Potential Airborne Release from Soil-Working Operations in a Contaminated Area

S. L. Sutter

August 1980

**Prepared for Rockwell Hanford Operations
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SUMMARY AND CONCLUSIONS

Experiments were performed to provide an indication of how much material could be made airborne during soil-working operations in a contaminated area.

Approximately 50 kg of contaminated soil were collected, dried, and mixed, and particle size distribution and ^{137}Cs content were characterized. In four experiments performed in a 2 ft x 2 ft wind tunnel at the Radioactive Aerosol Release Test Facility, soil was pumped into an airstream moving at 3.2, 10.4, 15.2, and 20 mph. These experiments were designed to maximize airborne releases by fluidizing the soil as it was pumped into the wind tunnel. Thus the airborne releases should represent upper limit values for soil-working operations.

Airborne concentration and particle size samples were collected and all of the material deposited downstream was collected to calculate a mass balance. The fraction airborne was calculated using these measurements.

The fraction of soil made airborne from a source increased as a linear function of wind speed. This relationship can be expressed in the form of the equation

$$y = 0.00599 x + 0.00543$$

where

y = fraction of source airborne

x = wind speed, mph

Cesium-137 activity airborne increased with wind speeds at a rate about 4 times that of the soil mass.

Source terms (i.e., fraction of material initially made airborne) can be estimated using the information developed. These can, in turn, be used in diffusion models to estimate downwind contamination levels. A simple release scenario has been included in this report for illustration.

More and smaller particles tended to become airborne at higher wind speeds. At 20 mph, 90% of the particles were 10 μm and less with a median diameter of 5.3 μm ; at 3.2 mph, 44% were less than 10 μm and the median diameter was greater than 10 μm .

Values for these experiments show agreement with field soil-working particulate loadings measurements at Savannah River. We feel, therefore, that our results can be used with some assurance that they estimate actual releases.

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INTRODUCTION

Any proposed disinterment of buried radioactive wastes could expose contaminated soil to the atmosphere. This exposure could occur when the soil is being excavated, moved, or dumped, or during any routine handling and manipulation of the soil. Release of contaminated soil to the atmosphere could also result from unexpected events during the routine soil manipulation.

If a disinterment is considered, the impact of airborne releases must be evaluated so that a safety assessment can be made and containment provided if necessary. The impact will depend on the amount of soil released and the size of the particles released. Particles in respirable sizes ($<10\text{ }\mu\text{m}$) are a particular concern. Evaluation of the impact of soil dispersal requires knowledge of soil characteristics and contamination levels, aerodynamic properties, and particle size as well as the operational procedures.

Radioactive particles actually or potentially released from contaminated surfaces in the environment and the mechanisms by which particles become airborne have been studied at the Pacific Northwest Laboratory (PNL). The objective for this study was to investigate the potential for airborne release of radioactive material that could be initially made airborne while working the soil in a contaminated zone.

Other information that relates to our objective is enhancement of radioactivity in airborne fractions. Other studies (Sehmel 1978) have showed a wide variability in the ratio of $\mu\text{Ci/g}$ airborne to $\mu\text{Ci/g}$ of soil, perhaps caused by discrepancies in surface soil characterization. Our well-mixed soil minimizes the soil characterization variability, and contributes to information on the relationship between the airborne and source radionuclide distribution.

As described in the next section, four experiments were performed in which contaminated soil was injected into a moving airstream in a wind tunnel. Airborne releases from this contaminated soil were measured as a function of wind speeds of 3.2, 10.4, 15.2, and 20 mph. The mass and ^{137}Cs activity of the samples collected in these experiments are tabulated in Appendix A. A comparison of our experimental results with those obtained in field tests at Savannah River is included in the Results section.

OBJECTIVE

The objective of this study is to measure airborne releases of contaminated soil under conditions that can be related to soil handling and manipulation operations.

EXPERIMENTAL METHOD

Contaminated soil was collected, characterized, and involved in four experiments where this soil was dropped into air moving at 3.2, 10.4, 15.2, and 20 mph through a 2 ft square shaped wind tunnel. Upper limit values for airborne soil should result from these procedures.

SOIL SAMPLING

Soil contaminated with traces of ^{137}Cs was collected on the Hanford reservation to use in these experiments. Some effort was made to locate soil that could be followed easily in the experiments. The soil was below control area radioactive limits, but still adequate to measure. Sampling depth was variable, with the maximum about 4 in.

Approximately 50 kg of the contaminated soil were dug up, dried with heat lamps, then tumbled to ensure uniform mixing of the soil.

SOIL CHARACTERIZATION

A portion of the homogenized soil, 2.3 kg, was sieved through standard sieves. An aliquot was classified using sonic sifting. The size distribution was calculated and is listed in Table 1 and plotted in Figure 1. The mass median diameter (MMD) is approximately 175 μm , which, using a soil density of 2, calculates to an aerodynamic equivalent diameter (AED) of 248 μm . Particles less than 10 μm (14 μm AED) comprise about 0.088% of the soil mass.

TABLE 1. Percent of Characterized Soil Less than Indicated Size

<u>Indicated Size,</u> <u>μm</u>	<u>Percent of Soil Less</u> <u>than Indicated Size</u>
1651	99.3
841	95.9
420	71.4
210	51.9
149	42.4
74	18.9
44	4.4
37	2.5
20	0.77
10	0.088
5	0.003

FIGURE 1. Size Distribution of Soil Used in Experiments

This soil is somewhat finer than other Hanford soils characterized in earlier work (Mishima 1974). The mass median diameter of the soil Mishima studied was 320 μm , with an AED of 453 μm , and approximately 0.033% of the mass was composed of particles less than 10 μm .

The ^{137}Cs activity of each size fraction was determined; this information and the mass fraction are included in Table 2.

TABLE 2. Characterization of Soil Used in Aerodynamic Entrainment Experiments

<u>Sieve Size, mm</u>	<u>Percent of Sample in Size</u>	<u>¹³⁷ Cs content, (a) μCi/g</u>
1.651	0.7	1.09×10^{-2}
0.841	3.3	5.91×10^{-3}
0.420	24.5	3.14×10^{-3}
0.210	19.6	4.45×10^{-2}
0.149	9.4	7.27×10^{-3}
0.074	23.5	7.27×10^{-3}
0.044	14.5	9.09×10^{-3}
0.037	1.9	1.50×10^{-2}
0.020	1.8	6.82×10^{-3}
0.010	0.7	1.73×10^{-2}
0.005	0.088	2.64×10^{-2}
<0.005	0.003	1.20×10^{-2}

(a) The average ¹³⁷Cs content is 6.36×10^{-3} .

APPARATUS AND PROCEDURES

Soil Delivery

A weighed portion of the characterized soil was placed in a powder pump and delivered into a 2 ft x 2 ft wind tunnel at a uniform rate. Figure 2 shows the pump in position and the wind tunnel ready for an experiment. Wind velocity and soil delivery instrumentation are indicated in the photograph. The soil delivery rate was constant during an experiment at about 50 to 100 g/min. Fluidized soil was dropped into the wind tunnel at right angles to air flow at speeds of 3.2, 10.4, 15.2, and 20 mph.

Sampling

Samples were collected at all portions of the wind tunnel as shown in Figure 3. Mechanisms for sampling included:

1. Plastic covering the flange immediately below the soil entry point.
2. Aluminum foil on the floor and wall of the wind tunnel.
3. A tray at the end of the wind tunnel in the release vessel.

FIGURE 2. Powder Pump on Wind Tunnel Ready for an Experiment

®Trademark of Moyno Pump Division, Robbins and Meyers, Inc.,
Springfield, Ohio

FIGURE 3. Wind Tunnel Sampling

4. Hi volume and impactor samplers[®] at the end of the wind tunnel and at the ceiling exhaust, as shown in Figure 4.

5. Aluminum foil on the vessel wall.

All of the soil not collected by a specific sampler was swept up and weighed to determine the material balance.

Airborne Particle Sampling

Hi volume samplers collected airborne particles on 8 x 10 in. filters. The total mass on the filters was then used to calculate the total airborne in the airstream.

Hi volume cascade impactors sized the particles in respirable size range aerodynamically.

Size ranges for the impactor collection plates are:

- 7 μm and over
- 3.3 to 7 μm

[®]Trademark of Andersen Samplers, Inc., Atlanta, Georgia.

FIGURE 4. Hi Volume and Impactor Samplers in Position

- 2.0 to 3.3 μm
- 1.1 to 2.0 μm
- 0.01 to 1.1 μm

A schematic of the impactor and collection system is shown in Figure 5.

Specially cut and perforated glass fiber filters, tared before use and weighed after sample collection, gave the mass of particles in each size range. This collection method enabled evaluation of the potential respiratory hazard of the airborne particles, since the particles 10 μm in diameter and less are considered respirable.

^{137}Cs Analysis

The ^{137}Cs in all materials was determined by gamma counting using a NaI(Tl) scintillation detector and a multichannel analyzer, or a lithium drifted silicon diode and multichannel analyzer for higher counting samples. The counting efficiencies of various counting configurations and materials were determined by spiking uncontaminated material with standardized ^{137}Cs at various levels. The efficiency of the NaI detector system ranged from 0.33

FIGURE 5. Schematic of Hi Volume Cascade Impactor

to 0.40 cpm/dpm. The counting efficiency of the diode arrangement calibrated in the same fashion was 0.006 cpm/dpm. Backgrounds were automatically subtracted using tapes prepared daily. Counting times ranged from 10 to 20 minutes.

SOURCE SOIL INTEGRITY

There was concern that one particle size might be delivered preferentially from the pump, and that the same soil particle size distribution was maintained at all times during a run. These possibilities were investigated.

To check preferential particle delivery, the size distribution of the pump hopper soil undelivered after a run was sized using standard sieves. This particle size distribution was similar to the source soil, and indicated no preferential particle size delivery.

A second verification was performed by placing 3 kg of soil into the pump and delivering the soil to a covered container. Five 10-min. samples were taken while the pump ran for 50 minutes. The particle size distribution of these samples was comparable to that of the source soil.

These tests verified that soil with the same particle size distribution was pumped into the wind tunnel at all times during the run.

RESULTS AND DISCUSSION

AIRBORNE RELEASE AS A FUNCTION OF WIND SPEED

The mass and ^{137}Cs activity of all the samples collected in the soil aerosolization experiments are described here. A table specifying these values is included in Appendix A.

Mass Airborne

Since the Hi volume filters and impactors collect a sample from a portion of the airstream, the total airborne soil was calculated from the mass on these filters. The percent airborne, based on the fraction recovered, was 20 mph, 12.2%; 15.2 mph, 10.6%; 10.4 mph, 6.6% and 3.2 mph, 2.4%. These values are plotted as a function of windspeed in Figure 6. The fraction airborne increased with increasing windspeed in a linear relationship. An equation to represent the mass fraction airborne during soil manipulation, as a function of wind speed is:

$$y = 0.00599x + 0.00543$$

FIGURE 6. Percent of Soil Airborne as a Function of Wind Speed

where

y = fraction of source airborne

x = wind speed, mph.

The correlation of 0.992 indicated a good fit of the equation to the data.

RADIOACTIVITY AIRBORNE

^{137}Cs radioactivity airborne increased as a function of wind speed at a rate about 4 times that of the soil mass, as shown in Table 3.

TABLE 3. ^{137}Cs Radioactivity Airborne
as a Function of Wind Speed

<u>Wind Speed, mph</u>	<u>Percent Mass Airborne</u>	<u>Percent ^{137}Cs Airborne</u>	<u>Ratio $^{137}\text{Cs}/\text{Mass}$</u>
3.2	2.4	8.5	3.5
10.4	6.6	48	7.3
15.2	10.6	30	2.8
20.0	12.2	36	3.0
Avg. =			4.15

The value at 10.4 mph is an anomalously high value: the ^{137}Cs levels collected for this estimation were about 1.7 times greater than other filter levels. This could be attributed to isolated particles of unusually higher activity collected on this filter. The specific activity of ^{137}Cs is 87 Ci/g (Bureau of Radiological Health 1970), so one Ci represents 1×10^{-8} g ^{137}Cs . Thus a small increase in ^{137}Cs mass could mean a larger increase in radioactivity.

IMPLICATIONS OF EXPERIMENTAL DESIGN

These experiments were designed to maximize airborne radioactive releases through two strategies: 1) As it was pumped into the wind tunnel, the soil was fluidized with the addition of air. This resulted in a powder dispersal giving maximum opportunity for air to entrain the soil particles downstream, since the soil was airborne on entry to the wind tunnel. 2) The soil was collected from

isolated higher activity spots on the terrain, giving the highest specific activity ($6.36 \times 10^{-3} \mu\text{Ci/g}$) for the contaminated soil. The experiments represent aerodynamic entrainment of material forcibly dispersed into an air flow, in contrast to resuspension of surface soil.

As part of an aerial survey of the BC control area, Bruns (1974) performed chemical analyses of composite samples taken from the top 5 cm of soil. The average activity of these samples showed $11.5 \mu\text{Ci/m}^2$ of surface. The average $\mu\text{Ci/cm}^3$ can be calculated using this value for a plot 1 m square and 5 cm in depth, assuming all the activity is confined to the top, resulting in a specific concentration value of $2.3 \times 10^{-4} \mu\text{Ci/cm}^3$. This probably gives a high average soil radioactive content. A more representative estimate of soil ^{137}Cs concentration for the Hanford site could be similar to that at the 200 East Hill surveillance sampling site. This value was $2.0 \times 10^{-5} \mu\text{Ci/g}$ during CY 1978, and the average for other onsite sampling locations was $2.7 \times 10^{-6} \mu\text{Ci/g}$ (Houston and Blumer 1979).

The work of Bruns (1974) and Houston and Blumer (1979) will be cited in the impact analysis of this work. They are considered more representative of actual conditions in the area than our samples selected for high ^{137}Cs levels.

USE OF SOURCE TERM CHARACTERIZATION IN DIFFUSION MODELS

When the results of these experiments are used to estimate a source term for an environmental assessment, a degree of engineering judgement is required. Since our releases were maximized, an estimate of releases from lesser stresses for a specific operation must be made. The soil contamination actually involved in the operation should also be estimated. A simple example will illustrate the use of the information we have developed.

The scenario used in our wind tunnel experiments simulated dropping soil through air. This could be a truck containing 2 cubic yards (1.52 m^3) of soil dumping that load. At a soil density of 2 g/cc, the soil weighs 3040 kg, and is assumed to have the average ^{137}Cs activity of $2.7 \times 10^{-6} \mu\text{Ci/g}$. The soil is dumped as a unit, so only a portion on the outside is subjected to air interface. This could be 10% of the soil mass, which calculates to 304 kg that is available for entrainment.

At 5 mph, the value of the percent resuspended, from Figure 6, is 3.5 , so about 10.64 kg of the soil containing $2.87 \times 10^{-2} \mu\text{Ci } ^{137}\text{Cs}$ are entrained in the air.

This source term can then be used in one of the numerous diffusion equations available to estimate the downwind concentration from a source. An equation selected from the Workbook of Atmospheric Dispersion Estimates (Turner 1970), for a plume source, will be used to present an example of how the work could be used. This equation that may be used for estimates of concentration downwind from a release from height, H is:

$$X(x,y,0;H) = \frac{2 Q_T}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z} \exp \left[- 1/2 \left(\frac{x-ut}{\sigma_x} \right)^2 \right] \exp \left[- 1/2 \left(\frac{H}{\sigma_z} \right)^2 \right] \exp \left[- 1/2 \left(\frac{y}{\sigma_y} \right)^2 \right]$$

where

X = downwind concentration	u = wind speed
Q_T = total emission	y = crosswind distance
H = release height	t = time after release
x = distance from source	0 = wind direction
σ_x = standard deviation in downwind direction of a puff concentration distribution	
σ_y = standard deviation in crosswind direction of the plume concentration distribution	
σ_z = standard deviation in vertical of the plume concentration distribution	

The numerical value of $(2\pi)^{3/2}$ is 15.75. The factor $\exp - a/b = e^{-a/b}$ where e is the base of natural logarithms and is approximately equal to 2.7183. Any set of consistent units may be used. For this instantaneous source, σ_x will be about the same as σ_y . Values for σ_y and σ_z are given in Table 4.

TABLE 4. Estimation of Dispersion Parameters for Quasi-Instantaneous Sources

	<u>x = 100 m</u>		<u>x = 4 km</u>	
	σ_y	σ_z	σ_y	σ_z
Unstable	10	15	300	220
Neutral	4	3.8	120	50
Very Stable	1.3	0.75	35	7

For purposes of this example, a 2-m release height, neutral conditions, 60 seconds after the release, and a 100 m distance from the source were used to calculate the downstream airborne concentration of ^{137}Cs . The calculated results are a total mass concentration of $2 \times 10^{-13} \text{ g/m}^3$, or $2 \times 10^{-19} \text{ g/cm}^3$. Using the value of $3 \times 10^{-6} \text{ } \mu\text{Ci/g}$, the downstream ^{137}Cs concentration is $5 \times 10^{-25} \text{ } \mu\text{Ci/cm}^3$.

This value would be undetectable in a routine surveillance ^{137}Cs sample concentration, which ranges between 10^{-14} and $10^{-15} \text{ } \mu\text{Ci/cm}^3$ (Houston and Blumer 1979). Even the "hot" spot soil we collected ($6.36 \times 10^{-3} \text{ } \mu\text{Ci/g}$) calculates to a downwind ^{137}Cs concentration of $1.37 \times 10^{-21} \text{ } \mu\text{Ci/cm}^3$ well below values suggested for MPC uncontrolled area levels of $5 \times 10^{-10} \text{ } \mu\text{Ci/cm}^3$ ^{137}Cs (10 C.F.R. 20).

This calculation was included for an example only, to show the use of the data we generated. Other diffusion equations and models are available to estimate airborne concentrations from area source, line sources, multiple sources, and other specific situations. An evaluation of an operation is made and the appropriate model or equation is selected for use.

Since this report is a source term characterization document, other equations and models will not be discussed.

AIRBORNE MASS AND RADIONUCLIDE CONCENTRATION

Concentration limits of radionuclides in air are established by the Nuclear Regulatory Commission (10 C.F.R. 20). Levels in air established for insoluble

^{137}Cs are: occupational, $1 \times 10^{-8} \mu\text{Ci}/\text{cm}^3$; uncontrolled area, $5 \times 10^{-10} \mu\text{Ci}/\text{cm}^3$. The airborne ^{137}Cs concentrations reached in our experiments will be compared to these values.

Airborne soil concentrations of 0.046, 0.108, 0.103, and 0.128 g/m^3 in air were reached for wind speeds of 20, 15.2, 10.4, and 3.2 mph respectively, at a distance about 20 ft from the source. Potential airborne ^{137}Cs concentration for 0.128 g/m^3 soil was calculated using each of the three levels of specific activity discussed earlier: $6.36 \times 10^{-3} \mu\text{Ci}/\text{g}$, $2.3 \times 10^{-4} \mu\text{Ci}/\text{g}$, and $2.0 \times 10^{-5} \mu\text{Ci}/\text{g}$. Values were calculated with and without enhanced airborne specific activity since radioactivity increased at a rate of about 4 times the mass. These values are shown in Table 5.

TABLE 5. Calculated Airborne ^{137}Cs Radioactivity Associated with 0.128 g/m^3 Resuspended Soil

Source Activity, $\mu\text{Ci}/\text{g}$	Airborne Concentration, $\mu\text{Ci}/\text{cm}^3$	Airborne Concentration Enhanced by a Factor of 4, $\mu\text{Ci}/\text{cm}^3$
6.36×10^{-3}	8.1×10^{-10}	3.2×10^{-9}
2.3×10^{-4}	2.9×10^{-11}	1.2×10^{-10}
2.0×10^{-5}	2.6×10^{-12}	1.0×10^{-11}

Even for the enhanced value, the airborne concentrations are lower than the current occupational standards. These measurements would correspond to those at the near source (20 ft from release), and it could be assumed concentrations would be lowered rapidly by diffusion as a plume moves downstream. The magnitude of these levels should not be of concern.

AIRBORNE PARTICLE SIZE DISTRIBUTION

Particles 10 μm and less in diameter can be inhaled and retained in the lung, and therefore are considered a health hazard. Some reduction in the impact of releases would result if the particle size is considered. We have not chosen to do this, since standards are set regardless of particle size.

Cascade impactor collection was used to estimate whether the fraction 10 μ m and less, and specifically the sample at the vessel exhaust, which could be representative of airborne particles that could be carried downstream. The aerodynamic mass median diameter and the percentage of particles 10 μ m and less in the collected fraction are listed in Table 6.

TABLE 6. Airborne Soil Particle Size Distribution

<u>Wind Speed,</u> <u>mph</u>	<u>Aerodynamic Mass Median</u> <u>Diameter, μm</u>	<u>%10 μm</u> <u>and less</u>
3.2	>10	44
10.4	6.7	63
15.2	9.8	50
20.0	5.3	90

More smaller particles at higher wind speeds could result from greater breakup of aggregates by aerodynamic stresses.

¹³⁷Cs was enhanced on the airborne particles collected in the impactors with an overall average of 2.3×10^{-2} μ Ci/g, compared with 6.3×10^{-3} μ Ci/g for the source.

COMPARISON WITH FIELD SOIL WORKING AT SAVANNAH RIVER

Particulate field loadings (sic) during agricultural operations on an old field at the Savannah River Plant (Milham et al. 1975) give an opportunity to evaluate our release concentrations.

Our concentrations average 96 mg/m³ and ranged from 46 mg/m³ to 128 mg/m³ based on samples taken about 20 ft from the release. At Savannah River, the sample dust concentrations taken 25 ft downwind from the operation were 67 mg/m³. The distance from both sources can be considered about the same, so these values show good agreement. Particulate loadings at the tractor were 16 mg/m³, and 0.3 mg/m³ at 30.5 m (100 ft) downwind. The sampling height at the tractor was unspecified, but could be assumed to be slightly ahead and above the operation. The effect of diffusion is evident in the low downwind levels.

Savannah River calculated these particulate loadings using the Pu loading. So it would be anticipated the relationship between airborne and soil contamination levels would be similar to ours. This is evident in soil and airborne radioactivity levels shown in Table 7.

TABLE 7. Soil and Airborne Radioactivity
From Two Sampling Situations

<u>Site</u>	<u>$\mu\text{Ci/g}$ Soil</u>	<u>$\mu\text{Ci/cm}^3$ Airborne</u>
Savannah River	3.1×10^{-6}	2.1×10^{-13} , 25 ft from source
PNL Experiments	6.3×10^{-3}	8.1×10^{-10} , 20 ft from source

Savannah River levels are about 3 orders of magnitude less for both soil and airborne collection. That is, the ratio of the contamination levels, PNL/SR, are in the order of 10^3 .

These comparisons imply that our experimental results are valid to use for estimating operational releases.

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APPENDIX A

MASS AND ^{137}Cs ACTIVITY OF SAMPLES COLLECTED
IN SOIL AERODYNAMIC ENTRAINMENT EXPERIMENTS

TABLE A-1. Mass and ^{137}Cs Activity of Samples Collected in
Soil Aerodynamic Entrainment Experiments

Sample	Experiment 1 20 mph for 30 min			Experiment 2 15.2 mph for 17 min		
	Weight (g)	$\mu\text{Ci/g}$	Total μCi	Weight (g)	$\mu\text{Ci/g}$	Total μCi
Source	1422.6	6.4×10^{-3}	9.1×10^0	1773.9	6.4×10^{-3}	1.1×10^1
Soil Under Entry	5.4388	3.1×10^{-4}	1.7×10^{-3}	95.9183	2.3×10^{-3}	2.3×10^{-1}
Wind Tunnel						
4				None		
3	14.0	2.7×10^{-3}	3.8×10^{-2}	None		
2	55.1	5.0×10^{-4}	2.8×10^{-2}	3.6615	4.0×10^{-3}	1.5×10^{-2}
1	114.2	2.4×10^{-3}	2.8×10^{-1}	42.8399	3.5×10^{-3}	1.5×10^{-1}
Floor Foil			5.0×10^{-3}			5.5×10^{-3}
Wall Foil			6.4×10^{-3}			1.0×10^{-2}
Sweepings	181.3	6.4×10^{-3}	1.0×10^0	239.2	4.3×10^{-3}	1.0×10^0
Tray in Vessel	675.9	3.8×10^{-3}	2.6×10^0	857.3	3.4×10^{-3}	2.9×10^0
Vessel Floor Foil	344.0	7.7×10^{-3}	2.7×10^0	406.6	8.2×10^{-3}	3.3×10^0
Vessel Wall Foil			8.2×10^{-5}			8.2×10^{-5}
High Volume Samplers						
Wind Tunnel	1.991	1.7×10^{-2}	3.5×10^{-2}	2.0696	1.1×10^{-2}	2.4×10^{-2}
Vessel Ceiling	2.0207	2.0×10^{-2}	4.0×10^{-2}	2.5921	1.9×10^{-2}	5.0×10^{-2}
Impactor Samples						
Wind Tunnel	2.7295	1.0×10^{-2}	2.8×10^{-2}	3.4233	1.0×10^{-2}	3.5×10^{-2}
Vessel Ceiling	0.6269	1.0×10^{-2}	6.4×10^{-3}	0.2686	2.9×10^{-2}	7.7×10^{-3}
Total	1397.3(1)		6.8×10^0	1653.9		7.7×10^0

(1) Material balance shows losses to HEPA filters, some RART surfaces, and physical loss during collection. Activity losses include these and changes due to variation in activity levels and physical forms of samples.

TABLE A-1. (contd)

Experiment #3 3.2 mph for 17 min				Experiment #4 10.4 mph for 17 min		
Sample	Weight (g)	$\mu\text{Ci/g}$	Total μCi	Weight (g)	$\mu\text{Ci/g}$	Total μCi
Source	1772.5	6.4×10^{-3}	1.1×10^1	1808	6.4×10^{-3}	1.1×10^1
Soil Under Entry	728.5	3.8×10^{-3}	2.8×10^0	230.9	3.6×10^{-3}	8.2×10^{-1}
Wind Tunnel						
4	712.7	6.4×10^{-3}	4.5×10^0	125.6	4.3×10^{-3}	5.5×10^{-1}
3	43.3363	1.1×10^{-2}	5.0×10^{-1}	213.4	4.4×10^{-3}	9.5×10^{-1}
2	13.8919	1.5×10^{-2}	2.1×10^{-1}	160.5	5.0×10^{-3}	8.2×10^{-1}
1	7.3994	1.5×10^{-2}	1.1×10^{-2}	238.8	5.9×10^{-3}	1.4×10^0
Floor Foil			4.5×10^{-3}			4.5×10^{-3}
Wall Foil			5.9×10^{-4}			5.9×10^{-4}
Sweepings	143.1	7.7×10^{-3}	1.1×10^0	447.8	4.2×10^{-3}	1.9×10^0
Tray in Vessel	2.1658	1.7×10^{-2}	3.6×10^{-2}	53.4	7.7×10^{-3}	4.1×10^{-1}
Vessel Floor Foil	12.8927	1.9×10^{-2}	6.4×10^{-3}	87.0	1.2×10^{-2}	1.0×10^0
Vessel Wall Foil			1.1×10^{-3}			5.5×10^{-4}
High Volume Samplers						
Wind Tunnel	4.6537	3.1×10^{-2}	1.5×10^{-1}	6.7953	2.0×10^{-2}	1.4×10^{-1}
Vessel Ceiling	3.0908	1.9×10^{-2}	5.9×10^{-2}	2.4775	3.3×10^{-2}	8.2×10^{-2}
Impactor Samples						
Wind Tunnel	1.8444	3.5×10^{-2}	6.5×10^{-2}	2.1123	1.9×10^{-2}	4.0×10^{-2}
Vessel Ceiling	1.0894	3.5×10^{-2}	3.8×10^{-2}	0.4673	3.7×10^{-2}	1.7×10^{-2}
Total	1674.6		9.5×10^0	1569.3		8.2×10^0

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