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3/16/88 JS (2)

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DRH 0413-8

RFP-4161
November 15, 1987

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SIMULATED SEISMIC EVENT RELEASE FRACTION DATA
PROGRESS REPORT APRIL 1986 - APRIL 1987

G. Langer

Rockwell International

North American Space Operations
Rocky Flats Plant
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U. S. DEPARTMENT OF ENERGY
CONTRACT DE-AC04-76DP03533

Printed in the United States of America
Available from the
National Technical Information Service
U.S. Department of Commerce
Springfield, Virginia 22161
Price Code: 001-025 pages, Code A02
Price Code: 026-050 pages, Code A03
Price Code: 051-075 pages, Code A04
Price Code: 076-100 pages, Code A05
Price Code: 101-125 pages, Code A06

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Printed
November 15, 1987

RFP-4161
UC-11 ENVIRONMENTAL CONTROL
TECHNOLOGY AND
EARTH SCIENCES
DOE/TIC-4500 (Rev. 73)

RFP--4161

DE88 006978

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NORTH AMERICAN SPACE OPERATIONS
ROCKY FLATS PLANT
P.O. BOX 464
GOLDEN, COLORADO 80402-0464

Prepared under Contract DE-AC04-76DPO3533
for the
Albuquerque Operations Office
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ABSTRACT

The object of this project is to obtain experimental data on the release of airborne particles during seismic events involving plutonium handling facilities. In particular, cans containing plutonium oxide powder may be involved and some of the powder may become airborne. No release fraction data for such scenarios are available and risk assessment calculations for such events lacked specificity describing the physical processes involved. This study has provided initial data based on wind tunnel tests simulating the impact of the debris on simulated cans of plutonium oxide powder. The release fractions are orders of magnitude smaller than previously available estimates.

INTRODUCTION

A Los Alamos Technical Associates (LATA) review[1] of Rocky Flats Plant (RFP) plutonium handling facilities concluded that several structures, including unanchored gloveboxes and other equipment, could fail during seismic events of different accelerations.

The RFP Safety Analysis Group performed risk assessments based on the consequences of such seismic events. The assessments were based on probabilities obtained from the Seismic Hazard Curves generated by TERA Corp. and presented in the RF Risk Assessment Guide (RFRAG).[2] These assessments are contained in the Final Safety Analysis Reports for the plutonium handling facilities. Based on the expected form of material involved in a release, assumptions were made regarding plutonium release fractions to estimate the initial source term for the release of radioactive material. These assumptions included estimates of the particle size distributions of the airborne releases, with emphasis on the respirable fractions. Sources of this information are the references listed in the RFRAG.[2]

The lack of specificity in the references made the release fraction and particle size distribution assumptions used for the RFP risk assessments very conservative. No directly relevant experimental data are available. In addition to overestimating the risks, this approach may place emphasis on irrelevant pathways. For instance, it is assumed for bulk powders that the material is made airborne by impact (e.g., a release fraction of 10%) or may become airborne by some means until a saturation concentration of 100 to 300 mg/m^3 is reached.[3] The latter are very high values. Such dust concentrations are encountered during dust storms, when winds over 50 mph blow across dry, plowed fields.

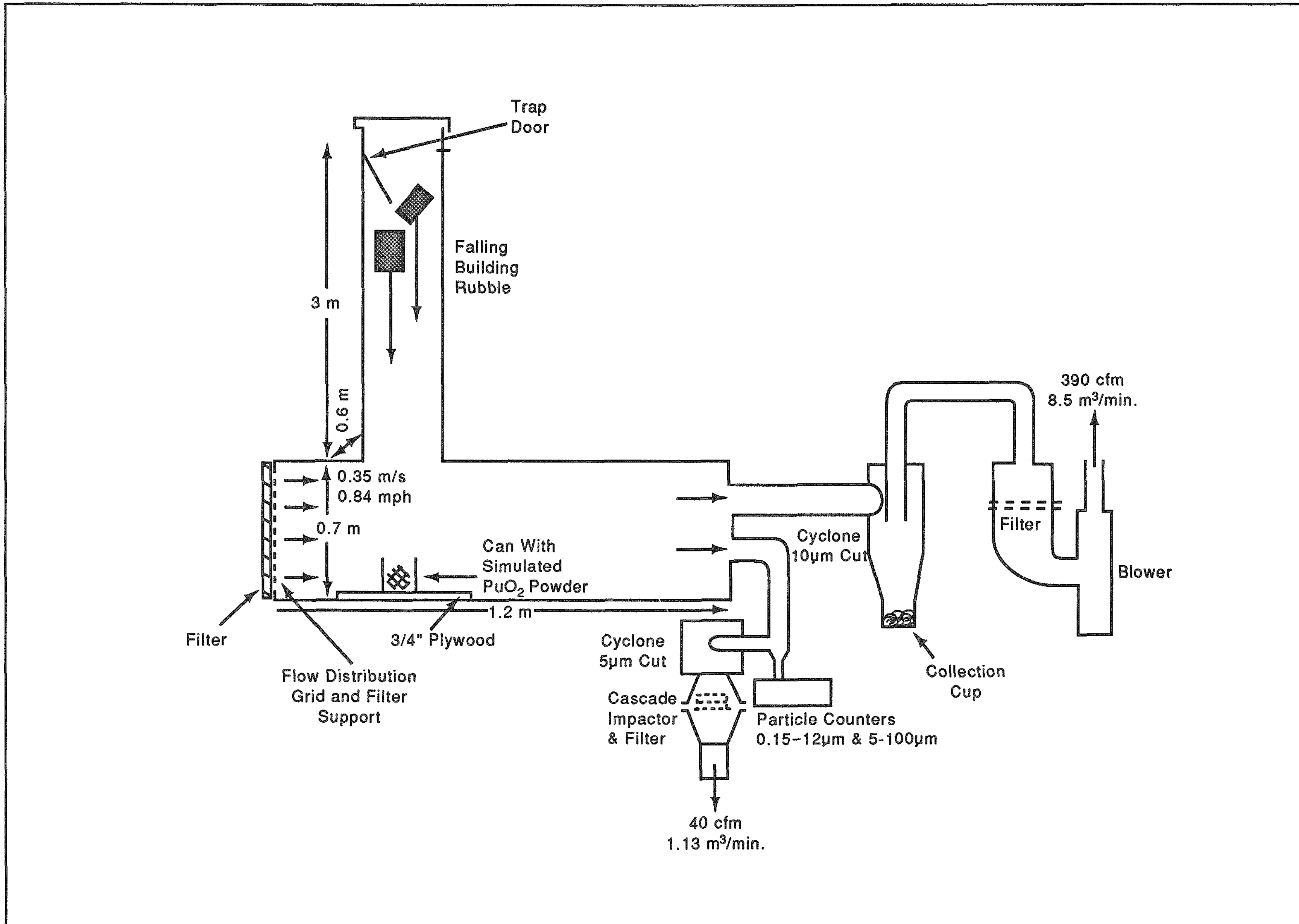
The object of this project is to conduct an experimental program to develop release fraction and particle size data to support the safety analysis program. This report covers experiments to determine the details of particle release when simulated plutonium powders are impacted by building debris under controlled conditions in a wind tunnel.

METHODS

Equipment

Figure 1 presents a schematic of the test facility. Figure 2 is a photograph of the same test facility. The target material was placed below the chute. If the material was confined to a can, the can was propped at a 60° angle to ensure that the can would tip over and the powder would be spilled. For tests where the powder was not confined (that is, the seismic event toppled the can and subsequently the powder was impacted by debris), the powder was poured out in the target area. The target area is a piece of 3/4-in. plywood to protect the wind tunnel floor. The three rocks shown in Figure 3, weighing 1,290 g, 1,170 g and 1,820 g, serve as the impacting debris. The rocks were released by the

FIGURE 1. Schematic of Facility to Simulate Aerosol Generation During Building Collapse



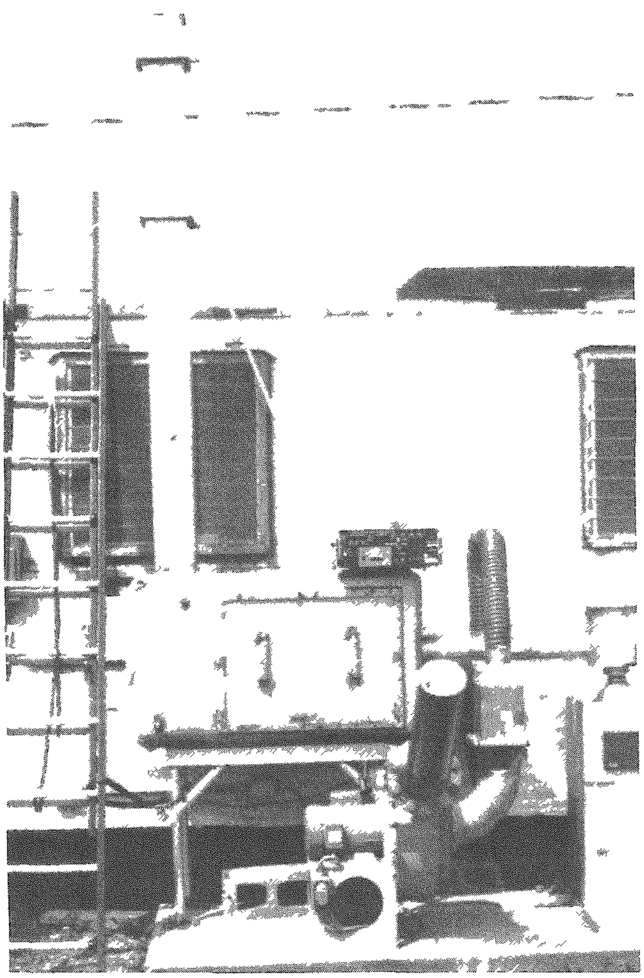


FIGURE 2. Photograph of Wind Tunnel Test Facility

trap door on top of the chute and fall 3.7 m before hitting the target.

The air entering the wind tunnel was filtered to remove all particles >5 μm. The filter and the supporting screen also serve to produce an even air flow pattern across the wind tunnel. This was verified with a thermo-anemometer. The velocity was about 0.8 mph.

Particulate Samplers

Most of the air was exhausted at 390 cfm through the 10-μm cyclone (B. G. Wickberg, 8 in. diameter model) that removes particles >10-μm aerodynamic equivalent diameter (AED). The cut-point curve for a cyclone is not sharp. Nominally, 50% of all the particles with an AED of 10 μm are collected with a collection efficiency rapidly increasing above 10 μm and, conversely, rapidly dropping off below 10 μm. Particles penetrating the 10-μm cyclone are collected on a special high-velocity filter paper.[4] A secondary airstream of 40 cfm was diverted through a 5-μm AED cut-point cyclone (Sierra Instrument Co., Model 230CP) and then to a one-stage impactor (Sierra Instrument Co. Model 230, Stage 1), which collected all particles >0.5-μm AED. Particles that passed through the impactor were collected on a standard fiber glass filter. The dust collecting surfaces of the Sierra cyclone and impactor were adhesive treated to

FIGURE 3. Spilled Powder Pattern After Impact by Three Rocks

prevent bounce-off and re-entrainment. The collecting cup of the 10-μm cyclone was oiled to prevent re-entrainment.

The preceding sampling devices provided mass concentrations. Two optical light-scattering counters provided real-time aerosol particle size and concentration data. A Particle Measurements Systems, Inc., (PMS) aerosol spectrometer Model LAS-250X was used for all the tests to measure particles in the 0.2- to 12-μm range. The instrument flow was 3 ℓpm. The data were reported in 16 size channels. A PMS Model LPC-550 probe to cover the 5- to 100-μm size range in 4 channels provided data for the last test reported in this period. The instrument has a flow of 1 cfm. Adhesive-coated microscope slides were also placed at various points in the wind tunnel to estimate the loss of released particles to the wind tunnel walls.

Test Powders

The test powder was weighed before each test, as well as the amount remaining in the wind tunnel after the test. The amount left in a can was also determined.

The test powders were characterized by dry sieving to determine the size distribution by mass using a set of 500-, 300-, 106-, 53-, 38- and 25-μm sieves assembled in series on a vibration mount. For some of the powders, wet sieving with chlorothene was used for the last two sieves to prevent sieve plugging. Attempts to determine the mass distribution of particles <25 μm, especially the inhalable (<10-μm AED) and respirable (<3-μm AED) material, have been unsuccessful so far. An attempt was made to brush small amounts of the powders through a 25-μm sieve into a cascade impactor to classify the particles. However, the sieve plugged before enough particles were brushed through. A larger opening sieve will be tried in the next series of tests. On a particle count basis, the particle size distribution <25 μm can be determined with the PMS LPC-550 optical probe, which has just become available.

The particle size distribution <25 μm is important, because it indicates the potential material available for dispersal. That range presents the greatest health threat. Fine particles, other than those present in the original powder, may be generated by the crushing of larger particles from the impact of debris. However, this is not expected to be a major source of fine particles, since sustained application of large amounts of energy is necessary to diminuate particles. Controlled experiments by Pui[5] have shown that direct application of hydraulic force to fracture pieces of sandstone released no weighable mass below 1.5-μm AED. The release fraction between 1.5 and 3.0 μm was approximately 0.5%.

Information on the test powders follows. The first four tests used a sandy, backfill material known as "squeegee" in the construction trade. It is a fragile sandstone aggregate and was sieved to remove oversized particles. The thought was that the debris impact may lead to the generation of more intermediate sized particles, i.e., in the 25 to 100 μm range. In contrast, the nickel test powder consisted of very hard, nearly spherical particles of high density, that flowed very freely. This powder should be similar to the plutonium oxide handled in the foundry. Aluminum oxide (Al_2O_3) was of interest because it has a large proportion of fines. It is a very gritty, free flowing material used for polishing hard metals.

The properties of plutonium oxide powders must be compared to that of the simulant powders. First of all, in these tests only the nickel powder approaches the density of 11.5 g/cm^3 for plutonium oxide. As for particle size, the respirable and inhalable fraction for typical foundry plutonium oxide is about 0.01% and 0.3% respectively based on optical microscope counts and *adjusting the size data to AED.* About 2.2% was <25 μm. For the nickel powder, applying the same analysis, the inhalable and respirable fractions were too small to measure quantitatively, but were at least one tenth less than that for plutonium oxide. In this case about 0.2% of the powder was less than 25 μm. Nickel powder was the coarsest material. Aluminum oxide had more fines than plutonium oxide, but its density is about one third of that for plutonium oxide. Therefore, we still have to find a heavy metal powder with more fines than nickel. A lead powder is available, but has to be analyzed for its size distribution. Depleted uranium oxide is also under consideration.

Test Procedures

After the tunnel was cleaned, it was operated for a short time, while the walls of the tunnel, ducts and cyclones were rapped to knock off remaining loose particles. This operation was monitored with the PMS probes. The sample collectors and media were mounted and the target assembly emplaced. The rocks were placed on the trap door after they had been dusted off. Operation of the wind tunnel was started and particle concentrations were monitored with the PMS probes. The counts stabilized in about 5 minutes. The PMS probes were then set to their highest data recording rates of 10- and 6-second intervals respectively for the LAS-250X and LPC-550. After the simulated debris was dropped, the tunnel was run until the particle counts returned to background levels.

Photographs were taken to record the position of the rocks and distribution of powder. The latter was recovered and weighed. The cyclone collections were recovered with a chlorothene wash and weighed. The same applies to the impactor sample. The back-up filters were also weighed. The microscope slides were examined microscopically.

The present tests were conducted in such a manner that all particles originated from the test powder. That is, no particulate material was introduced with the simulated debris (three clean rocks). In future tests, where the debris will include particulate matter (e.g., drywall and concrete), a tracer will be added to the test powder to identify it. In this situation, particle count data will not be very informative, because it does not distinguish between tracer particles, particles from the simulated debris and particles from the target powder. Therefore, these present tests were carried out with clean debris to study the fundamentals of powder dispersion by falling objects.

RESULTS AND DISCUSSION

First, these tests were designed as an exploratory series, because no previous research was found.

Table 1 presents the summary of the results. The averages for the release fraction data are given only

TABLE 1. Summary of Release Fraction Data

	Test Powder Specifications						Mass Release Fractions, (%)					
Test No.	Material[a]	Density (g/cm^3)	Container	Amount (g)	Mass Med. Dia. (µm)	STD Dev. of Dia.	<3 µm[c] Resp. PMS Probe	<5 µm AED Impactor	<10 µm[c] Inhal. PMS Probe	>5 µm AED Cyclone	>10 µm AED Cyclone	No. of <12 µm[d] Particles Released Per g of Charge
1	Sand, <2000 µm	2	Qt. Can	7.4×10^2	–	–	1.3×10^{-3}	–	2.5×10^{-4}	3.4×10^{-2}	2.6×10^{-2}	1.9×10^5
2	Sand, <500 µm 1.8% <25 µm	2	Qt. Can	1.2×10^3 [b]	1.9×10^2	2.4×10^0	8.7×10^{-4}	–	2.0×10^{-3}	2.8×10^{-2}	2.8×10^{-2}	1.5×10^5
3	Sand, <500 µm 1.8% <25 µm	2	In Open	1.1×10^3	1.9×10^2	2.4×10^0	3.1×10^{-3}	7.1×10^{-3}	3.1×10^{-2}	6.6×10^{-2}	5.6×10^{-2}	6.7×10^5
4	Sand, Plus 2.6% Al_2O_3	2	In Open	1.2×10^3	1.9×10^2	2.4×10^0	1.7×10^{-3}	2.5×10^{-3}	7.2×10^{-3}	1.7×10^{-2}	4.3×10^{-2}	3.4×10^5
5	Al_2O_3 <300 µm 24% <25 µm	4	In Open	4.6×10^2	9.1×10^1	3.6×10^0	3.2×10^{-2}	2.6×10^{-2}	3.3×10^{-2}	7.8×10^{-2}	8.9×10^{-2}	2.9×10^6
6	Nickel 0.2% <25 µm	8.9	In Open	1.0×10^3	7.0×10^1	1.4×10^0	1.7×10^{-3}	1.9×10^{-3}	1.0×10^{-2}	1.3×10^{-2}	7.5×10^{-3}	3.6×10^5
						AVERAGE	6.8×10^{-3}	9.4×10^{-3}	1.4×10^{-2}	3.9×10^{-2}	4.2×10^{-2}	9.5×10^5

r=0.89 (<3 µm Resp. PMS Probe vs. <5 µm AED Impactor); r=0.88 (>5 µm AED Cyclone vs. >10 µm AED Cyclone); r=0.86 (>10 µm AED Cyclone vs. No. of <12 µm Particles)

a. Size in terms of sieve data.
b. 400 g remained in can after impact.
c. AED, converted from geometric diameter using densities in Column 3.
d. Geometric diameter.

TABLE 2. Size Distribution of Particles Released by Debris Impact as Measured by PMS LAS-250X Probe

Size Range (μm)	Particle Size Distribution (%) Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
0.2-0.3	35.40	17.00	4.56	17.90	7.13	0.00
0.3-0.4	17.10	15.00	10.90	14.00	9.07	8.10
0.4-0.5	11.40	11.60	12.80	11.00	12.00	18.70
0.5-0.6	6.10	7.27	8.06	7.22	10.00	14.50
0.6-0.8	9.70	11.70	12.80	10.70	15.90	15.70
0.8-1.0	6.00	7.17	8.08	6.88	10.70	8.20
1.0-1.2	4.20	5.96	6.01	5.28	9.32	6.36
1.2-1.5	3.20	5.17	4.93	4.51	8.46	6.05
1.5-2.0	2.60	5.38	4.41	4.45	8.63	7.19
2.0-3.0	1.70	5.11	4.31	5.13	2.41	8.87
3.0-4.0	0.52	2.33	3.18	2.91	1.85	3.09
4.0-5.0	0.36	1.79	3.89	2.67	2.27	1.64
5.0-7.0	0.58	3.19	7.60	4.25	0.80	1.10
7.0-9.0	0.55	1.75	4.25	2.09	0.85	0.30
9.0-12	0.38	0.97	2.34	0.82	0.41	0.10
>12	0.30	0.91	1.86	0.18	0.22	0.10

TABLE 3. Run 6 Size Distribution of Particles Released by Debris Impact as Measured by PMS LPC-550 Probe

Size Range (μm)	Particle Size Distribution (%)
5.0-10	68.90
10.0-25	26.50
25.0-50	3.80
>50	0.70

to exemplify the trends of release fractions versus size range. We are dealing with different powders, so averages per se are not appropriate. Tables 2 and 3 summarize the numerical particle size distributions for the particles that became airborne upon impact. Distributions in Table 1 and 2 are presented as the percentage in each size range. The distributions did not follow a log normal curve, as might be expected.

The release fractions, based on the mass of particles larger than 10 μm that became airborne, are the most accurate data. Almost gram quantities of material were collected. The Sierra 5-μm cyclone collection correlated well (r=0.88) with the 10-μm cyclone collection. The 5-μm cyclone was expected to collect more material, because it contains the 5 to 10 μm increment as well, but it collected a little less (see the averages for Columns 11 and 12 in Table 1). The 5-μm cyclone samples one tenth the volume of the 10-μm cyclone, but its collection surface is very much larger. That presents a dust recovery problem.

The fact that the mass of particles collected <5 μm is relatively small is of importance. It indicates that the health hazard, i.e., respirable dust generation, is small.

Overall, the mass release fractions are nearly 1/100 less than those used in previous safety analyses.[6] The nickel powder release fraction was another order of magnitude lower. Nickel powder simulates plutonium oxide the closest as far as density is concerned but it is much coarser than plutonium oxide. Upon impact, it spread out farther, but not as much material became airborne. The powder is very free flowing and may dissipate the impact energy more throughout the bulk of the powder. The data show that Al_2O_3, the finest (see Table 1) powder tested, released roughly an order of magnitude more particles on a particle count basis and on a mass basis for the <5-μm particles. This is not unexpected, because Al_2O_3 contained roughly an order of magnitude more of <25-μm particles by mass than the rest of the powders.

The number of <12-μm particles released per gram of charge is a direct measurement of particle release by the debris impact. Table 1 shows that this amount varies by a factor of greater than 10 but correlates with the mass release fraction for particles larger than 10 μm (linear correlation factor = 0.86). More data need to be acquired to confirm that this correlation is generally applicable.

The details of converting the count (PMS probe) data to mass have interest. The count data are easily obtained and the means of data collection avoids the more tedious weighing of the mass collection procedure. The particle size data in Table 2 were used to calculate the volume/mass of the <10-μm (inhalable) and the <3-μm (respirable) particles for Table 1. This was done in terms of respirable particles being <3 μm and inhalable particles being in the 3- to 10-μm range. These ranges are defined by AED measurements. Therefore, for each of these ranges, the volume of the particles was calculated after adjusting the count diameter to AED using the powder densities given in Table 1. These volumes were converted to the corresponding mass to estimate the mass release fractions associated with the respirable and inhalable particles. The results are given in Table 1. The mass release fractions for the respirable and inhalable particles appear reasonable and correlate (r=0.81) with the >10-μm release fractions. These results are encouraging and confirm that this experimental approach is sound.

The inhalable (<10-μm) mass release fractions from the PMS probe are somewhat low, because no correction was made for sampling-line losses in the counter. These losses gradually increase from about 0% at 1 μm to 40% near 10 μm.[7] Other uncertainties are introduced by shape factors and refractive index effects. No attempt was made to compensate for these effects, because of the basic uncertainties involved in converting particle count data to mass, i.e., the diameter cubed relationship between the optical diameter and volume.

Table 3 gives the particle size distribution data for the large particles (5 to 100 μm geometric diameter) released during Run 6. In this range 1.1×10^4 particles per gram were released, versus 3.6×10^5 in the <12-μm range.

The microscope slides placed on the floor and sides of the wind tunnel showed only a few particles <100 μm. Qualitatively, the wall losses were low.

SUMMARY AND CONCLUSIONS

A wind tunnel procedure was developed to measure the release fractions for powders impacted by falling building debris. The release fractions are relatively small. On the average, 0.04% of the original particle mass became airborne in particles larger than 10 μm. In terms of particle counts, 9×10^5 particles per gram of powder charged become airborne in the <10-μm range. The release fraction for the inhalable particles was 0.01%. The corresponding respirable particle mass release fraction was estimated from the particle counts as 0.008%. It appears that previously used estimates for the release fractions may be two orders of magnitude too high.

These release fractions may be compared to dust released when powders are dropped in a conveying system. For a 5 ft fall, the dust emission was 0.0001% to 0.1% of the material dropped, depending on moisture content and treatment to prevent dusting.[8] These results bracket our data and give further credence to the test procedures.

FUTURE WORK

Efforts should be made to fully characterize the test powders as to the mass distribution <25 μm, i.e., to establish how much material by mass is available for resuspension in the powder as charged. At the same time, direct measurement of the mass of particles <5 μm released needs improvement. The simulated building debris should be varied. As a next step, a lead brick might be used to explore the effect of a large increase in kinetic energy of the impacting mass on dust release.

Attempts should be made to fit appropriate size distribution curves to the aerosol data.

The wind tunnel velocity should be increased to 3 mph or more. Changing the velocity distribution and scale of turbulence is of interest. Finally, the loss of released particles to the wind tunnel walls might be investigated further with a tracer.

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