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Engineering Scale Electrostatic Enclosure Demonstration

L. C. Meyer

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Engineering Scale Electrostatic Enclosure Demonstration

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ABSTRACT

This report presents results from an engineering scale electrostatic enclosure demonstration test. The electrostatic enclosure is part of an overall in-depth contamination control strategy for transuranic (TRU) waste recovery operations. TRU contaminants include small particles of plutonium compounds associated with defense-related waste recovery operations. Demonstration test items consisted of an outer Perma-con enclosure, an inner tent enclosure, and a ventilation system test section for testing electrostatic curtain devices. Three interchangeable test fixtures that could remove plutonium from the contaminated dust were tested in the test section. These were an electret filter, a CRT as an electrostatic field source, and an electrically charged parallel plate separator. Enclosure materials tested included polyethylene, anti-static construction fabric, and stainless steel. The soil size distribution was determined using an eight stage cascade impactor. Photographs of particles containing plutonium were obtained with a scanning electron microscope (SEM). The SEM also provided a second method of getting the size distribution. The amount of plutonium removed from the aerosol by the electrostatic devices was determined by radiochemistry from input and output aerosol samplers. The inner and outer enclosures performed adequately for plutonium handling operations and could be used for full scale operations.

SUMMARY

This report presents results from an engineering scale electrostatic enclosure demonstration performed at the Idaho National Engineering Laboratory's (INEL's) test Reactor Area (TRA). This demonstration was sponsored by the Buried Waste Integrated Demonstration for the DOE office of Technology Development. Electrostatic curtain (ESC) technology may be applied as a contamination control technique during handling of transuranic (TRU) material such as retrieval of buried waste. The experiments in this demonstration included an inner and outer enclosure with a ventilation system and was designed to demonstrate the applicability to full scale operations. The electrostatic curtain is part of an overall in-depth strategy for contamination control during TRU waste recovery operations.

The engineering scale experiments were performed inside a double enclosure with a ventilation system. These tests represent a considerable size enhancement over previous glove box tests that confined the experiment to a 4 cubic inch test section within the glove box. The outer enclosure consists of a 12 by 8 ft stainless steel Perma-con structure with two personnel doors. The inner enclosure was a Nuclear Power Operators tent 4 by 6 by 6 1/2 ft. The inner enclosure contained the dust generator and test materials on the test rack. The ventilation system and HEPA filter interface and test section passed through the back side of the Perma-con enclosure connecting to the output opening of the inner enclosure.

The test section in the ventilation system interface was used for testing the various electrostatic devices for removing plutonium from the aerosol. The ESC devices consist of 3M electret filter material, a test fixture that used the electric field from a CRT, and a parallel arrangement of metal plates referred to as a separator.

The materials tested in the inner enclosure were polyethylene, anti-static building fabric material; and stainless steel. The materials had coupons (made of the same material) attached for gravimetric and radio chemical analysis.

Photographs taken with a scanning electron microscope (SEM) operated in the compositional mode identified particles containing high Z elements. The high Z element could then be identified as plutonium by using the SEMs dot mapping capability. The SEM also provided size distribution printouts for selected samples to help characterize the aerosol for contamination control. The SEM analysis and photographs showed that the plutonium was attached to and compounded with the soil particles. This explains why all the plutonium could not be separated from the dust particles. The electrostatic separation process requires that the plutonium particles be self-charging and develop a net positive charge.

The Inhalation Toxicology Research Institute (ITRI) at Albuquerque, NM, prepared the soil mixture for the engineering scale tests. The ^{239}Pu -labeled soil was checked for activity level and size distribution to characterize the soil for the demonstration tests. The activity levels varied from 16.2 to 590 pCi/g with an arithmetic average of 187.1 pCi/g. This distribution was considered non-homogeneous compared to the planned values. The average particle diameter ranged from 8.89 μm to 13.77 μm as determined by SEM analysis with the largest particle 220.6 μm in diameter. The cascade impactor data indicated that 47% of the mass was greater than 10 micrometers in diameter and less than 1% was smaller than 1.1 micrometers.

The non-homogeneity (16 to 590 pCi/g for source dust samples) was also observed in previous glove box tests using the plutonium contaminated Rocky Flats/INEL soil blend. Thus it is probably what might be expected in a waste recovery operation involving TRU waste.

The percent of PuO₂ removed in the engineering scale tests was lower than for the glove box tests. This indicates that longer distances and higher elevation of the separator in the engineering scale test resulted in heavier PuO₂ particles falling out before reaching the test section. In addition, many of the smaller particles attached to dust particles passed through the electrostatic field on neutralized dust particles. Only those particles that contained enough plutonium to be self-charging could be separated. The amount of plutonium that could be removed by the parallel plate separator used in these experiments ranged from 20.5 to 51.1%.

The inner and outer enclosures worked adequately for Plutonium handling operations. The Perma-con enclosure with its clip-together construction method was easy to assemble and can be moved or extended with additional panels. The configuration can be changed when reassembling because the panels are interchangeable. The inner enclosure was a light-weight, see-through PVC with an aluminum tubing frame that could also be moved easily. This kind of inner enclosure could be adapted to a larger configuration such as might be used in a full scale waste recovery operation.

Evaluation of the electrostatic materials controlling plutonium confirmed what was learned in prior glove box tests. A conducting material that is grounded is the best choice to minimize electrostatic charge build up on the walls and collect minimum amounts of dust and plutonium. The conducting material will also minimize the spread of contamination because electrostatic build up is eliminated. A grounded, anti-static, construction fabric was second best in that it also eliminates charge buildup. However the longer discharge time for static charges allows more time for the particles to stick to the surface than for conducting materials. Insulating material sheets like polyethylene will collect various amounts of static charge that can have either a positive or negative sign. Thus the test results on polyethylene were unpredictable.

Evaluation of the electret filter as an electrostatic device in the ventilation system also confirmed previous glove box test results. Electrets filter out respirable size dust particles very well and have a lower air resistance than pure mechanical filters. The mass removal efficiency was within the manufacturers specification of 97.5% to 99% for the air velocities used in the tests.

The electrostatic field from the CRT was too low (65.8 V/cm) to make it a good electrostatic source for this application. The capability to attract plutonium using the CRT would be the same as that for parallel plates but with a lower voltage of only 65.8 V on the stainless steel plates.

A 98% plutonium removal efficiency was considered a successful application according to the test plan. Since the plutonium is so well attached to and compounded with the dust particles, removing 98% or more of the plutonium with electrostatic devices would require a higher voltage electrostatic precipitator. The other options are to use electret filters or a virtual impactor. All of these devices would remove both dust and plutonium from the air flowing in the ventilation system. However, the virtual impactor could be tuned to remove only those particles above a given diameter.

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ACRONYMS AND ABBREVIATIONS

CRT	cathode ray tube
LVCI	low volume cascade impactor
DOE	Department of Energy
ESC	electrostatic curtain
fpm	ft/min
lpm	l/min
INEL	Idaho National Engineering Laboratory
ITRI	Inhalation Toxicology Research Institute
PVC	polyvinylchloride
RFP	Rocky Flats Plant
SEM	scanning electron microscope
TRA	Test Reactor Area
TRU	transuranic

ENGINEERING SCALE ELECTROSTATIC ENCLOSURE DEMONSTRATION

ELECTROSTATIC CURTAIN DEMONSTRATION

Introduction

This report presents results from an engineering scale electrostatic enclosure demonstration performed at the Idaho National Engineering Laboratory's (INEL's) test Reactor Area (TRA). This demonstration was sponsored by the Buried Waste Integrated Demonstration for the DOE office of Technology Development. Electrostatic curtain (ESC) technology may be applied as a contamination control technique during handling of transuranic (TRU) material such as retrieval of buried waste. The experiments in this demonstration included an inner and outer enclosure with a ventilation system and was designed to demonstrate the applicability to full scale operations. The Electrostatic Curtain is part of an overall in-depth strategy for contamination control for TRU waste recovery operations.

Background information is discussed first, then a description of experiments and experimental results. This is followed by conclusions and recommendations. Appendix A lists the equipment used in the demonstration tests; Appendix B provides the electrostatic properties of the antistatic construction material; Appendix C contains a list of test samples and the gravimetric and radiochemistry data.

Background

The Department of Energy (DOE) weapons complex produced waste contaminated with TRU elements, primarily plutonium and americium. Historically, the INEL received some of this contaminated waste for interim storage. Past practices had this waste buried in shallow pits and trenches or stored aboveground under earthen cover. Retrieving and processing these stored materials for final deposition has the potential for considerable spread of TRU contamination due to the highly mobile nature of the TRU contaminants. Because of high toxicity and low allowable body burden, maximum achievable control of these materials is mandatory. Compounding the control problem is the potential for plutonium to attach to dust particles and migrate with the fugitive dust generated through retrieving or handling this waste.

One method considered for controlling the fugitive dust is the electrostatic curtain (ESC). Insulator, antistatic, and conductor materials were studied as candidate materials for ESCs. The FY-90, FY-91, and FY-92 ESC studies demonstrated that the minimum amount of dust and contamination is collected on a conducting surface that is grounded.¹⁻³ The results of these studies also showed that the positively charged plutonium and americium particles are strongly attracted to negative surfaces in an electrostatic field. Since a negative surface will attract and a positive surface will repel positively charged particles, we have the basis for control of charged airborne particles passing within range of the electric field.

Particle size was found to be an important parameter. From cascade impactor data and radiochemistry analysis it was shown that as the equivalent aerodynamic diameter (particle size) decreased, the pCi/g of Pu-239 increased. Since electrostatic attraction also becomes stronger as

particle size decreases, the ESC devices may be a viable means of separating the Pu-239 from the general dust population.

Experiments were conducted to separate the positively charged plutonium particles from dust particles in the aerosol. Parallel plate electrostatic devices using electric fields of 300 V/cm were able to separate 78.7% of the plutonium from the aerosol in glove box experiments. Small plutonium particles attached to larger dust particles could not be separated. Higher voltage devices would remove both dust and plutonium.

Electret materials were found to be effective filters (99%) for both dust and Pu-239. Since the fibers in the electret filters have a permanent electrostatic charge, the filter mat is less dense than the mat needed for mechanical filters and presents a lower resistance to air flow. These filters should offer an effective low hydraulic resistance solution to filtering air in a ventilation system associated with retrieval efforts.

The scanning electron microscope (SEM) was found to be a valuable tool for photographing and identifying particles of Pu-239 from coupon samples. The SEM also has the capability for determining particle size distribution.

The obvious application of electrostatic curtains is for establishing enclosure walls that can neutralize and contain plutonium/ameridium contaminants. By having a grounded (electrically conductive) surface, charged particles contacting the surface would be discharged with a minimum number becoming attached. Alternatively, electrostatically charged ESCs could attract plutonium/ameridium contaminants to collection areas or repel them from doorways and work areas. Application of electrostatic devices in ventilation systems can also promote cleaning of airborne plutonium/ameridium from the aerosol.

DESCRIPTION OF EXPERIMENTS AND EXPERIMENTAL RESULTS

The engineering scale experiments were performed inside a double enclosure with a ventilation system. The outer enclosure consists of a 12 by 8 ft stainless steel Perma-con structure with two personnel doors. A picture of the Perma-con enclosure is shown in Figure 1. The inner enclosure was a Nuclear Power Operators tent 4 by 6 by 6 1/2 ft. The test area of the inner enclosure showing the dust generator, three strips of test material on the test rack, and two of the four glove ports can be seen in Figure 2. The ventilation system and HEPA filter interface and test section passed through the back side of the Perma-con enclosure as shown in Figure 3 connecting to the output opening of the inner enclosure. See Appendix A for a list of the test fixtures and equipment used in the experiments. The guiding document for these experiments was the *Test Plan for Engineering Scale Electrostatic Enclosure Demonstration*.⁴

Preliminary tests were run in a glove box to get the size distribution of the ²³⁹labeled soil with a cascade impactor and data for comparing with previous glove box tests.

Tests were run with three different electrostatic devices in the ventilation system test section. The ESC devices consist of 3M electret filter material, a test fixture that used the electric field from a CRT, and parallel arrangements of metal plates. Each electrostatic device test series was run with three ventilation system air velocities.

The materials tested in the inner enclosure were polyethylene, anti-static building fabric material, and stainless steel. The materials had coupons (made of the same material) attached for gravimetric and radio chemical analysis. One set of materials were left in the inner enclosure for 1/2 hour and a second set was in for 2 hours.

The experimental investigations were quantified by measuring the amount of dust collected on input and output particulate sampler filters, separator plates from the glove box experiment, material coupons, and the various stages of the low volume cascade impactor (LVCI) using a Sartorius balance with five place accuracy. Size distribution of the aerosol was determined from the amount of dust collected on the various stages of the LVCI. Radiochemistry analysis performed on selected samples determined the Pu-239 content. A scanning electron microscope operated in the compositional mode was used to identify particles containing high Z elements. The high Z element could then be identified by using the SEMs dot mapping technique. Photographs and size distribution printouts were also provided for selected samples.

An electret air filter is one in which the dust particles are captured by electrostatic forces in addition to the mechanical capture of ordinary filters. This filter is made of polymer fibers that have a permanent polarization induced in the electret fibers during manufacture and therefore carry a permanent positive and negative charge. They can be made less dense than conventional filters and offer less resistance to air flow without loss of efficiency in capturing submicrometer particles. The 3-M company makes the filter material and custom filters under the trade name FILTRETE. An electret filter was placed in a specially fabricated filter holder and put into the experiment test section replacing the separator. Particulate samplers were also placed before and after the electret filter for sampling the aerosol flowing in and out.

Figure 1. Perma-con enclosure used in the demonstration tests.

Figure 2. Inner enclosure test area showing dust generator and material samples.

Figure 3. Ventilation system with HEPA filter attached to the Perma-con enclosure.

The test fixture for the CRT test had a grounded plate on the back side and a plastic film on the other side. The face of the CRT was placed against the plastic film. The electric field from the CRT interacting with the charged dust particles provided the attraction force for the PuO₂ and dust collection process.

The ESC separator experiment configuration in the ventilation system test section is shown in Figure 4 as seen from inside the inner containment. The separator assembly consists of 23 stainless steel plates (6 by 12 by 1/8 in.) with 1 cm spacing between them. The even-numbered plates were negatively charged (to collect positively charged Pu-239) and odd-numbered plates were grounded (to collect negatively charged dust particles). Voltages of -550 and -300 V were used on the plates to determine the effect of the magnitude of the electric field on the amount of dust and Pu-239 collected. The electric field strength is determined by dividing the voltage by the distance between the plates. For example, with the 1 cm spacing between the plates and -300 V applied, the electric field strength is 300 V/cm (30,000 V/m).

A laboratory power supply provided the voltages and the power supply ground terminal acted as a reference point for the system ground. Cables from the power supply and ground connection passed through feedthroughs in the two enclosures to the various plates and conducting materials in the tests.

Polyethylene (insulator), anti-static construction grade fabric, and stainless steel (conductor) were the materials investigated. Materials may be classified (with regard to holding an electrostatic charge) as static-prone materials (insulators), static-free materials (anti-static), and conductors. Materials with more than 10⁹ ohms/square (i.e., the resistance of a sample of square size, whether it is 1 cm² or 1 m², yields the same results) such as polyethylene are likely to develop electrostatic potentials that will not bleed off by themselves due to the high resistance of the material. Materials with less than 10⁹ ohms/square, even if not real conductors, will not keep the charge imbalance very long because recombinations will occur throughout the material itself. See Appendix B for electrical specifications on the antistatic construction grade material. Materials with a resistivity of less than 10⁶ ohms/square are usually considered conductors. Stainless steel was used for the conducting material. Grounding the anti-stat and conducting materials should drain off any static charges that accumulate on these materials and minimize the amount of dust and PuO₂ collected on them. To verify this hypothesis, coupons made of each of these materials were attached to strips of the materials placed in the test enclosure. The coupon size was two square inches. The amount of dust collected on each material was then determined by gravimetric means and the activity level of selected samples was determined by radiochemistry. Appendix C contains a list of samples taken along with the gravimetric and radiochemistry data.

Experiment Preparation

The aerosolizer and material samples were placed inside the inner enclosure and particulate samplers installed at the input and output of the test section. Wires were connected to the material samples and plates in the separator. The power supply was connected to provide either the negative voltage or ground as required.

Figure 4. The parallel plate separator as viewed from inside the inner enclosure.

Experiments with the electret filter were arranged in a similar manner except that the separator was replaced with the electret filter assembly that required no electrical connections. The CRT test required only a ground connection to the backside ground plate. All filters and material samples were weighed and placed in position prior to running each experiment.

Experiment Procedure

Each experiment was initiated by turning on the ventilation system and adjusting the airflow to the required setting. Next the particulate samplers were started and the sample air flow was set to 2 lpm. Lastly, the aerosolizer was turned on. Experiments lasted for 15 minutes with the aerosolizer on, which was sufficient time to collect a visible coating of dust on the material samples and input and output filters. The experiment was then shut down in reverse order from that in start up. The filters, and material samples were then removed to get the post weights and placed in petri dishes for subsequent radiochemistry and SEM analysis. The data are discussed along with the results for each of the experiments.

²³⁹Pu-labeled INEL Soil

The Inhalation Toxicology Research Institute (ITRI) at Albuquerque NM prepared the soil mixture for the engineering scale tests. ITRI added polydispersed PuO₂ having an average equivalent aerodynamic diameter of 1 μm to clean INEL soil using the following procedure. A portion of uncontaminated soil shipped from the INEL in 1992 for soil suspension tests was desiccated by heating to about 50°C and subjected to gentle milling to reduce clumps of dirt. A suspension of plutonium hydroxide at a concentration of about 1 mg ²³⁹Pu/ml was aerosolized using a Lovelace nebulizer. The nebulized droplets were dried by passing through a 1100°C heating column and mixed with diluting air. The dried particles of ²³⁹PuO₂ were collected on a membrane filter. Subsequently the ²³⁹PuO₂ particles were resuspended from the membrane filter into deionized water at pH = 10 and the concentration was determined. Five replicate samples of the ²³⁹PuO₂ suspension were made, the radioactivity determined, and the results averaged. After determining the concentration of ²³⁹PuO₂, a volume was removed from the suspension to provide 2.0 nCi/g of soil. This amount of ²³⁹PuO₂ was mixed into the soil volume using a V-type mixer. Subsequently the soil was triple bagged and placed into two cans with rolled lids and shipped to INEL. The soil was shipped as nonradioactive material because the concentration of ²³⁹Pu does not exceed 2 nCi/g of soil.

The ²³⁹Pu-labeled soil was checked for activity level and size distribution to characterize the soil for the demonstration tests. Radiochemical analysis of several soil samples indicated a non-uniform activity level so additional samples were analyzed. The results for seven soil samples of approximately 500 mg each are given in Table 1. The activity levels varied from 16.2 pCi/g to 590 pCi/g with the arithmetic average of 187.1 pCi/g.

The soil size distributions as determined from three soil samples using the SEM are given in Table 2. The average particle diameter ranged from 8.89 μm to 13.77 μm. The largest particle in these three samples was 220.6 μm in diameter. Photographs of the three soil samples with the SEM in the secondary emission mode (SEI) and compositional mode are shown in Figures 5 through 7. The SEI operating mode provides a picture of a portion of the dust sample and the bright spots in the compositional photograph of the same area indicate that a high Z material is present. Looking at these same areas in the dot mapping mode using two different

Table 1. Radiochemical analysis for the ^{239}Pu -labeled soil.

Sample number	Activity (pCi/g)
Composite sample	70.0 $\pm$ 4
Soil # 1	71.0 $\pm$ 4
Soil # 2	32.2 $\pm$ 1.9
Soil # 1A	590 $\pm$ 30
Soil # 1A-1	16.2 $\pm$ 1.0
Soil 3 2B	30.6 $\pm$ 1.8
Soil # 2B-1	500 $\pm$ 30
Arithmetic average	187.1 $\pm$ 9.2

Table 2. Average parameter values for soil samples examined with the SEMs.

Parameter	Soil shown in Figure 5	Soil shown in Figure 6	Soil shown in Figure 7
Area (μm^2)	91.35	100.84	139.24
No of particles	123	88	54
Perimeter (μm)	51.67	88.43	78.4
Diameter (μm)	8.98	13.77	11.56
Length (μm)	11.57	17.53	14.61
Width (μm)	6.57	9.84	8.36
Minimum Diameter (μm)	1.45	1.81	1.67
Maximum diameter (μm)	71.92	220.69	82.15

crystals (a PET and a LIF crystal) that are sensitive to different forms of emissions from the high Z material and both of them indicating areas with bright dots positively identifies the high Z material as plutonium. This plutonium identification process is illustrated with another soil sample shown in the compositional mode in Figure 8a and the dot mapping modes with the two crystals in Figure 8b and 8c.

The Anderson low volume cascade impactor (CI) was also used to determine the size distribution of the ^{239}Pu -labeled soil. Table 3 shows the size distribution and activity level for selected stages. The prefilter collected 47.71% of the total mass (non-respirable particles having an aerodynamic diameter greater than 10 μm or PuO_2 particles greater than 2.95 μm). The activity level for the larger particles in the prefilter and stage zero was 0.49 nCi/g and 0.5 nCi/g respectively. The stage 3 activity increased to 0.59 nCi/g and stage 5 was 2.44 nCi/g. This is consistent with previous glove box experiments in that activity level per unit mass increases with decreasing particle size.

The cascade impactor measures the aerodynamic particle size and is based on the behavior of a particle having a density of 1 g/cm^3 . A higher density particle will behave the same as a 1 g/cm^3 particle, but with the diameter increased by the ratio of the square root of the densities. For example, PuO_2 has a density of 11.46 g/cm^3 and a 1 μm particle of PuO_2 is aerodynamically equivalent to a 3.39 μm diameter particle with a density of 1 g/cm^3 . The equivalent PuO_2 particle sizes measured on the various stages of the cascade impactor are also shown in Table 3.

Figure 5a. Dust particles magnified x500 and used for SEMs particle count.

Figure 5b. High Z particles identified on and among dust particles with SEM in the composition mode.

Figure 6a. Large dust particles among smaller ones magnified x400 and used for a second SEMs particle count.

Figure 6b. Plutonium particles identified on large dust particle and among other dust particles with SEM in the composition mode.

Figure 7a. Dust particles magnified x650 and used for a third SEMs particle count.

Figure 7b. Plutonium particles identified on and among dust particles with SEM in the composition mode.

Figure 8a. High Z material identified on and among dust particles magnified x600 with SEMs in composition mode.

Figure 8b. Plutonium particles identified on dust particles in Figure 8a (shown as bright spots) by means of a LIF crystal in the SEMs.

Figure 8c. Plutonium particles identified on dust particles in Figure 8a (shown as bright spots) by means of a PET crystal in the SEMs.

Table 3. Cascade impactor data for soil size distribution and activity on selected filters.

Stage	Activity (nCi/g)	% of total dust collected	Particle size (micrometers)	Equivalent PuO ₂ particle size (micrometers)
Prefilter	0.49	47.71	>10	>2.95
0	0.50	12.15	9.0-10.0	2.65 - 2.95
1		14.77	5.8-9.0	1.71 - 2.65
2		6.76	4.7-5.8	1.39 - 1.71
3	0.59	8.97	3.3-4.7	0.97 - 1.39
4		6.25	2.1-3.3	0.62 - 0.97
5	2.44	2.57	1.1-2.1	0.32 - 0.62
6		0.74	0.7-1.1	0.21 - 0.32
7		0.07	0.4-0.7	0.12 - 0.21
F		0.01	0-0.4	0 -0.12

The respirable size distribution (particles less than 10 μm) of the ^{239}Pu -labeled soil is shown in Table 4. This is the same data as shown in Table 3, but without the mass collected in the prefilter.

The bulk density of INEL soil is 1.30 g/cm^3 and the particle density is 1.84 g/cm^3 . For the same size particles, the heavier PuO_2 particles (11.46 g/cm^3) will settle out faster than the soil particles. Some larger dust particles appear to have smaller PuO_2 particles attached as can be seen in Figures 5, 6, and 9. The natural negative static charge of the larger dust particles dominate the attached positively charged PuO_2 particles and carry them through any electric field of a collection device.

Table 4. Cascade impactor data for soil distribution less than 10 micrometers.

Stage	Mass (mg)	% of total dust collected	Particle size (micrometers)
0	42.2	12.15	9.0-10.0
1	51.3	14.77	5.8-9.0
2	23.5	6.76	4.7-5.8
3	31.2	8.97	3.3-4.7
4	21.7	6.25	2.1-3.3
5	8.9	2.57	1.1-2.1
6	2.6	0.74	0.7-1.1
7	0.3	0.07	0.4-0.7
F	0.1	0.01	0-0.4

Figure 9. High Z material on a dust particle.

Glove Box Tests

The glove box was used primarily to get the aerosol size distribution with the cascade impactor. The cascade impactor distributions are presented in Tables 3 and 4. One test was run with the small parallel plate separator having 550 V/cm on the plates. This arrangement removed 76.9% of the PuO_2 and 71.96% of the mass from the aerosol. This was slightly lower than 78.7% Plutonium removal found in previous glove box experiments with 300 V/cm on the plates using the Rocky Flats/INEL soil mixture. Radiochemical analysis for plutonium was performed on one negatively charged plate and one grounded plate. The results were nearly identical with 10.6 pCi on the negative plate and 10.3 pCi on the grounded plate and 20.9 mg of dust collected on each. Thus the behavior of the ^{239}Pu labeled soil is slightly different from the Rocky Flats/INEL soil used in previous glove box tests where the negative plate collected the most plutonium. This difference was probably due to more small plutonium particles being attached to or combined with larger dust particles.

TESTS RESULTS

A goal of 98% PuO₂ removal efficiency was set for the engineering scale demonstration tests. This was achieved with the electret filters but not with the parallel plate separator or CRT electrostatic field source which had removal efficiencies ranging from 20.5% to 51.1%. The reasons for the lower removal efficiencies with the electrostatic field separators are: (a) this test used a PuO₂ soil mixture and previous glove box tests used a contaminated RFP/INEL soil blend, (b) the engineering scale tests had a longer distance for particle travel and the heavier particles fell out before reaching the separator, and (c) many of the smaller plutonium particles became attached to or combined with larger dust particles which carried them through the separator. The detailed test results and data are discussed in the following sections.

Electret Filter Tests

The mass removal efficiency for electret filters was within the manufacturers specification of 97.5% to 99% for the air velocities used in the tests. The amount of dust removed by the filter as measured on the 47 mm samplers for three different air velocity settings on the ventilation system are shown in Table 5. The manufacturer's data for the same air velocities through this type of filter is also given in Table 5. The mass measured on the output sampler for each test run was quite small (0.08 mg to 0.13 mg) and has a large uncertainty. The manufacturer's data falls within the error band of the measured data. However, the sample mass was too small for a reliable determination of the radioactivity on the output samples.

CRT Tests

On the face of the plastic film in front of the CRT face a measurement of 2000 V was obtained and was smaller than anticipated. For the 30.48 cm (12 in.) wide ventilation system test section the average electric field was 65.8 v/cm from the plastic film to the grounded plate on the opposite side. The amount of PuO₂ removed in this test was also less because of this low electrostatic field.

The mass and plutonium removed from the aerosol passing through the test section and collected on the film and grounded plate is in Table 6. At an air velocity of 83 fpm, 39.4% of the mass and 41.5% of the PuO₂ were removed. When the velocity increased to 95 fpm the amount removed decreased to 15.8% for the mass and 27.4% for the PuO₂.

Separator Tests

The percent of mass and PuO₂ removed in the separator tests with 550 V on the plates and various air speed velocities is shown in Table 7. The mass removed decreased from 73% to 35.8% as the air velocity increased from 40 fpm to 70 fpm. For this same increase in velocity, the PuO₂ removed from the aerosol also increased from 20.5% to 51.1%. This was somewhat unexpected. The most logical explanation is that as the velocity increased, the air flow contours around the plates widened, forcing particles closer to adjacent plates where more were captured by the electric field. This effect was not observed in the CRT test that had the electric field across the full 12 in. wide test section and the amount of PuO₂ removed decreased with increasing air velocity.

Table 5. Percent mass removed with electret filter for various ventilation system air velocities compared with manufacturers data.

Air velocity (fpm)	Mass removed by filter (%)	Manufacturers data (note a) (%)
20	----	99.98
63	96.7 +/- 2.6	99.0
96	95.9 +/- 2.2	98.0
110	94.9 +/- 4.4	97.5

Note a. Data from 3-M Filtration Products brochure # 70-0700-9786-3

Table 6. Amount of mass and plutonium removed from the aerosol in the CRT test for two air velocities.

Air velocity fpm (cm/s)	Mass removed (%)	PuO ₂ removed (%)
83 (42)	39.4	41.5
95 (48)	15.8	27.4

Table 7. Mass and plutonium removed from the aerosol by the separator with 550 V on plates and various air velocities.

Air velocity		Mass removed	PuO ₂ removed
fpm	(cm/s)	(%)	(%)
40	(21)	73.0	20.5
61	(31)	49.8	43.8
70	(36)	35.8	51.1

The mass removed in the test with 300 V on the plates also showed a decrease as air velocity increased as shown in Table 8. The range was 47.2% for a velocity of 40 fpm to 29.% for a velocity of 70 fpm. The activity analyzed for one set of input and output filters was in the sub-pico curie range and considered too small for a reliable measurement.

Material Tests

The three materials tested were polyethylene, an anti-static construction material, and stainless steel. Two in. square coupons of each material were placed on strip curtains of the same material. The materials were held in place with a frame inside the inner enclosure. The coupons were located 7.5, 15, 22.5, and 30 in. above the floor. The amount of dust collected on the coupons varied significantly with height above the floor as can be seen in Table 9. The heavier particles did not rise as high as the lighter ones. However, the average amount of dust collected on this test followed the same trend as found in previous glove box tests with the polyethylene (insulating material) collecting the most (1.65 mg), and the conducting material (stainless steel) collecting the least (1.43 mg). The anti-static construction material was in the middle with an average of 1.56 mg. The anti-static material and stainless steel coupons were grounded and always had the same relationship in that the conducting material collected less than the anti-static material in all the tests.

Polyethylene collected significantly less mass when left in the enclosure for a longer period of time. Table 10 shows the results for materials left in the inner enclosure for two hours. Significantly more mass was collected on all the materials with the anti-static material collecting the most which was 78.86 mg. The reason for the smaller amount of dust collected on polyethylene in the longer tests is that the polyethylene was charged negatively by the constant air flow and thereby repulsed the negatively charged dust generated by the aerosolizer. This resulted in the polyethylene collecting less dust than either the anti-stat material or the stainless steel. The average mass collected on each of the three materials and the amount of PuO_2 on one selected sample of each is shown in Table 11. Since the negative charge buildup on the polyethylene did not attract more PuO_2 , that indicates the plutonium particles were attached to larger dust particles and repulsed along with the dust particles.

Similar results were obtained in the glove box experiment with these same type of materials when higher dust concentrations were obtained, as can be seen in Table 12.

Table 8. Mass removed from the aerosol by the separator with 300 V on plates and various air velocities.

Air velocity fpm (cm/s)	Mass removed (%)
40 (21)	47.2
61 (31)	37.2
70 (36)	29.5

Table 9. Mass data for 2 in. x 2 in. material coupons in 15 minute test.

Height above floor (inches)	Polyethylene (mg)	Anti-static (mg)	Stainless steel (mg)
7.5	5.85	4.10	3.31
15.0	2.55	1.64	1.84
22.5	0.50	0.45	0.48
30.0	0.58	0.03	0.10
Average	1.65	1.56	1.43

Table 10. Mass data for 2 in. x 2 in. material coupons in two hour test.

Height above floor (Inches)	Polyethylene (mg)	Anti-static (mg)	Stainless steel (mg)
7.5	16.94	78.86	37.95
15.0	12.41	34.60	19.75
22.5	4.45	57.56	6.16
30.0	2.62	5.73	2.07
Average	9.11	44.20	16.48

Table 11. Amount of mass and plutonium collected on 2 in. x 2 in. coupons during a two hour test.

	Average mass from four samples (mg)	PuO ₂ (nCi/g)
Polyethylene	9.11	1.20
Anti-static material	44.19	4.00
Stainless steel	16.48	2.50

Table 12. Amount of mass and plutonium collected on 2 in. x 2 in. coupons in glove box test.

	Average mass from four samples (mg)	PuO ₂ (pCi/g)
Polyethylene	2.40	298.3
Anti-static material	7.64	435.8
Stainless steel	6.55	175.2

CONCLUSIONS

The ^{239}Pu labeled soil with the polydispersed PuO_2 was non-homogeneous in that the radiochemical analysis of seven samples had a wide variation in activity ranging from 16.2 to 590 pCi/g. This made the data interpretation more difficult than for a homogeneous mixture. This non-homogeneity was also observed in previous tests using the plutonium contaminated Rocky Flats/INEL soil blend. Thus it is probably what might be expected in a waste recovery operation involving TRU waste. The PuO_2 particles appeared to be well dispersed and many of the smaller ones attached to larger soil particles, as can be seen in the SEM photographs. Thus the plutonium does not all stay in the aerosol as individual particles with a positive charge that can be used to electrostatically separate it from the other dust.

The percent of PuO_2 removed in the engineering scale tests was lower than for the previous glove box tests. This is primarily due to a different soil mixture and geometric effects between the engineering scale and the glove box scale. This indicates that, because of the longer distance and higher elevation of the separator in the engineering scale test set up, the heavier PuO_2 particles fell out before reaching the test section and many of the smaller particles attached to dust particles passed through the electrostatic field on neutralized dust particles. Only those particles that contained enough plutonium to be self-charging could be separated. The amount of plutonium that could be removed by the parallel plate separator used in these experiments ranged from 20.5% to 51.1%. Since the plutonium is so well attached to and compounded with the dust particles, removing 98% or more of the plutonium with electrostatic devices would require a higher voltage electrostatic precipitator that would ionize the dust and remove both dust and plutonium from the aerosol.

The inner and outer enclosures performed adequately for plutonium handling operations and could be used for full scale operations. The Perma-con enclosure with its clip-together construction method was easy to assemble and can be moved or extended with additional panels. The configuration can be changed when reassembling because the panels are interchangeable. The inner enclosure was a light weight, see-through PVC with an aluminum tubing frame that could also be moved easily. This kind of inner enclosure could be adapted to a larger configuration such as might be used in a waste recovery operation.

The material tests involving polyethylene, antistatic, and conductive materials agreed with the results from previous glove box tests. A conducting material that is grounded is the best choice to minimize electrostatic charge build up on the walls and collect minimum amounts of dust and plutonium. The conducting material will also minimize the spread of contamination because electrostatic build up is eliminated. A grounded, anti-static, construction fabric was second best in that it also eliminates charge build-up. However the longer discharge time for static charges allows more time for the particles to stick to the surface than for conducting materials. Insulating material sheets like polyethylene will collect various amounts of static charge that can have either a positive or negative sign. Thus the test results on polyethylene were unpredictable.

The electret filter tests also confirmed previous glove box test results. They filter out respirable size dust particles very well and have a lower air resistance than pure mechanical filters. The mass removal efficiency was within the manufacturers specification of 97.5% to 99% for the air velocities used in the tests.

The electrostatic field from the CRT was too low to make it a good electrostatic source for this application. The effects observed would be the same as that for parallel plates having a lower voltage.

Recommendations

The properties of ESCs for transuranics are understood enough to proceed to practical applications in first the cold large-scale demonstration followed by full-scale operations. Recommendations for future work include the following:

- The inner and outer enclosures performed adequately in the engineering scale tests and would be ready to demonstrate in the cold test pit followed by full scale operations. A grounded metal (preferably stainless steel) outer enclosure would act as a weather shield. This would be a temporary structure that could be easily moved. The inner enclosure would be a light weight tube and fabric or clear conductive plastic that could cover the immediate dig area and allow easy movement with digging equipment.
- In order to remove 98% of the activity from plutonium contaminated dust in the ventilation system, one of the following three options exists: (a) use an electret filter, (b) use a higher voltage electrostatic precipitator, or (c) use a virtual impactor. Each of these options would remove greater than 98% of the particles from the air stream. The virtual impactor, a new device recently developed by U of M researchers, can be tuned to selectively remove particles above any given size. The virtual impactor would require a scaled test with the existing ventilation system prior to large scale cold test pit demonstration.

REFERENCES

1. Meyer L. C., Transuranic Contamination Control Using Electrostatic Curtains (Proof-Of-Principal Experiments), EGG-WTD-9336, November 1990.
2. L. C. Meyer, Electrostatic Curtain Studies, EGG-WTD-10255, May 1992.
3. L. C. Meyer, Preconceptual design for the Electrostatic Enclosure. EGG-WTD-10450, September 1992.
4. L. C. Meyer, Test plan for Engineering Scale Electrostatic Enclosure Demonstration, EGG-WTD-10635, February 1993.

APPENDIX A

**ELECTROSTATIC CURTAIN DEMONSTRATION TEST
EQUIPMENT LIST**

APPENDIX A

ELECTROSTATIC CURTAIN DEMONSTRATION TEST EQUIPMENT LIST

The following equipment was used in the electrostatic curtain demonstration tests. The manufacturer, model number, and instrument ranges are also given where applicable.

1. Ventilation System and HEPA Filter

Flanders Nuclear Grade HEPA filter,
model no. T-007-F02-05-NU-51-43-GG-FUS
Pre-filter is a ECO-Air Products model no. E35-5
Fan model no. HDBI-200, serial no. 8905711
480 volt 3 phase motor
Reliant controls m/n 1AC4005U

2. PERMA-CON Enclosure,

mfg: Radiation Protection Systems
Material: Stainless steel
Size: 8 ft wide, 12 ft long, and 8 ft high

3. Inner Enclosure Tent

mfg.: Nuclear Power Operators
Material: PVC
Size: 4 ft wide, 6 ft long, and 6.5 ft high

4. Test Section and Ventilation System Interface

mfg: INEL machine shop
Material: 1/2 in. Plexiglass
Size: 1 ft x 1 ft x 2 ft (test section)
1 ft x 1 ft x 1.5 ft (interface with mounting flanges)

5. Separator Test Fixture

mfg: INEL machine shop
Material: Case is 1/2 in. Plexiglass and plates are 1/8 in stainless steel plates 6 in. x 12 in.
Size: 1 ft x 1 ft x 1 ft

6. Electret Filter Fixture

mfg: INEL machine shop
Material: 1/2 in. Plexiglass with Plexiglass frame for holding filter
Size: 1 ft x 1 ft x 1 ft

7. CRT Test Fixture

mfg: INEL machine shop
Material: 1/2 in. Plexiglass with plastic film screen shield
Size: 1 ft x 1 ft x 1 ft

8. Dust Generator

mfg: INEL machine shop
Material: 1/2 in. Plexiglass V-shaped trough with 3/8 in. hose
Size: 1 ft x 8 in. x 8 in.

9. Power Supply

mfg: John Fluke
Model: 407D
Range: 0-555 volts

10. Low Volume Cascade Impactor:

mfg: Anderson
Stages: Eight
Filters: Glass fiber

11. 47 mm air samplers

mfg: unk
Filters: Glass fiber

12. Mass Measurement Balance

mfg: Satorious
Model no: R180D
Accuracy: 5 places

13. Glove Box

mfg: INEL machine shop
Material: 1/2 in. Plexiglass
Size: 2 ft. wide x 30 in. high x 5 ft. long

14. Vacuum System

mfg:	unk
Vacuum pump Model no.	0522-v103-018DX
Line one vacuum gauge	p/n 708174
Line one flow meter	p/n 708179
Line 2 vacuum gauge	p/n 708175
Line 2 flow meter	p/n 708180

15. Anemometer

mfg: Solomat
Model no: MPM500
Range: 2 fpm to 3000 fpm (0.01 to 15 m/s)

16. Electrostatic Locator

mfg: acl incorporated
Model no: ACL 300B
Range: 0-30,000V

APPENDIX B

ANTISTATIC FABRIC MATERIAL SPECIFICATIONS

APPENDIX B

ANTISTATIC FABRIC MATERIAL SPECIFICATIONS

The following information on the electrical specifications for the antistatic construction grade material was received from the vendor.

- ASTM 0257 Surface Resistivity Face & Back 10^8 - 10^9 ohm/sq
- ASTM 0257 Volume Resistivity 10^9 ohm/sq
- ASTM F150 Resistivity 500V 10^7 ohm Face & Back
 100V 10^7 ohm Face & Back
- EOS/ESD S-4 point—Face & Back 10^7 ohm at 10V & 12.5% RH
- Static Decay Federal Test 4046.1 @ 12.5 % RH, 500V to 0V in 0.01 seconds.

The cost is about 10% to 15% higher than their regular material. The fabric is blue in color with one smooth side and one side with a slightly wavy pattern.

APPENDIX C

SAMPLE GRAVIMETRIC DATA AND ACTIVITY LEVELS

APPENDIX C

SAMPLE GRAVIMETRIC DATA AND ACTIVITY LEVELS

The sample gravimetric data and activity levels for the ESC demonstration tests are given in Table C-1.

Table C-1. Sample data and activity levels.

<u>Sample ID</u>	<u>Mass (g)</u>	<u>Total Activity (pCi)</u>	<u>Activity (pCi/g)</u>
Soil com	0.005	-----	70.00
Soil #1	0.005	-----	71.00
Soil #2	0.005	-----	32.20
Soil #1A	0.005	-----	590.00
Soil #1A-1	0.005	-----	16.20
Soil #2B	0.005	-----	30.60
Soil #2B-1	0.005	-----	500.00
B1CI Prefilter	0.16571	82.00	494.84
(B1CI-0)	0.04221	25.40	601.75
(B1CI-1)	0.05129	ND	ND
(B1CI-2)	0.02349	ND	ND
(B1CI-3)	0.03115	18.30	587.48
(B1CI-4)	0.02169	ND	ND
(B1CI-5)	0.00891	21.70	2435.47
(B1CI-6)	0.00257	ND	ND
(B1CI-7)	0.00025	ND	ND
(B1CI-F)	0.00005	ND	ND
B1P1	0.00781	ND	ND
B1P2	0.02091	10.60	506.93
B1P3	0.02092	10.30	492.35
B1P4	0.01966	ND	ND
B1P5	0.00929	ND	ND
B1 IN	0.04076	29.80	731.11
B1 OUT	0.01143	6.90	603.67
B2CI Prefilter	0.10420	20.00	191.94
(B2CI-0)	0.00697	7.40	1061.69
(B1CI-1)	0.12530	ND	ND
(B2CI-2)	0.00495	ND	ND
(B2CI-3)	0.00810	5.70	703.70
(B2CI-4)	0.00564	ND	ND
(B2CI-5)	0.00244	2.06	844.26
(B2CI-6)	0.00016	ND	ND
(B2CI-7)	0.00008	ND	ND
(B2CI-F)	0.00000	ND	ND

Table C-1. (continued).

<u>Sample ID</u>	<u>Mass (g)</u>	<u>Total Activity (pCi)</u>	<u>Activity (pCi/g)</u>
B2P1	0.00190	ND	ND
B2P2	0.00176	ND	ND
B2P3	0.00422	ND	ND
B2P4	0.00171	0.51	298.25
B2C1	0.00452	1.97	435.84
B2C2	0.00642	ND	ND
B2C3	0.01552	ND	ND
B2C4	0.00408	ND	ND
B2S1	0.00491	0.86	175.15
B2S2	0.00642	ND	ND
B2S3	0.00759	ND	ND
B2S4	0.00728	ND	ND
D2P1	0.00058	ND	ND
D2P2	0.00050	ND	ND
D2P3	0.00255	ND	ND
D2P4	0.00585	ND	ND
D2C1	0.00003	ND	ND
D2C2	0.00045	ND	ND
D2C3	0.00164	ND	ND
D2C4	0.00410	ND	ND
D2S1	0.00010	ND	ND
D2S2	0.00048	ND	ND
D2S3	0.00184	ND	ND
D2S4	0.00331	ND	ND
D1 IN	0.00276	0.73	264.49
D1 OUT	0.00009	BD	BD
D2 IN	0.00316	1.82	575.95
D2 OUT	0.00013	BD	BD
D3 IN	0.00158	ND	ND
D3 OUT	0.00008	ND	ND
D4 IN	0.00359	ND	ND
D4 OUT	0.00008	ND	ND
D5 IN	0.00678	1.06	156.34
D5 OUT	0.00267	0.62	232.21
D5P1	0.00262	ND	ND
D5P2	0.00445	ND	ND
D5P3	0.01241	14.50	1168.41
D5P4	0.01694	ND	ND
D5C1	0.00573	ND	ND
D5C2	0.05756	ND	ND
D5C3	0.03460	138.00	3988.44

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