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Letter Report

REVIEW OF ACCIDENT ANALYSIS CALCULATIONS, 232-Z SEISMIC SCENARIO

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REVIEW OF ACCIDENT ANALYSIS CALCULATIONS, 232-Z SEISMIC SCENARIO

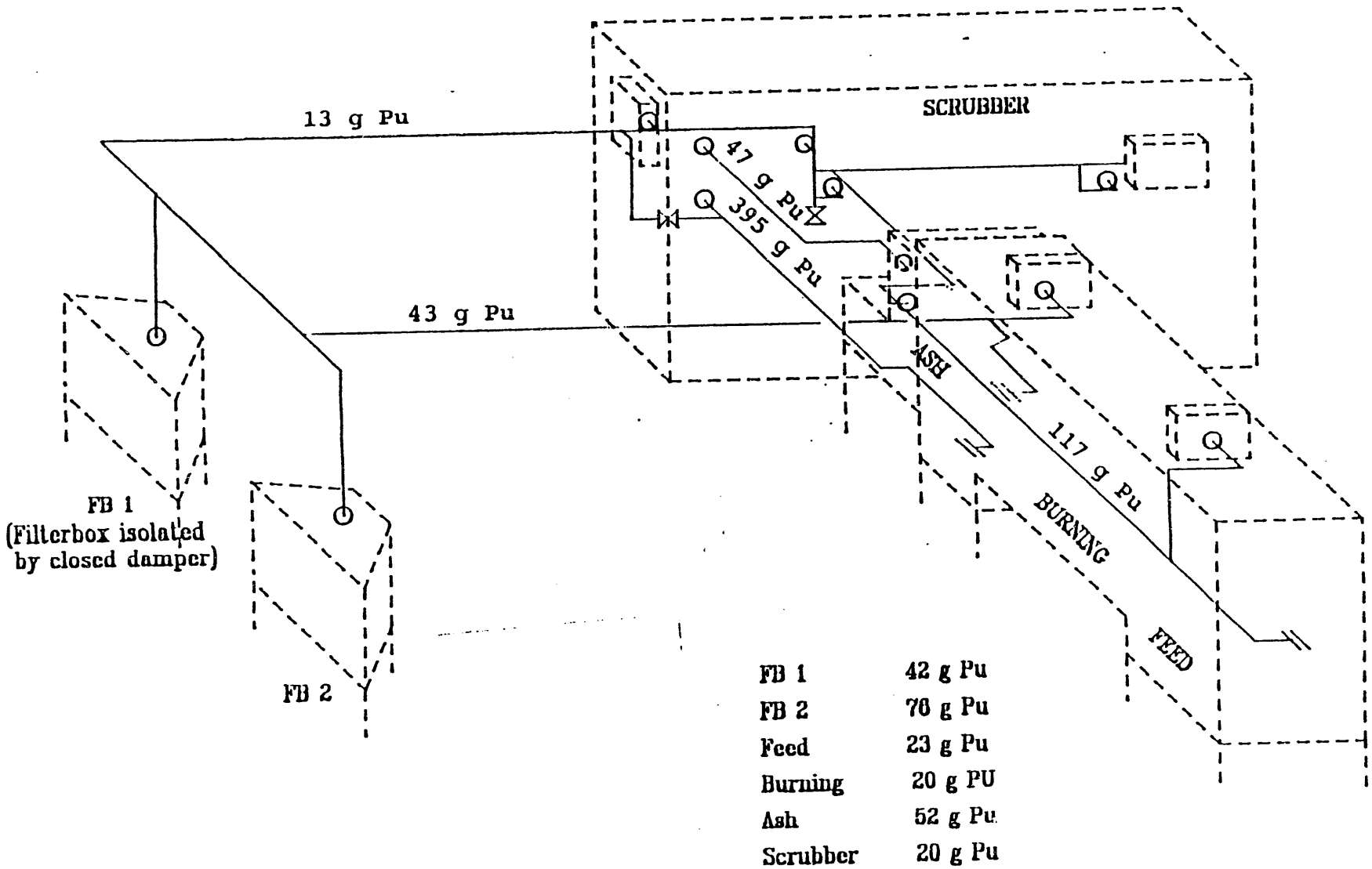
The 232-Z Building houses what was previously the incinerator facility, which is no longer in service. It is constructed out of concrete blocks and is approximately 37 ft wide by 57 ft long. The building has a single story over the process areas and two stories over the service areas at the north end of the building. The respective roofs are 15 ft and 19 ft above grade and consist of concrete over a metal decking, with insulation and a built-up asphalt gravel covering. This facility is assumed to collapse in the seismic event evaluated in the safety analyses, resulting in the release of a portion of the residual plutonium inventory remaining in the building.

The seismic scenario for 232-Z assumes that the block concrete walls collapse, allowing the roof to fall, crushing the contaminated duct and gloveboxes within. This paper is a review of the scenario and methods used to calculate the source term from the seismic event as presented in the Plutonium Finishing Plant Final Safety Analysis Report (WHC 1991) also referred to as the PFP FSAR. Alternate methods of estimating the source term are presented. The calculation of source terms based on the mechanisms of release expected in a worst-case scenario is recommended.

1.0 INVENTORY

About 850 g of plutonium powder are distributed throughout gloveboxes and connecting ductwork. The ductwork is composed of 6-in. and 4-in. schedule 10 pipe. The inventory is distributed as follows: about half of the total is located in an approximate 10-ft length of pipe connecting the incinerator glovebox with a scrubber glovebox; about one-quarter is spread throughout approximately 100 ft of pipe; the remaining quarter is distributed on the inside surfaces of an incinerator glovebox, scrubber glovebox, and two filter boxes. Figure 1 shows the estimate of material at each location.

Figure 1. 232-Z BUILDING HOLDUP



2.0 EVALUATION OF PFP FSAR SOURCE TERM CALCULATIONS

The pages of the PFP FSAR that were reviewed are in attachment 1 of this report. Several different methods were used to determine the release fraction (fraction of radioactive material made airborne from crushing of the ducting and gloveboxes) in the PFP FSAR:

- a bounding equation derived from spills, pressurized releases, and explosions
- a model to estimate the aerosol from powder spills
- a model to estimate the aerosol from detonations.

The spill model provided the most conservative basis (highest release fraction) and was used to calculate the source term. A number of concerns in the use of the models are listed below, then alternative methods of determining the source term are presented. A different method from those used in the analysis is recommended because it corresponds to the mechanism of release that is assumed to occur in this scenario--resuspension of holdup material from crush-impacts.

2.1 COMMENTS ON FIRST RELEASE CALCULATIONAL METHOD USED IN PFP FSAR

The equation shown in Halverson and Mishima (1986 p. 39) is apparently used as one method of calculating a release fraction. As described in the Halverson and Mishima report, this equation was developed in an effort to find a relationship among different mechanisms of release. Data from spills, pressurized releases, and explosions were combined to see if the energy input into a source material (E/M) is related to the aerosol produced. No definite relationship was found, but an overall bounding curve was produced over all the data, which included the weight percent airborne from free-fall spills, pressurized releases, and detonations. (Data on resuspension from crushed material were not included.)

This equation was presented in NUREG-1320 (Ayer et al. 1988) as a method to be used when the mechanism of release is not well defined. In the 232-Z seismic scenario, the mechanisms of release can be defined as follows:

- the earthquake causes the gloveboxes to tip over and the ducting to tear loose, spilling the inventory onto the floor
- the earthquake causes portions of the roof to fall onto the uncontained inventory, resuspending a portion of the plutonium
- ambient wind resuspends some of the inventory in the rubble following the seismic event.

These conditions are more realistically modeled using data or equations based on experiments exploring the release mechanism than those using the bounding equation. Section 3.0 presents the recommended models.

The PFP FSAR includes calculation of an energy to mass ratio (E/M), which is required as input to the bounding equation. The E/M value of 5E4 (see Attachment A, pg. 9-489) is outside the range of the bounding equation curve. It is not clear how the weight percent value of 0.005 (WHC 1991, p 9-489) was obtained because an E/M value of 5E4 provides an error in the equation for the curve (Halverson and Mishima 1986, eqn 41, p. 39) and does not match with any curve values on Figure 4.1 of the report (Halverson and Mishima 1986, p. 38).

In addition, this portion of the accident analysis calculations is difficult to follow: equation symbols are not defined, some units are incorrect, and some calculations appear to be in error. These difficulties in following the calculations and errors are not pursued in this review because the results of this analysis were not ultimately used in the source term calculations, and this method is not recommended for the scenario.

2.2 COMMENTS ON SECOND RELEASE CALCULATIONAL METHOD USED IN PFP FSAR

The value of 0.7 weight percent for powders spilled 4.6 m (15 ft) appears to be obtained by extrapolating data from powder spill experiments (Sutter et al. 1981, Table 6, p. 23). The maximum weight percent airborne for depleted uranium dioxide was 0.007 for spills from 1 m, and 0.07 for spills from 3 m. The 0.7 value is a rough estimate of the results from a spill from 5 m.

The powder spill data reported by Sutter et al. (1981) was analyzed statistically in Ballinger et al. (1988). This analysis shows that the

release fraction from powder spills appears to be a function of the spill height to the 2.37 power (Ballinger et al. 1988, p. 4.4). Thus, an extrapolation factor of spill height to the 2.37 power is recommended.

The maximum respirable release fraction from spills of depleted uranium dioxide (DUO) reported in Sutter et al. (1981) should be used as the base for the extrapolation. The statistically-derived equation (Ballinger et al. 1988, equation 42) is not used because it would result in an expected release fraction rather than a bounding release fraction. Also, the statisical equation is based on total aerosol generation and does not consider the fraction of particles in the respirable size range (<10 μm aerodynamic equivalent diameter or AED). Respirable plutonium particles are of concern because of the adverse health effects resulting from inhalation.

The maximum DUO respirable release fraction reported in Sutter et al. (1981, Table B.3) is 5.9E-4 (the maximum release fraction of 1.19E-3 is multiplied by a respirable fraction of 0.49, which was measured for the release) for a spill of 1000 g from 3 m. The extrapolation is shown:

$$5.9E\text{-}4\ (5m/3m)^{2.37} = 0.002 \text{ or } 0.2 \text{ wt\%}$$

The value of 0.2 wt% as a maximum respirable release fraction from a 5-m spill height has a better basis than the 0.7 wt% value.

2.3 COMMENTS ON THIRD RELEASE CALCULATIONAL METHOD USED IN PFP FSAR

The Steindler-Seefeldt model to estimate the mass and particle size of aerosols produced from detonations is inappropriate for at least two reasons: 1) the mechanism of release for a detonation is much more severe than for resuspension from crushing contaminated equipment, 2) the model was developed from data with weight of inert/weight of explosive ratio of 1 to 10. Using the model on a ratio of 923,000 wt inert/wt explosive (see attachment 1, p. 9-490) is far beyond the applicable range. In addition, the Steindler-Seefeldt model may not be conservative for powders. As stated in Halverson and Mishima (1986, p. 37-38):

> The Steindler-Seefeldt model is based on experimental data involving explosive dissemination of liquids and solids, and on the assumption that some unit energy input into the source material will give a unit amount of surface area.... In the case of powders, surface area creation

is negligible and a larger part of souce energy can be used to disperse material. This leads to the higher weight percent airborne seen for powders.

In conclusion, the Steindler-Seefeldt model should not be used to determine the source term in the 232-Z seismic scenario.

3.0 ALTERNATIVE SOURCE TERM METHODS

This section describes alternative methods to calculate the source term from the 232-Z seismic scenario. The first method is presented as a different method that has been used in past analyses and may be appropriate in scenarios where the source term is volume-constrained. The second method combines the source term from the mechanisms of release expected in a worst-case seismic scenario for the 232-Z Building (spills, crushing after the material is spilled, and resuspension of loose material). The second method is recommended for the 232-Z seismic scenario.

3.1 VOLUME-CONSTRAINED SOURCE TERM

A method that has been frequently used to estimate the source term from crush-impacts is a maximum transient airborne concentration of 300 mg/m^3 for powders, and the use of a resuspension factor of 1E-3/m for surface contamination (Mishima et al. 1978, 1979, 1980, 1981). Using the data given in the reviewed accident analysis, the calculations are as follows:

846 g PuO_2 total
733 g PuO_2 in the duct
113 g PuO_2 in gloveboxes
Duct structure is 75 ft of 6 in. diameter, 75 ft of 4 in. diameter
Duct volume (ignoring pipe wall thickness) is roughly

$$75 \text{ ft} \times \text{pi} \times [(1/4 \text{ ft})^2 + (1/6 \text{ ft})^2] = 21 \text{ ft}^3 = 0.60 \text{ m}^3$$

Duct surface area is 75 ft x pi x (1/2 ft + 1/3 ft) = 200 ft^2 = 18 m^2
Average contamination level in the duct is 733 g/18 m^2 = 41 g/m^2.

This contamination level is above 7.5 g/m^2, which is considered just visible (Mishima et al. 1978, p. 35). Therefore, contamination in the ducts is assumed to be composed of loose powder, and a concentration level of 300 mg/m^3 is assumed to be produced from the crush-impact. The weight percent of Pu in PuO_2 is 88 and the mass fraction of airborne material in the respirable size range (<10 μm AED) is assumed to be 0.1 (Mishima et al. 1978). The source term from the crushed duct is

$$300 \text{ mg/m}^3 \times 0.6 \text{ m}^3 \times 0.88 \text{ g Pu/g PuO}_2 \times 0.1 \text{ respirable} = 15.8 \text{ mg Pu.}$$

The source term from the gloveboxes depends on their surface area and volume.

Although this method has been used in the past, it relies on volume constraints for the aerosol. Since the duct and gloveboxes are assumed to be crushed, the volume may be changed by the event. A lower volume may result if the containment is crushed, but not broken open; a greater volume may result if the duct splits, breaks open, and pours contents out into the room. The method is not recommended for the scenario because there is not enough detailed data on the collapse of the building during the seismic event to determine the volume constraints (or lack thereof).

3.2 SPILLING, CRUSHING, AND RESUSPENSION SOURCE TERM

In this scenario, falling debris from a ceiling or wall collapse could cause gloveboxes to topple or be crushed. Glovebox windows or walls might be ruptured and connecting ducting (4- and 6-inch schedule 10 pipe) torn off. The worst-case scenario (leading to maximum consequences) is one in which the inventory (assumed to be a loose powder) spills out of ducting and gloveboxes, then is impacted by portions of the roof, walls, or other equipment in the room. After the seismic event, additional aerosol is produced from resuspension of powder exposed to ambient winds. Aerosol is formed from three separate mechanisms of release: 1) spilling of powder from ducts and gloveboxes, 2) crushing of powder by falling debris, and 3) resuspension of exposed powder.

The maximum duct spill height is about 3 m and corresponds to the maximum spill height examined in powder spill experiments (Sutter et al. 1981). The greatest respirable release fraction from DUO spills was 5.9E-4. This value is rounded off to 6E-4 and is considered conservative when applied to all of the inventory in the seismic scenario because

- it is a maximum from experiments involving comparable spill height, powder characteristics, and powder mass
- some of the plutonium inventory in the ducts and gloveboxes may be more firmly fixed and would not spill out
- the release height of some of the spilled material would be less than 3 m.

Also, the inventory is distributed throughout several locations. Spilling of all of the inventory from each of these locations is a conservative scenario assumption.

Experiments performed by Langer (1987) explore the second mechanism of release expected in this scenario. In the Langer experiments (which were performed to determine the release of plutonium powders impacted by building debris) rocks were dropped 3.7 m onto powder on a plywood sheet or held in a can in a vented metal box. Respirable release fractions ranged from 2.5E-6 to 3.3E-4. The highest respirable release fraction was obtained by impacting a loose fine powder. (Material in 232-Z is believed to be attached to surfaces as opposed to a loose powder and use of this data is believed to be conservative). Since the size and weight of the debris in the 232-Z seismic scenario might be greater than those in the experiments, a more conservative respirable release fraction of 1E-3 is used to estimate the source term.

The third mechanism of release, powder resuspended from ambient winds, has been investigated by Sehmel and Lloyd (1976), who measured the resuspension of a tracer due to ambient wind stresses from a lightly vegetated soil surface. Resuspension rates ranged from 1E-8/s to 1E-10/s. In the 232-Z seismic scenario, the inventory is shielded from the ambient wind by fallen debris and the resuspension factor is conservatively estimated to be 1E-9/s or 4E-6/hr. All of the resuspended aerosol is assumed to be in the respirable size range, and resuspension is assumed to continue for 48 hours (until remedial measures are taken to mitigate the release). Thus, the respirable release fraction recommended for resuspension is 2E-4 (4E-6/hr x 48 hr).

The total generation of plutonium aerosol from the 232-Z seismic event can be calculated by adding the spill, crushing, and resuspension respirable release fractions and applying them to the total inventory as shown in the following calculation.

$$846 \text{ g } PuO_2 \times (6E\text{-}4 + 1E\text{-}3 + 2E\text{-}4) \times 0.88 \text{ g Pu/g } PuO_2 = 1.3 \text{ g Pu.}$$

This estimate is based on data from the release mechanisms that are expected to occur in this scenario and thus is more appropriate than the estimate given in the accident analysis.

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ATTACHMENT 1

Accident Analysis Calculations for 232-Z Seismic Event

9.2.4A.6.3.7 Accident Analysis-Calculations, 242-Z. The release of 110 g from walls and hoods is similar to that presented in Section 9.2.4A.6.3.1.A and L, and is considered to be negligible.

9.2.4A.6.3.8 Accident Analysis-Calculations, 241-Z. The release from 241-Z was discussed in Marusich (1988a) assuming that the coverblocks failed. The release was 0.4 g. Since that time it has been shown that the coverblocks remain in place but there may be a release to the ground if the cells fail and the tanks leak. The consequences to the public are quite small under these conditions (DOE 1987, Appendix R).

The consequences to the worker are also small. Transfers to 241-Z have very low plutonium concentration (about 0.005 g Pu/L) and the amount of liquid transferred is on the order of 200 L. See also Section 9.2.3. Any release which occurs will be under the ground and so little will rise to the surface.

9.2.4A.6.3.9 Accident Analysis-Calculations, 291-Z. The analysis for the filter rooms and upstream duct work showed that the release from vibratory motion of the duct to be small. The same will be true in 291-Z because the number of grams on the surface and the surface area are similar. The release from the previous section was less than 0.01 g.

9.2.4A.6.3.10 Accident Analysis-Calculations, 232-Z. The 232-Z facility was used for incineration of contaminated waste. It contained gloveboxes for sorting, leaching, chopping, and burning. The offgases were processed through a scrubber and filter. The building is of block construction which may collapse during the earthquake. The gloveboxes have undergone terminal clean out but the E-4 duct and filterboxes are contaminated. The total holdup in the facility is 846 g (733 g in the duct, and 113 g in the gloveboxes) (Steel 1987). → [illegible]

Impact of the concrete blocks or pillars onto the duct could result in a large release because the impact of the concrete blocks could suspend all of the powder in that general area and could split the duct creating an immediate release into the facility (i.e., the concept of 100 mg/m^3 in the duct could not appropriately be used in this case). Assume the ceiling falls on top of the ducts containing plutonium. Drawing H-2-23105 shows the ceiling to be 26 ft 4 in. wide and 56 ft 8 in. long. The ceiling is 4.5-in.-thick concrete. The volume of the ceiling is 560 ft^3. The weight of the ceiling is 84,000 lb (using 150 lb/ft^3 as the density of concrete). The value of 100,000 lb will be used to take into account re-bar and the fact that the walls and columns also fall. The duct is shown on H-2-31348. The total length is 150 ft. The duct is about 50% 6-in. schedule-10 and 50% 4-in. schedule-10. The volume of duct is found by noting that the wall thickness of 6-in. pipe is 0.134 in. for 4-in. pipe it is 0.120 in.

$$V = 75 \frac{\pi}{4} [6^2 - (6 - 0.238)^2] + 75 \frac{\pi}{4} [4^2 - (4 - 0.24)^2]$$

$$V = 1.14 \text{ ft}^2 + 0.76 \text{ ft}^2 = 1.9 \text{ ft}^3$$

$$\text{Mass} = 1.9\ ft^3 \left(486\ \frac{lb}{ft^3}\right) = 923\ lb$$

The relationship in Halverson calls for the energy of the roof as it hits the duct.

The ceiling falls from 15 ft.

$$S = \frac{1}{2}at^2$$

$$15 = \frac{1}{2}\ 32.2\ \frac{ft}{s^2}\ (t^2)$$

where:

$t = 0.96\ s$

$at = \upsilon = 32.2(0.96) = 31\ ft/s^2.$

So energy which is given by $1/2\ m\upsilon^2$ is

$$0.5\ (10^5\ lb)\left(454\ \frac{g}{lb}\right)\left(31\ \frac{ft}{s^2}\right)^2\left(30.5\ \frac{cm}{ft}\right)^2\left(\frac{1}{980}\right) = 2.1x10^{10}\ \text{dyne-cm}$$

Therefore,

$$\frac{E}{M} = \frac{2.1x10^{10}}{923\ lb\ (454)} = 5x10^4$$

using the curve in Halverson (1986, p 38). The "weight percent" made airborne is 0.005. Marusich (1988a) shows that the "weight percent" of spilled powder alone made airborne due to a fall from 15 ft is 0.7. This is the value that will be used for release fraction from the falling roof and walls. A lower value could have been used (about 0.1 wt% as compared to 0.7 wt%) which takes

into account the fact that not all of the plutonium will get out of the ducts when they are impacted and includes the fact that the method in Halverson gave a value of 0.005 wt%.

The total plutonium in the facility is 846 g.

The total suspended is

$$\frac{0.7}{100}\ (846\ \text{g}) = 5.9 \text{ in the worst case}$$

and 0.8 g in the "best estimate" (using 0.1 wt%) case.

Another approach is to assume that the concrete roof falling on the duct is like TNT explosion. Using Halverson (1986 p 20), the TNT equivalent of the roof falling is

$$2.1\text{x}10^{10}\ \text{ergs}\left(9.48\text{x}10^{-11}\ \frac{\text{Btu}}{\text{erg}}\right) = 2\ \text{Btu}$$

$$M_{TNT} = \frac{2\ \text{Btu}}{1{,}940\ \text{Btu/lb TNT}} = 0.001\ \text{lb}$$

The (weight of inert)/(weight of TNT) is

$$\frac{923\ \text{lb}}{0.001\ \text{lb}} = 923{,}000$$

where:

923 lb = Weight of the duct.

$$\text{Mass aerosolized} = 2.783\ (923{,}000)^{0.3617}\ (0.001)$$

$$= 0.4\ \text{lb or } \frac{0.4}{923}\ \text{wt\%}$$

The amount of plutonium made airborne is 0.4/923 (846 g Pu) = 0.4 g. Based on this, the release is 0.4 to 5.9 g from the facility.

9.2.4A.6.3.11 Accident Analysis-Calculations, Criticality. Previous sections have shown how a criticality may be possible in the west gallery glovebox. This will be assumed.

9.2.4.3.2 Short Term Risk Acceptance, Building 232-Z. The release from Building 232-Z is considered separately because the source will soon be removed from the facility.

The release from Building 232-Z came as a result of the impact of the concrete roof and block walls on the contaminated ventilation ducts. The release was calculated to 5.9 g. The consequences are shown in Table 9.2.4-13.

Table 9.2.4-13. Seismic Induced Dose (rem) with Guidelines for 5.9 g Pu Release.

Location	Organ	Dose	Guidelines
Onsite	EDE	29.5	10
	Bone surface	372.0	100
Offsite	EDE	1.1	4
	Bone surface	16.0	40

The offsite dose is below the risk acceptance guidelines (Section 9.4) but the onsite dose is above the guidelines. To alleviate this situation, the source within Building 232-Z will be reduced as fast as possible. A dedicated task team has been assembled to expedite the modifications necessary to reduce the source term. The risk in the interim is considered to be acceptable because:

- The value of 5.9 g release of plutonium out of the ducts as a result of falling debris assumes that all of the powder suspended during impact is transported out of the inside of the duct. No credit is taken for retention in the duct. The value of 5.9 g is also based on experimental data concerning resuspension of spilled powder. The powder used in the experiments was in a jar which was simply tipped over. In the case of Building 232-Z because the powder is enclosed within a duct, the resuspension under actual conditions should be much less.

- No credit is taken for agglomeration - defined as that process which occurs within dense dust clouds in which large particles (which fall out rapidly) are made from the attraction of many small particles.

Because of the above, the onsite doses are considered to be within the Risk Acceptance Guidelines.

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