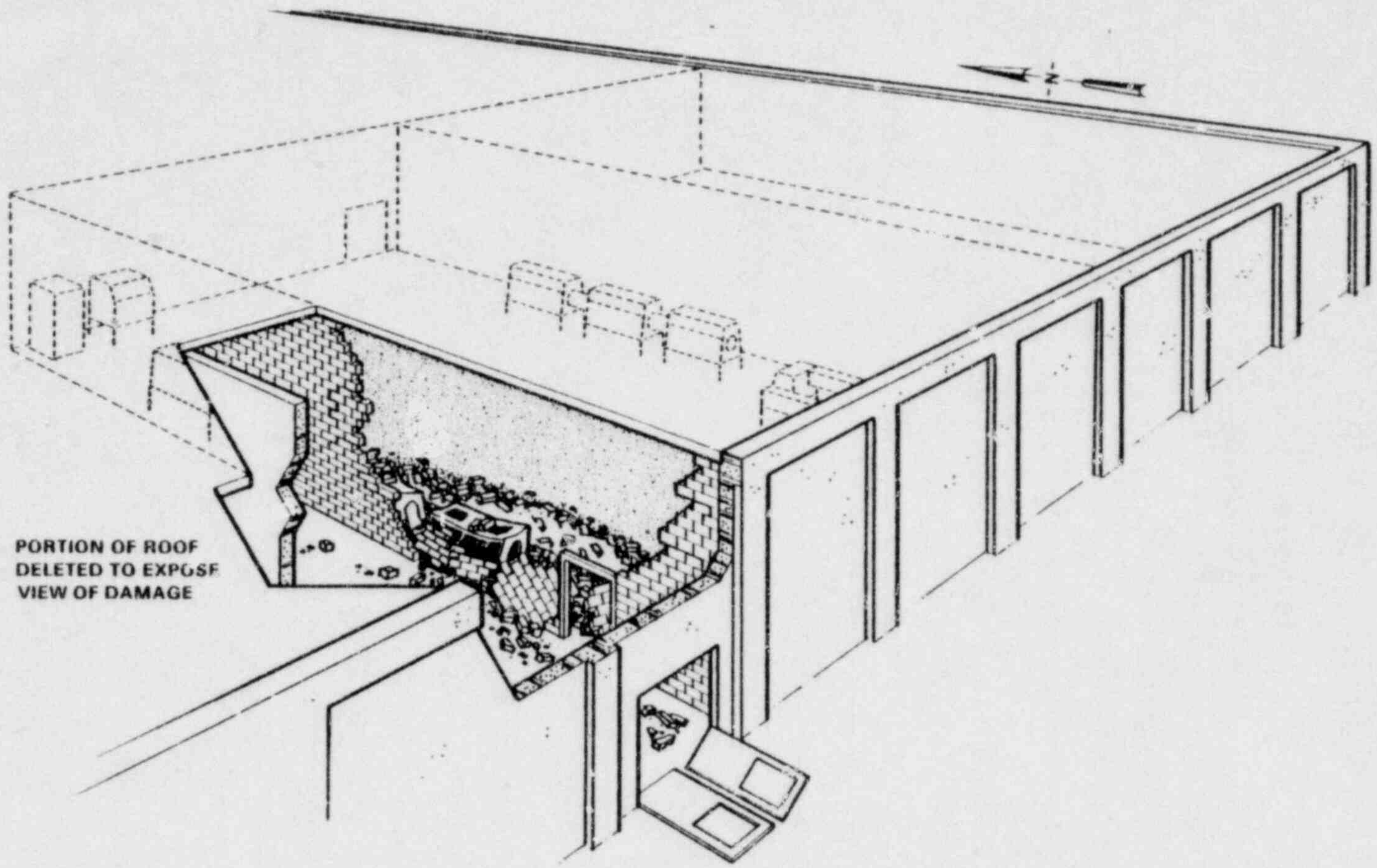
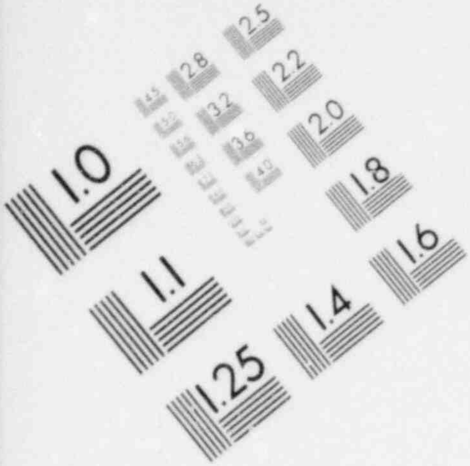


FIGURE 5. Range and Type of Damage Postulated in the CL-MS-PRF Area at a Nominal Wind Speed of 150 mph



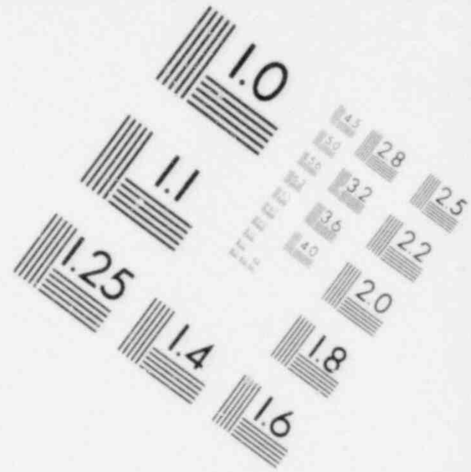
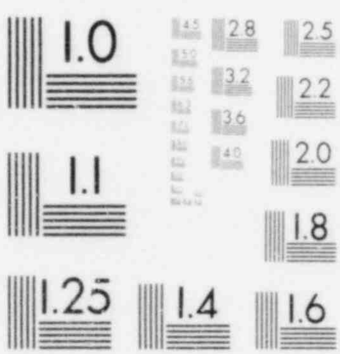


IMAGE EVALUATION TEST TARGET (MT-3)



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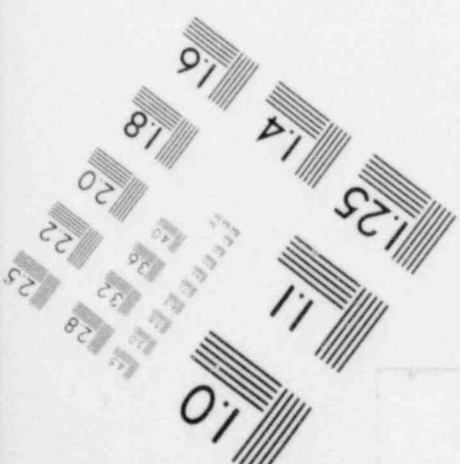
MICROCOPY RESOLUTION TEST CHART



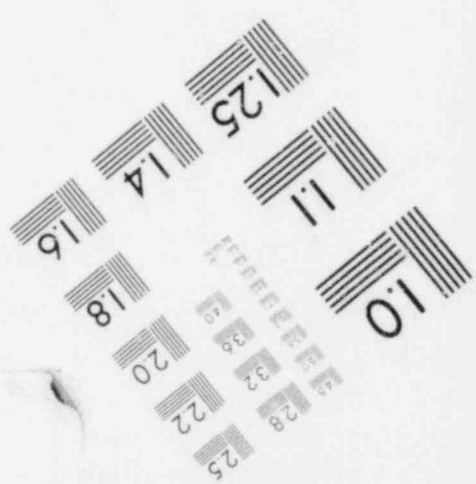
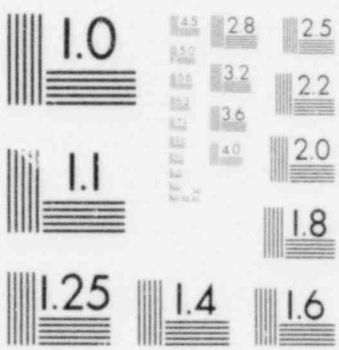


IMAGE EVALUATION TEST TARGET (MT-3)



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MICROCOPY RESOLUTION TEST CHART

The instantaneous release estimated is the total of the 10% released from each crushed filter (2), the 10^{-2}/m of the surface contamination made airborne during the crushing of glove boxes, and powder suspended by the event.

The time-dependent airborne release of particulate material is estimated from the material exposed to the wind field in both areas--powder, particulates accumulated on filters, and surface contamination. The calculated windspeed in both areas is less than 5 mph and a rate of 10^{-10}/s is used. The releases range from 2×10^{-4} to 0.1 g Pu for the four-day period and were shown in Table 1.

- <u>Nominal Wind Speed 190 mph, 6×10^{-8}/yr probability of occurrence.</u> A 20 ft section of the south wall near the southeast corner collapses, causing the collapse of the roof section supporting the wall. Three-quarters of the glove boxes under the roof section (upper and lower damage bounds are all to one-half respectively) are postulated to be crushed and half of the remaining glove boxes (upper and lower damage bounds are three-quarters to one-third respectively) are assumed to be perforated.

  All the glove boxes in the MOP, and thus the inventory listed in Table 2 for 36 kg/day throughput plus all the material postulated to be present on filters or as surface contamination, are involved. The instantaneous release is the summation of the powder made airborne in glove boxes by the incident, the material released during the crush or perforation of filters, and the contamination dislodged from surfaces. For the sake of conservatism, it is assumed that all particulate material released from filters or from surfaces is in the respirable range. The powder made is assumed to have the same size distribution as other process powders and only 10% is in the respirable range. Two values for the instantaneous release were shown in Table 1: the mass in the respirable fraction and the total mass released (in parentheses).

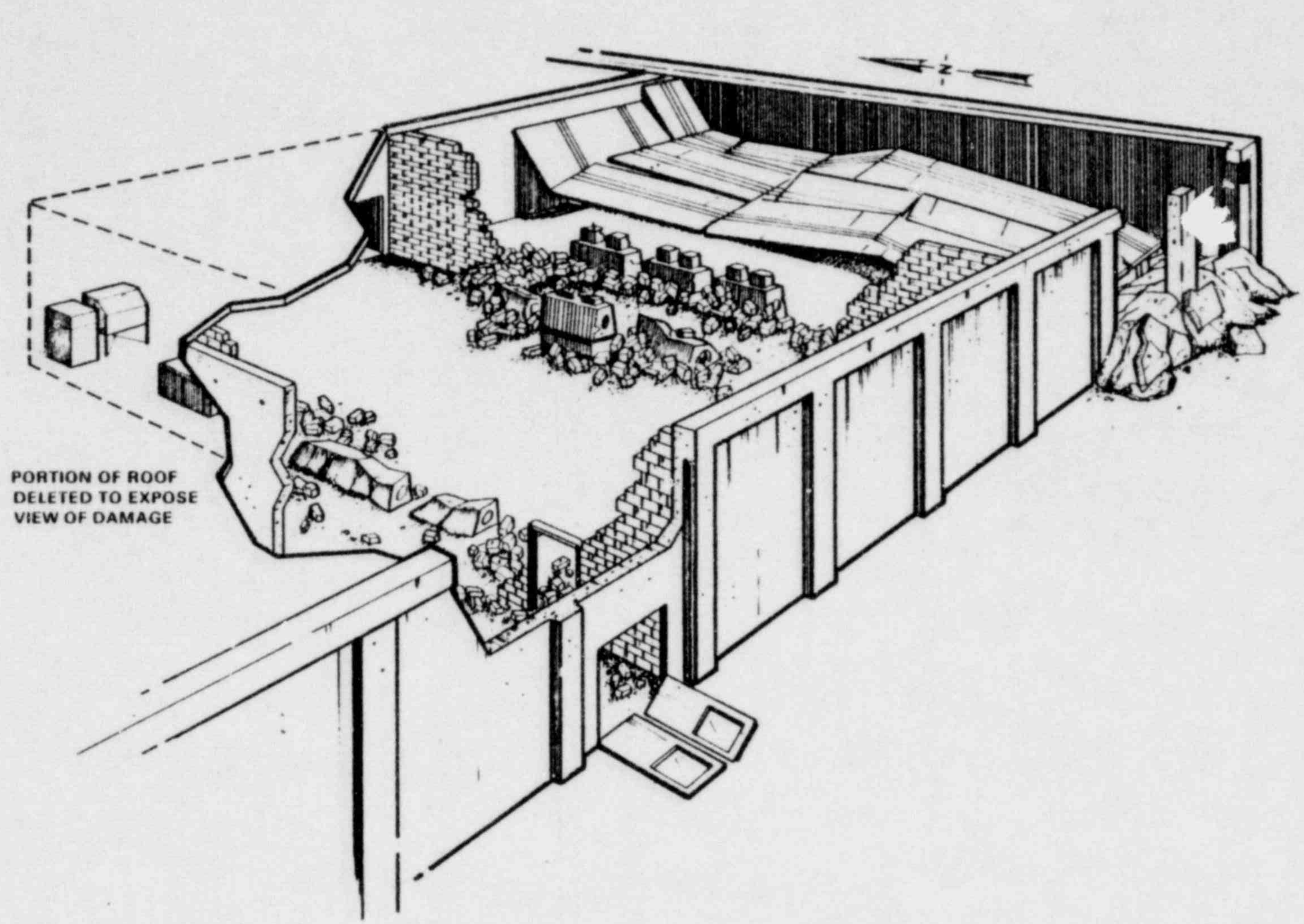

FIGURE 6. Type and Range of Damage Postulated in MOFP at Nominal Wind Speed of 190 mph

The time-dependent release is [illegible]timated from the total mass of plutonium exposed by the incident multiplied by a suspension rate. The wind field in the area exceeds 5 mph [illegible]nd a rate of 10^{-8}/s is applied.

The types and range of damage are illustrated in Figure 6 and the estimated airborne releases from the facility at this wind speed were listed in Table 1.

At the higher design throughput (72 kg/day), the CL-MS-PRF also contains plutonium and damage to that area will contribute to the airborne release from the facility. Both interior walls (east and west) are postulated to collaps[illegible] into the area crushing half of the glove boxes in the area. The upper and lower damage bounds are three-quarters and one-third respectively. The plutonium inventory present in the area is half the quantities listed in Table 2 under case 2. The factors governing the instantaneous and time-dependent airborne releases from the facility are the same as outlined for the MOP area. The combined estimated airborne release (MOP plus CL-MS-PRF area) was shown in Table 1 under case 2.

- Nominal Wind Speed 250 mph, 3 x 1[illegible]/yr probability of occurrence. Loss of portions of the south and interior walls causes the roof over the entire high bay area to fall. It is postulated that all the glove boxes in both areas are crushed. The situation is illustrated in Figure 7.

The instantaneous release is estimated from the quantity of powder (PuO_2 or MO) and surface contamination made airborne by the crushing of glove boxes and the quantity of accumulated particulate material released by the crushing of the glove box and building HEPA filters. These materials are not directly exposed to the existing wind field since the areas are buried under the debris from the collapsing walls and roof. In the absence of a method of predicting the air velocity under the debris, the higher resuspension rates are

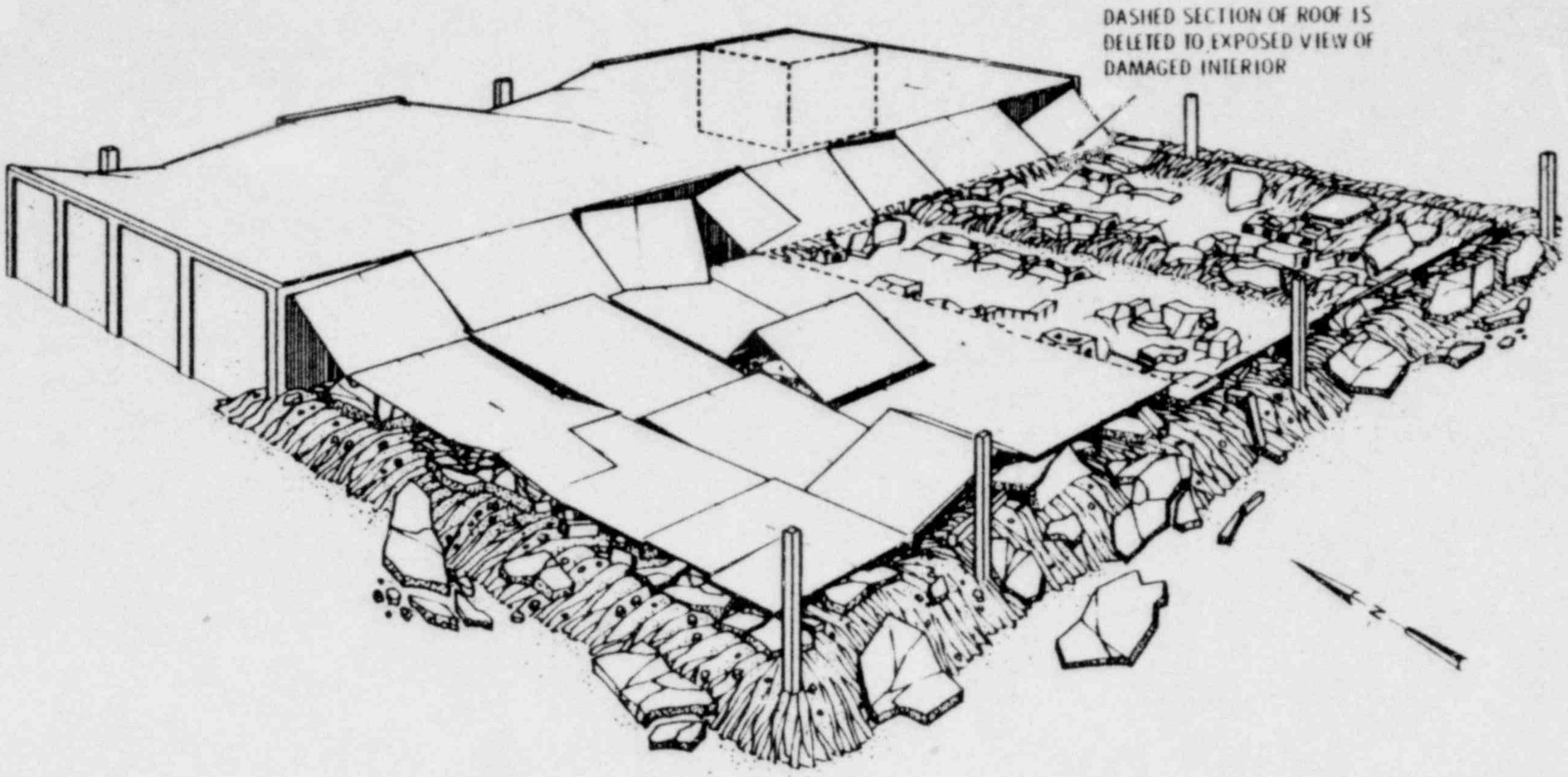

FIGURE 7. Type and Range of Damage Postulated for the MOFP at Nominal Wind Speed of 250 mph

applied. The estimated airborne release from the facility for the two levels of processing was listed in Table 1.

SOURCE TERM ESTIMATES FROM EARTHQUAKE DAMAGE

- Ground Shaking of less than 0.3 g, 10^{-5}/yr probability of occurrence at 0.3 g. There is no significant effect on the facility.
- Ground Shaking of 0.3 to 1.0 g, 10^{-5}or less/yr probability of occurrence. No significant structural damage resulting in the airborne release of plutonium is postulated. Concrete damage, yielding of some steel connections, and minor slippage of wall foundation joints may occur.
- Ground Shaking of 1.0 and Greater, much less than 10^{-5} g/yr probability of occurrence. As the ground shaking increases beyond 1.0 g, wall slippage increases and, at a level of 1.37 g, roof truss connections begin to fail. Somewhere beyond this level, the south wall initiates the collapse of the entire high bay area. It is estimated that three-quarters of all glove boxes (upper and lower damage bounds are seven-eighths and one-half respectively) are crushed. The situation is illustrated in Figure 8.

The basis for estimating the airborne releases caused by earthquake damage is the same as outlined for a wind speed of 250 mph. In both scenarios, there is complete collapse of the high bay area where all the process plutonium is held. The estimated airborne releases from the facility for the two levels of processing are listed in Table 1.

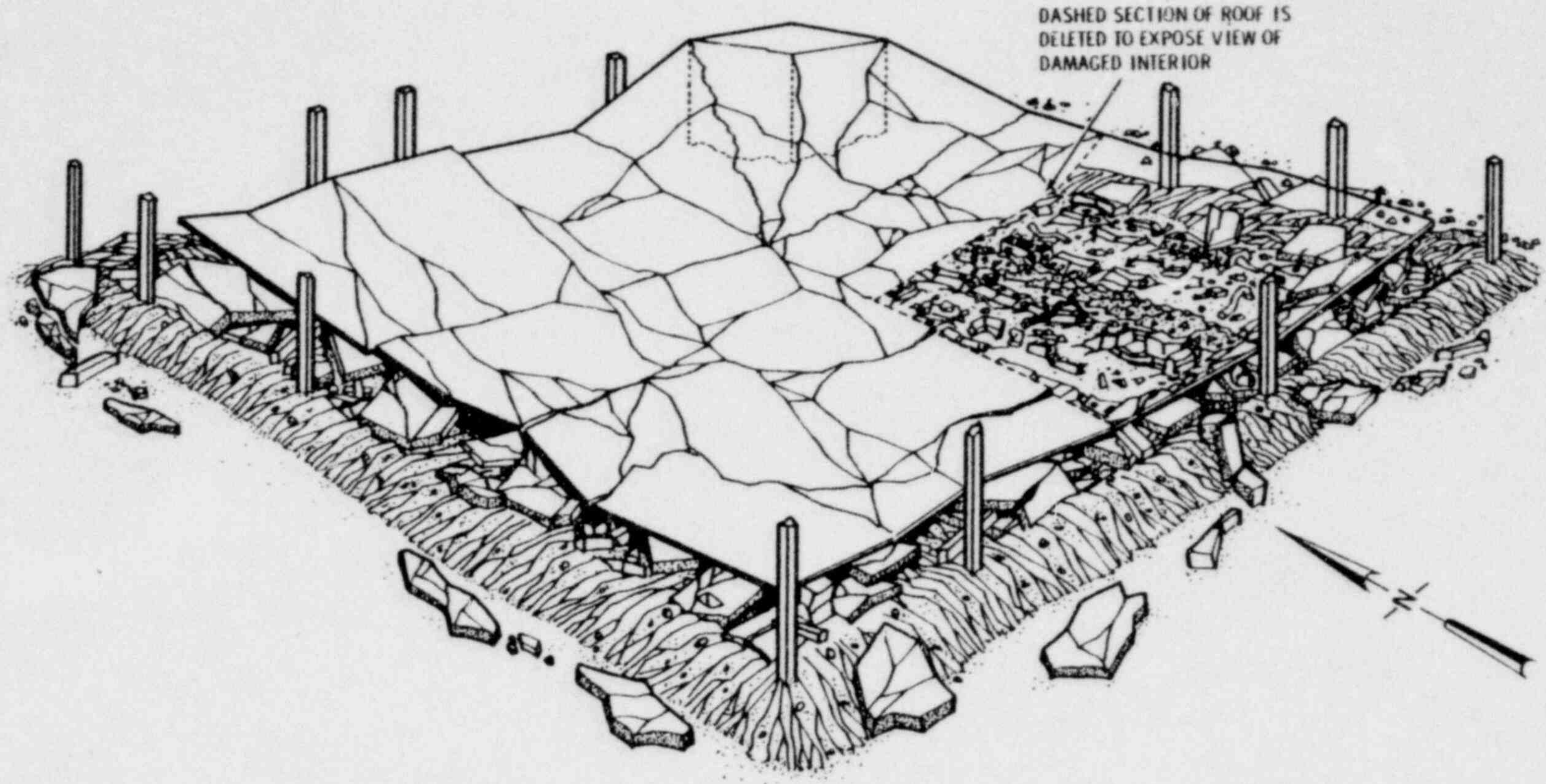

FIGURE 8. Type and Range of Damage Postulated for the MOFP at Ground Shaking in Excess of 1.0 g

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