Air Quality Impacts Analysis for Area G

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Final Report

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Air Quality Impacts Analysis for Area G

Abstract

The impact of fugitive radioactive emissions from the disposal site, Area G, was evaluated in support of site characterization for the Performance Assessment and for the Radioactive Air Emissions Management (RAEM) program. Fugitive emissions of tritiated water and contaminated windblown dust were considered. Data from an extensive field measurement program were used to estimate annual emissions of tritiated water. Fugitive dust models were used to calculate estimates of the annual emissions of windblown dust. These estimates were combined with data on contamination levels in surface soils to develop annual emission rates for specific radionuclides: tritium, uranium-238, cesium-137, plutonium-238, plutonium-239,240, and strontium-90. The CAP-88 atmospheric transport model was used to predict areas potentially affected by long-term dust deposition and atmospheric concentrations.

The annual emission rate of tritiated water was estimated from the field data to be 14.0 Ci/yr. The emission rate of soil-borne radionuclides from open areas and from soils handling operations totaled less than 1×10^{-4} Ci/yr. The CAP-88 results were used to develop effective dose equivalents (EDEs) for receptor locations downwind of Area G. All EDEs were several orders of magnitude below the national standard of 10 mrem/yr. Fugitive air emissions from Area G were found not to pose a health threat to persons living or working downwind of the facility.

1.0 INTRODUCTION

This section contains information regarding the background, site description, and project objectives for the impacts analysis.

1.1 Background

Los Alamos National Laboratory (LANL) has operated a solid, low-level radioactive disposal facility in Area G of Technical Area 54 (TA-54), since 1957. A smaller adjacent disposal area, designated Area L, is used for the storage of low-level mixed waste. Various types of wastes have historically been disposed of in TA-54, including tritium waste, transuranic element (TRU) waste, volatile organic compounds (VOCs) such as solvents, and mixed waste. Currently, however, only low level radioactive waste is disposed of in TA-54. The waste disposal practices in Area G are designed to contain the waste and prevent or minimize migration of contaminants via all pathways, including the air pathway. To evaluate the waste containment, environmental monitoring has been routinely performed to look for possible migration of contaminants. The air pathway is addressed by a fence-line ambient air monitoring network. The air monitoring program consists of biweekly samples analyzed for tritium, alpha, beta, and isotopic gamma and samples analyzed quarterly for TRU (specifically, isotopic plutonium, americium-241, and total uranium). Additional monitoring is performed to examine concentration levels of various contaminants in the surface soils, vegetation, pore gas, and runoff.

The environmental monitoring to date has indicated that no significant air emissions of radioactive species at TA-54 has

occurred during the ambient air monitoring (AAM) program. There could, however, be relatively low-level emissions or localized emission "hot spots" that need additional characterization. The gas-phase contaminants that are the most mobile in the subsurface are tritium, radon, and VOCs; therefore, these species could be migrating from the subsurface waste disposal pits/shafts and could be released to the atmosphere once they migrate to the soil surface. Particulate matter containing radioactive species also could be released from transportation or excavation activities on site. This air quality analysis involved compiling emission estimates for fugitive sources of radioactive emissions from Area G and evaluating the downwind impacts of emissions from these sources.

The analysis is in support of the Radioactive Air Emissions Management (RAEM) program's characterization of radioactive air emissions from waste sites to assure compliance with the National Emission Standards for Hazardous Air Pollutants (NESHAP) for radionuclides.

1.2 Site Description

Technical Area (TA) 54 occupies about 63 acres on the southern half of Mesita del Buey on the Pajarito Plateau. Mesita del Buey is a narrow mesa about 2 miles long that extends to the southeast. The elevation of the mesa is roughly 6900 ft. on the west and 6600 ft. at the eastern end. The mesa is bounded by Parajito Canyon to the south and Canada del Buey to the north. The edges of the mesa have been cut to near vertical and vary in height from 50 to 100 ft. Area G is located on Mesita del Buey approximately 4.5 miles southeast of the town of Los Alamos and 1 mile northwest of the subdivision of White Rock.

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The soil covering the mesa is classified as a Hackroy sandy loam. It varies in thickness from 3-4 feet at the interior of the mesa and thins out near the canyon rims. Below the surface soil is underlying layers of volcanic rock. The layer immediately underneath the surface soils is ashfall material called the Bandelier tuff that includes pumiceous tuff and weathered rhyolitic tuff. Undisturbed tuff is subject to mass wasting. The disturbed tuff is subject to wind and rain erosion when it is exposed.

The tuff at the surface has a moisture range from 2% to 8% (by weight), with the moisture content decreasing with depth. Below 10 ft., the moisture content ranges from 0.5% to 2%. The hydraulic conductivity of the tuff is about 10^{-8} cm/min (at 5% moisture content by volume), so the liquid phase movement through this material is small. Waste has been deposited to a depth of roughly 60 ft. below the top of the mesa. The ground water beneath the mesa is more than 800 ft. below the mesa top and no perched water is present between the disposal area and the main aquifer. The mesa contains stands of pinion and juniper as well as some underbrush. Overall, the vegetation is relatively sparse.

Summer days at the site are generally sunny with moderately warm days and cool nights. Maximum daytime temperatures are usually below 90°F and nighttime summer temperatures usually drop below 60°F. The surface winds are variable, but the most common meteorology is a moderate SW up-valley wind during the day and either a light NW to N drainage wind or a moderate SW wind at night. The average wind speed is 2.9 m/sec (6 mph), with the most prevalent wind direction being south to southwest. The LANL area is semi-arid. The laborato-

ry receives a gradient in precipitation of from about 14 to 18 inches per year. Area G is on the dry end of this gradient. Approximately 40% of the annual precipitation occurs during July and August.

Area G occupies over 60 acres at the southern end of Mesita del Buey. A wide variety of waste has been disposed of underground at Area G, including the following categories: polychlorinated biphenyls (PCBs), low-level radioactive waste, mixed waste, transuranic waste (TRU), animal tissue, and tritium waste. Low-level waste has been disposed of in 30 pits and 209 shafts.

Low-level waste containing tritium with an activity less than 20 mCi/m³ is disposed of with noncompactible waste. This material includes large or bulky waste (i.e., greater than 16 in. x 19 in. x 36 in.) and other waste such as heavy pipe, angle iron, equipment, lumber, building rubble, and soil. The noncompactible waste is buried in disposal pits without compaction prior to burial. Additional material is buried after compaction. The wastes are buried in layers and covered with clean fill; i.e. sanitary landfilled.

The tritium waste disposed of at Area G is solid waste contaminated with tritium in excess of 20 mCi/m³ (waste with levels below 20 mCi/m³ is disposed of as routine low-level waste in pits, as described above). Waste contaminated with tritium between 20 and 100 mCi/m³ is packaged in 55-gallon or 30-gallon, asphalt-lined metal drums. The lids of the drums are sealed with asphalt and the waste is disposed of in unlined shafts. Tritium waste with levels exceeding 100 mCi/m³ must be completely encapsulated in asphalt. This typically involves putting a

30-gallon drum inside a 55-gallon drum and filling the annular space between the two drums with asphalt. These drums are disposed of in asphalt-lined shafts labeled high-level tritium disposal.

The pits and shafts at Area G may be no deeper than 65 feet, which is at least 10 feet above the floor of the adjacent canyon. Pits and shafts can be filled to a level no higher than 3 feet below the spill point (i.e., the lowest elevation of the pit rim). The top layer of a pit has at least 3 feet of crushed tuff covered by 4 inches of topsoil. The final cover of a shaft is uncontaminated concrete at least 3 feet thick, slightly rounded, and 0.5 feet above the surrounding land surface.

TRU wastes in 55-gallon drums also are stored above-ground, either in domes or on asphalt pads that are covered with dirt. The drums thus stored are scheduled for excavation and inspection in the near future. TRU wastes also are stored in fiberglass reinforced plywood (FRP) boxes and in standard waste boxes.

1.3 Objectives

This study is being performed for several reasons:

- Emissions data are needed to support the Radioactive Air Emissions Management (RAEM) program's characterization of radioactive air emissions from waste sites to assure compliance with the National Emission Standards for Hazardous Air Pollutants (NESHAP) for radionuclides.
- Although not a regulatory requirement, there is a need to characterize

non-radioactive air emissions to determine if the Laboratory's waste operations are releasing toxic amounts of pollutants.

- The Department of Energy (DOE) requires that all facilities follow Best Management Practices (BMP) with regards to all of their activities. Quantifying releases of pollutants, even though not required by regulators, is a BMP.

As part of the Los Alamos National Laboratory's (LANL) environmental surveillance program, radionuclide dose estimates resulting from airborne releases are determined through modeling techniques. The effective dose equivalent (EDE) is the principal measurement used in radiation protection, and is modeled to provide a measure of the health impacts of any releases of radioactivity to the public. As stated in DOE Order 5400.5, "Radiation Protection of the Public and Environment," the EDE is "the summation of the products of the dose equivalent received by specific tissues of the body and a tissue-specific weighing factor. The sum is a risk-equivalent value and can be used to estimate the health-effects risk of the exposed individual."

Standards exist that regulate the maximum effective dose to the public. As stated in 40 CFR 61.93 Subpart H, "Emissions of radionuclides to the ambient air from Department of Energy facilities shall not exceed those amount that would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/year." In addition, 40 CFR 61.93 Subpart H states that "radionuclide emissions shall be determined and effective dose equivalent values to members of the public

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calculated using EPA approved sampling procedures, computer models (CAP88-PC or AIRDOS-PC), or other procedures for which EPA has granted prior approval."

The specific objectives of the test program were to:

- Develop an overall emission rate (mass/time) for Area G based on the emission flux measurements performed under another task.
- Evaluate various fugitive dust emission models to determine which model is most appropriate to Area G. The U.S. EPA's "Unlimited Erosion Model" and "Limited Erosion Model," models currently being used by the U.S. NRC, and other appropriate models were evaluated.
- Use the fugitive dust emission model determined to be appropriate to Area G, along with surface isopleths showing concentrations of radionuclides in Area G soils constructed from data obtained by EM-8 during 1993, to model atmospheric releases of radioactive fugitive dust from Area G.
- Use atmospheric transport models to predict areas potentially affected by long-term dust deposition and atmospheric concentrations.
- Review the concentration and deposition estimates in relation to environmental surveillance data. Discuss the strengths and weaknesses of the various emission estimation techniques, the significance of these results (and estimated dose) in rela-

tion to the potential effect on the off-site populace, and the degree of uncertainty in the various techniques employed.

Following the guidance given by DOE Order 5400.5 and 40 CFR 61.93, the USEPA approved CAP88-PC model was selected to determine the EDE resulting from fugitive releases of tritium gas and fine particulate radionuclides to nearby members of the public. Results of the modeling were compared to the national standard of 10 mrem/year, and the EDE determined for the 1992 LANL Environmental Surveillance Report (ESR).

2.0 PLOT PLAN

An area map of the TA-54 facility and surrounding land is provided as Figure 2-1. A plot plan of Area G is provided as Figure 2-2.

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Figure 2-1. Area Map of TA-54

Figure 2-2. Plot Plan of Area G

3.0 EMISSION SOURCES

The two emission sources considered in this analysis were fugitive emissions of tritium vapor and contaminated dust.

3.1 Tritium Emissions

Tritium emissions were determined from field measurements made using flux chambers during the summers of 1993 and 1994. A total of 240 tritium flux measurements were made at points distributed across the TA-54, Area G facility. The measurements were taken on the top of the mesa and along canyon walls, both inside and outside the facility fenceline. The total area covered during the sampling was 182 acres, including 60 acres (243,000 m²) within the Area G fenceline. The measured tritium flux data (pCi/m²-min) were used to determine an average emission rate (Ci/year) for the site. The resulting average tritium release rate of 14.0 Ci/year¹ for TA-54 Area G was used in the modeling analysis. For the dispersion modeling analysis, the tritium emissions were considered to be homogeneously distributed across the entire 60 acre area.

The various emission flux measurements were combined to develop an estimate of the overall emission rate from Area G as described in the following paragraphs. The general approach was to divide the site into grids and develop an average emission flux value for each grid. If the variability within a grid was large, the grid was further subdivided into more grids to decrease the variability. The majority of Area G was represented by the twenty locations spread across the site (i.e., T1 to T20). This was considered to be a single grid. Additional areas were identified such as the three initially suspected tritium hot spots (TR1, TR2, and

TR3). In all, a total of 16 different grids was used. The average emission flux for each grid was developed by averaging the measurements made within that grid. Data were corrected for the estimated background/blank flux of 3 pCi/m²-min; i.e., the measured emission fluxes were reduced by the estimated contribution from blank contamination in the samples. The reduction amounted to 7.71% of the total emissions. Once this was accomplished, the area of each grid was estimated. The emission flux was multiplied by the area to yield an emission rate for each grid. These emission rates were then summed to yield an emission rate for the entire site as shown in Table 3-1.

The emissions shown in Table 3-1 include areas both inside and outside the fenceline of Area G. Several relatively small (in total area) "hot-spots" inside of Area G account for the vast majority of the tritium emissions, with the majority of Area G having relatively small tritium emissions. To account for this, the area of the hot-spots were estimated and summed. The total area comprising the "hot-spots" (approximately 10 acres) were subtracted from the total Area G acreage (60 acres) to yield approximately 50 acres. The emissions from this 50 acres, are represented by the twenty T points (e.g., Points T-1 through T-20). Figure 3-1 shows the locations of these twenty T points.

The most difficult areas to assign an area to were the hottest spots: TR1- 24, 29, 105, 106, 107, 108, 109, 111, 112 and TR2-45, 58, 67, 69, 101, 102, and 103 which all corresponded to a tritium burial shaft. The location of these points are shown in Figures 3-2 (TR1 sites) and Figure 3-3 (TR2 sites). Each of these points were

**Table 3-1.
Overall Emission Rate for Area G**

General Location	Sampling Locations	n	Est. Area (m ²)	Emission Flux (pCi/m ² -min)	Emission Rate		% of Total Emissions
					pCi/min	Ci/yr	
T points	T1-T20	19	201,000	1.33	268,000	0.141	1.00
T points	T17	1	100	46.01	4,600	0.002	0.02
TR1	1-41	35	14,400	141	2.46e+06	1.29	9.22
TR1	24 & 29	2	2.5	2,010	5,020	0.003	0.02
TR1	101-121	14	290	975	2.83e+06	1.49	10.63
TR1	105-109 111-112	7	5.0	3.82e+06	1.91e+07	10.04	71.72
TR2	1-69	31	3120	7.34	22,900	0.012	0.09
TR2	45,58,- 67,69	4	5.0	204	1,020	0.001	0.00
TR2	101-103	3	3.75	65,800	247,000	0.130	0.93
TR3	1-18	18	14,900	2.43	36,100	0.019	0.14
Grassy Field	F1-F6	6	18,600	67.7	1.26e+06	0.661	4.72
Trench #10	P10 1-6	6	1930	0.24	464	0.000	0.00
Shaft nr. 54-11	TR1 19-22	4	232	8.8	2,040	0.001	0.01
Mesa side	C 1-10	10	5810	9.0	52,300	0.027	0.20
Canyon	C 11-30	18	476,000	0.72	342,000	0.180	1.29
Canyon	19 & 20	2	200	37.1	7,420	0.004	0.03
Totals	-	180	736,598	--	2.66E+07	14.0	100

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Figure 3-1. Location of Sampling Points T1-T20.

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Figure 3-2. Location of Sampling Points at Tritium Hot-spot No. 1 (TR1)

Figure 3-3. Location of Sampling Points at Tritium Hot-spot No. 2 (TR2)

assigned an area of 1.25 m². The rationale for this was as follows. It was assumed that each shaft was a 4-ft diameter concrete cylinder and that all emissions were from the edge of the cylinder; i.e., there was a preferential pathway for vapor transport along the outer edge of the cylinder where it met the soil. A 4-ft circle has a diameter of 150.8 in. or 9.42 flux chamber diameters. That is, 9.42 flux chambers placed around the shaft would completely encircle it with the chamber half-on and half-off the concrete. The area of the flux chamber is 0.13 m², so 9.42 flux chambers have a total area of 1.23 m². This was rounded up slightly to 1.25. For shafts where two measurements were made, the total area assigned for both measurement locations was 1.25 m².

The estimated total annual emissions of tritiated water from Area G are 14.0 Curies per year. The obvious finding from the data in Table 3-1 is that over 90% of the emissions are coming from tritium hot spot #1 and over 70% of the emissions are coming from just three shafts: 150, 151, and 154. The annual emission rate estimate is thus dependent on only a handful of the over 200 flux measurements that were performed. As such, the estimate is not affected by changes in the assumed background/blank correction, the estimate emitting area outside the fence, or other assumptions except one. The emission rate estimate is highly dependent on the assumed area of the hottest spots.

3.2 Fugitive Dust Emissions

This section presents the calculated results of the fugitive dust emissions. The equations that were used to determine the dust emissions are presented and described in Appendix A. Example calculations are given in Appendix B.

Fugitive dust emissions were assumed to come from a single area, 200 meters south of Dome 48, and results from two activities/scenarios: dust from open areas; and dust from materials handling (excavation, dumping, etc). As shown in Appendix B, the emission rates of particulate matter from Area G are 0.438 g/sec for open areas and 0.0092 g/sec for materials handling operations such as excavation. Dust from paved or unpaved roads were not included in the analysis. It was assumed that road dust contained no radionuclides (or radioactivity above background activity levels).

Fugitive dust emissions from open areas were determined using the USEPA "Control of Open Fugitive Dust Sources" (USEPA 1988), approach assuming a finite reservoir of material (Limited Dust Erosion Model). Additional input to this calculation is a particle size distribution (based on unpublished Radian data from 1993), and the fastest mile wind speed between site disturbances, measured at the site. Additional assumptions concern the estimate of the time between disturbances and the fraction of Area G that is covered with "non-erodible elements" such as buildings, plants, and large rocks. The assumed time between disturbances is once per year on average for the 60 acre site. It is a conservative assumption that 50 percent of Area G is covered with roads, buildings, rocks, and plants. As shown in Appendix B calculations, all these factors resulted in an erosion potential of 114 g/m² and an emission estimate of 0.438 g/sec.

According to the 1993 soil sampling data provided by LANL, 42 soil samples were collected with results being reported for tritium in each sample, and for uranium and ¹³⁷Cs in 22 of the samples. Contour plots of these soil data are shown in Figures 3-4 through 3-6 for tritium, uranium and cesium, respectively. Table 3-2 displays the

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Figure 3-5. Contour of Uranium in Surface Soils

Figure 3-6. Contour Plot of Cesium-137 in Surface Soils

Table 3-2.
Average Soil Concentrations for Area G

Species	Units	Average Level in Surface Soils	Background Level in Surface Soils ¹
Tritium	pCi/g	0.975	0.03 (0.3) ²
Uranium	μg/g	1.62	2.4 (0.2)
Cesium-137	pCi/g	0.213	0.7 (0.1)
Plutonium-238	pCi/g	0.005	0.001 (0.002)
Plutonium-239,240	pCi/g	0.025	0.021 (0.003)
Strontium-90	pCi/g	0.88	N/A ³

1. Average data for regional soils from seven sampling locations, 1991 Environmental Surveillance Report. Values in parenthesis are radioactivity counting uncertainties ($\pm$ one standard deviation).
2. Tritium concentration in units of nCi/L, measured as tritiated water distilled from soils.
3. Analysis not performed. Background statistical limit for strontium-90 is 0.88 pCi/g. This is the average plus 2 standard deviations of measurements of regional soil samples during 1974-1986.

Table 3-3.
Emission Rates of Soil-Borne Radionuclides from Open Areas

Species	Emission Rate (Ci/yr)
Tritium ¹	1.3e-05
Uranium-238	7.5e-06
Cesium-137	2.9e-06
Plutonium-238	6.9e-08
Plutonium-239,240	3.5e-07
Strontium-90	1.2e-05

1. This value represents soil-borne tritium concentrations only. Vapor phase tritium, i.e., that measured by the Flux Chamber sampling method, is not included.

average soil concentrations from the sampling measurements. The tritium value presented in this table assumes 5 percent soil moisture; surface soils normally range from 4-6 percent moisture. The tritium spread by windblown dust is separate and distinct from the emissions of tritiated water measured with the flux chambers. Also based on 1993 soil sampling results, other radionuclides found in the surface soil are ^{238}Pu , $^{239, 240}\text{Pu}$, and ^{90}Sr . Except for tritium and $^{239, 240}\text{Pu}$, these values are approximately background levels. The concentrations shown in Table 3-2 were multiplied by the erosion potential to get the average emission rate. Table 3-3 contains the emission rates for open areas used in the modeling analysis. Note that the units for uranium are in $\mu\text{g}/\text{sec}$. This concentration was multiplied by a specific activity value of $3.364\text{e-}07\text{ Ci/g}$ for ^{238}U to result in an emission rate of $7.5\text{e-}06\text{ Ci/yr}$.

Fugitive dust emissions from materials handling were determined using the USEPA AP-42 emission factor method, assuming an average wind speed of 6.3 mph (LANL, 1994), and a soil moisture content of 2% for tuff. Although average soil moisture content of soils from 3-4 ft below the surface range from 4 to 6 percent or more, the 2% value is appropriate for surface soil. The amount of material moved/dumped was assumed to be 200,000 tons per year. The resulting emission factor using these assumptions is 0.00920 g/sec . The emission rates resulting from these assumptions were determined by multiplying the concentration found in Table 3-2 by the emission factor. Table 3-4 lists the emission rates for materials handling used in the modeling analysis.

Table 3-4.
Emission Rates of Soil-Borne Radionuclides from Soils Handling

Species	Emission Rate (Ci/yr)
Tritium ¹	2.8e-07
Uranium-238	1.6e-07
Cesium-137	6.2e-08
Plutonium-238	1.5e-09
Plutonium-239,240	7.3e-09
Strontium-90	2.6e-07

1. Emission rate based on soils handling only. Does not include vapor phase tritium (i.e., tritium Flux) or wind blown dust from open areas.

4.0 RECEPTOR LOCATIONS

CAP88-PC can be used to determine EDEs for either a polar grid of distances and directions for a radius of 80 km (50 miles) around the facility, or a set of user specified distances downwind from the facility. Both were used in this study.

There were five sets of receptors used in this analysis:

1. The distance to the nearest facility receptor, which is 1957 m ENE of the facility in White Rock;
2. The distance to the Area G maximum exposed individual (MEI) which is 1200m NNE (a theoretical receptor);
3. A set of 16 distances from the center of Area G to the LANL/DOE property line;
4. The 80 km polar grid receptor data, centered over Building 2; and
5. The distance to the LANL MEI, which is 4956 m NNW, as determined in the LANL Environmental Surveillance Reports.

The fifth receptor, the LANL MEI, was not expected to be impacted by emissions from Area G, but was included in the analysis for consistency with other air quality studies performed by LANL.

Tables 4-1 and 4-2 show the distances used for the property line receptors and the 80 km polar grid. CAP88 and other Gaussian dispersion models are not accurate for receptors very close to large fugitive

area sources. No data are reported for receptors within 500m of the source. The dust emissions were assumed to come from a 493m by 493m square. It is recommended that the distance between an area source and the nearest receptor be greater than the length of the side of the area source. In some cases, however, the property line of Area G is within 500m of the emitting area and property line values could not be modeled. For these cases, the property line receptor distances shown in Table 1 of 500m represent the minimum distance that was modeled rather than the actual distance to the property line. The 80 km polar grid contains population information from the 1990 U.S. Census (updated to represent 1993 conditions), and can be used to determine the collective EDE resulting from the fugitive release of the radionuclides. A similar calculation is performed by LANL for all radionuclide releases, and is listed in the annual Environmental Surveillance Report.^{2,3}

Table 4-1
Property Line Receptors

Direction	Distance (m)
N	500*
NNE	500*
NE	500*
ENE	500*
E	500*
ESE	2080.89
SE	3395.77
SE	4037.64
SE	4858.45
SSE	7333.48
S	8583.45
SSW	5859.77
SW	5234.48
WSW	5923.90
W	7089.13
WNW	10475.41
NW	4212.98
NW	7760.51
NW	10232.04
NNW	1408.73

*Property line for this direction is too close to the source.

Table 4-2
80-km Polar Grid Receptor Distances (meters)

500	17500
1500	25000
3000	35000
6000	70000
11500

5.0 MODELING DISCUSSION

5.1 Dispersion Modeling

The CAP88-PC model consists of modified versions of AIRDOS-EPA and DARTAB. These codes use measured radionuclide release rates and meteorological information to calculate transport and airborne concentrations of radionuclides released into the atmosphere. The CAP88-PC program applies a Gaussian plume equation to estimate the average dispersion of radionuclides released into the atmosphere. The sources may be either stacks or uniform area sources. For this analysis, TA-54 Area G was modeled as an uniform ground-level area source. The DARTAB model uses a database of dose and risk factors to estimate the dose and risk for maximum exposed individuals and populations.

The CAP88-PC model estimates radiation exposures from inhalation of radioactive materials, external exposure from radionuclides present in the atmosphere and deposited on the ground, and ingestion of radionuclides in produce, meat, and dairy products (Nuclear Regulatory Commission Guide 1.109 terrestrial food chain models). The EDE is the sum of the inhalation, ingestion, and external (air and ground) doses, and is calculated using the weighing factors in ICRP Publications 26 and 30. Note that EDE estimates from CAP88-PC are applicable only to low-level chronic exposures, since health effects and dosimetric data are based on low-level chronic intakes.

The uniform ground-level area source (Gaussian) assumption is a simplified approach that also assumes that the terrain is relatively flat and has uniform surface conditions in all directions. This is a reason-

able assumption concerning the terrain conditions at the top of the mesa at Area G. However, this assumption is invalid for complex terrain features such as valleys and canyons, that exist between the mesas. The Gaussian assumption used by CAP88-PC was not designed to resolve wind patterns generated by complex terrain. Instead of a straight downwind trajectory, the plume may be wrapped around or lifted above terrain features. This limitation of the CAP88-PC model should not adversely affect the analysis results because most of the receptors are located at terrain heights similar to that of the source.

5.2 Model Options

The CAP88-PC model is a menu driven model, which contains many databases (agricultural data, meteorological data, radionuclide data) and queries the user on input for the databases and dispersion parameters. Options used in this analysis include:

- uniform ground-level area source of 242,820 m²;
- tritium release rate equal to 14.0 Ci/yr (see Table 3-1).
- urban/suburban agriculture land use assumption; and
- zero plume rise (no mechanical or buoyancy rise).

5.3 Meteorological Data

CAP88-PC applies the USEPA Stability Array (STAR) data to determine EDEs downwind from the facility. The 1992 TA-54 meteorological tower data was used

Area G - Air Impacts Analysis

in the modeling calculations. These data were selected since this was the most recent validated data available for TA-54. Additional meteorological data used in the analysis include:

- 1992 annual average temperature measured at TA-54 of 9.0° C;
- 1992 annual average precipitation measured at TA-54 of 34 cm/yr; and
- boundary layer mixing height of 1,525 m.

The USEPA STAR data processing program summarizes meteorological data by generating joint frequencies of 6 wind speeds, 16 wind directions, and 6 stability categories. The program generates a count of the number of entries for each wind speed/wind direction category by stability class, as well as the percent frequency for each wind speed/wind direction by stability class.

The six Pasquill-Gifford atmospheric stability classes used for the CAP88-PC model are defined as follows:

A	Extremely constable
B	Unstable
C	Slightly unstable
D	Neutral
E	Slightly stable
F	Stable

The NRC uses a seventh classification, G-Extremely stable, that can be used in CAP88-PC, if information on that stability category is available.

The 6 wind speed categories are defined as follows: 1 to 3 knots, 4 to 6

knots, 7 to 10 knots, 11 to 16 knots, 17 to 21 knots, and greater than 21 knots. The 16 wind directions are as follows: N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, and NNW.

The CAP88-PC GETWIND module converts the site-specific USEPA STAR data into a format readable by CAP88-PC. It breaks the STAR data down into tables of average wind speeds as a function of direction and stability, and the frequencies of stability classes (Table 5-1). The model applies the information found in these tables to the determination of concentration and dose.

Table 5-1 displays the 1992 TA-54 STAR data, in CAP88-PC format, used in the modeling analysis. Note that the CAP88-PC model assumes that the wind blows toward a particular direction, terminology which is opposite of the normal meteorological convention. For example, in Table 5-1, the south wind direction indicates that the wind is traveling to the south from the north. Figures 5-1 through 5-3 display the 1992 annual wind roses during night-time hours, day-time hours, and all hours, respectively. The dominant wind direction for the Area G site are from the south-southwest (to the north-northeast) and from the northwest (to the southeast). These are the result of the diurnal wind pattern that develops due to the complex terrain surrounding the site. During the daytime hours, the wind is mostly from the south-southwest, reflecting the thermally driven upslope winds which develops over the Pajarito Plateau and channels through the Rio Grande Valley. The night-time wind flow shifts from the northwest, as shallow cool air drainage flows develop and winds channel through the Pajarito Canyon towards

Table 5-1
1992 TA-54 STAR DATA
CAP88-PC Format
Frequencies of Stability Classes (Wind Towards)

Pasquill Stability Class							
Direction	A	B	C	D	E	F	G
N	0.0655	0.0380	0.1337	0.6559	0.0789	0.0280	0.0000
NNW	0.2159	0.1140	0.1773	0.4039	0.0658	0.0230	0.0000
NW	0.4167	0.1255	0.1410	0.2081	0.0621	0.0466	0.0000
WNW	0.4839	0.1687	0.1391	0.1357	0.0453	0.0273	0.0000
W	0.5256	0.1555	0.1175	0.1118	0.0565	0.0332	0.0000
WSW	0.3802	0.1523	0.1849	0.1945	0.0639	0.0243	0.0000
SW	0.1276	0.0825	0.2011	0.4218	0.0870	0.0799	0.0000
SSW	0.0396	0.0238	0.0578	0.5231	0.2116	0.1440	0.0000
S	0.0241	0.0071	0.0201	0.3593	0.3554	0.2340	0.0000
SSE	0.0204	0.0069	0.0115	0.2537	0.4153	0.2922	0.0000
SE	0.0081	0.0052	0.0194	0.2135	0.3807	0.3731	0.0000
ESE	0.0114	0.0076	0.0490	0.2805	0.3657	0.2859	0.0000
E	0.0140	0.0096	0.0479	0.2949	0.2908	0.3426	0.0000
ENE	0.0222	0.0098	0.0425	0.3586	0.2433	0.3236	0.0000
NE	0.0200	0.0088	0.0377	0.4955	0.2945	0.1435	0.0000
NNE	0.0259	0.0187	0.0627	0.7259	0.1281	0.0386	0.0000

Figure 5-1. 1992 Area G Wind Rose for Night-time Hours

Figure 5-2. 1992 Area G Wind Rose for Day-time Hours.

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Figure 5-3. 1992 Area G Wind Rose.

White Rock. The CAPP88-pc modeling used only the average annual wind rose shown in Figure 5-3. CAP88-PC model output files, which include all the input values used in the analysis, are found in Appendix C.

6.0 ANALYSIS RESULTS

This section contains the results of the air impacts analysis. The calculated values are given below and include a comparison of the results to environmental surveillance data and to applicable health and regulatory standards.

6.1 Gaseous Tritium Concentration/EDEs

6.1.1 Area G Results

The atmospheric dispersion modeling provided ground-level ambient tritium concentrations at various locations which could be used to calculate an effective dose equivalent (EDE). The ground-level ambient tritium concentrations and EDEs are given in Table 6-1 for the maximum exposed individuals (MEIs), the nearest facility receptor, and the maximum value from the 80-km grid. The same information is given in Table 6-2 for the boundary line receptors.

All EDEs are several orders of magnitude below the national standard of 10 mrem/year. The maximum concentration and EDE values occur 500m downwind east of Area G. Secondary maximum values occur 500m east-northeast, northeast, north-northeast, and north of Area G. Maximums occur at these locations due to the short distance between the source and the receptor, and because these receptors are located along the dominant wind directions from the south-southwest, southwest, and west (see annual wind rose).

6.1.2 Comparison with 1992 LANL ESR Data

The 1992 LANL Environmental Surveillance Report (ESR)² states that the maximum individual EDE attributed to inhalation of airborne tritium (as titrated water vapor) was $5.0\text{e-}03$ mrem/year at White Rock. This is the estimated maximum dose from all laboratory operations to an individual at or outside the LANL boundary where the highest dose occurs and where a person actually resides. The tritium EDEs for this study at the Area G MEI (1200m NNE) and at the nearest facility receptor in White Rock (1957m ENE) are $3.9\text{E-}03$ mrem/year and $3.4\text{E-}03$ mrem/year, respectively. These doses are 78% and 68% of the ESR value.

The total EDE to a member of the public from all Area G operations during 1992, estimated using the CAP88 mainframe version, was $9.0\text{E-}03$ mrem/year. The tritium EDE for this study at the Area G MEI is 43% of this total value.

The maximum individual EDE, attributed to inhalation of all radionuclides, was 7.9 mrem/year for 1992 at the LANL MEI located NE of the LAMPF (TA-53) facility. More than 98% of the maximum individual EDE resulted from external exposure to air activation products from LAMPF. The tritium EDE for the LANL MEI in this current study is only 0.035% of the LANL MEI EDE. The tritium EDE from Area G for the LANL MEI is low because the LANL MEI is not located in the dominant downwind direction of Area G, it is located almost 5000m from Area G, and the amount of tritium released from Area G is only a small fraction of all radionuclides released from all laboratory operations.

Table 6-1
Ambient Concentrations and EDEs
for Gaseous Tritium Releases

Receptor Location	Concentration (pCi/m ³)	EDE (mrem/year)	Distance (meters)	Direction (degrees)
MEI - LANL ^a	2.2e-02	2.8e-03	4956	NNW
Nearest Facility Receptor	4.3e-01	3.4e-03	1957	ENE
Maximum for 80 km Grid	1.7e+00	2.1e-03	1500	SE
MEI - Area G ^b	8.1e-01	3.9e-03	1200	NNE

Notes: a) The total tritium emissions from LANL in 1992 are estimated at 1,298 Ci/yr.
b) The total tritium emissions from Area G are estimated to be 14 Ci/yr.

Table 6-2
Gaseous Tritium Concentration/EDE Result
for Property Line Receptors

Distance (meters)	Direction	Concentration (pCi/m³)	EDE (mrem/year)
500	N	2.5e+00	6.1e-03
500	NNE	3.9e+00	8.0e-03
500	NE	4.8e+00	9.2e-03
500	ENE	6.0e+00	1.1e-02
500	E	7.9e+00	1.3e-02
1408.73	NNW	1.7e-01	3.0e-03
2080.89	ESE	8.4e-01	3.9e-03
3395.77	SE	4.7e-01	3.4e-03
4037.64	SE	3.7e-01	3.3e-03
4212.98	NW	2.6e-02	2.8e-03
4858.45	SE	2.8e-01	3.2e-03
5234.48	SW	7.8e-02	2.9e-03
5859.77	SSW	8.9e-02	2.9e-03
5923.90	WSW	2.9e-02	2.9e-03
7089.13	W	1.7e-02	2.8e-03
7333.48	SSE	9.4e-02	2.9e-03
7760.51	NW	1.1e-02	2.8e-03
8583.45	S	6.5e-02	2.9e-03
10232.04	NW	7.1e-03	2.8e-03
10475.41	WNW	6.6e-03	2.8e-03

The collective EDE for 1992 LANL operations to persons living within 80 km of the Laboratory was determined to be 1.4 person-rem/year.² The collective EDE from the release of tritium from Area G was determined in this study to be 1.31e-02 person-rem/year, which is <1% of the total LANL collective EDE.

The comparison of tritium EDEs calculated in the current study with the 1992 LANL ESR data indicate that:

- Tritium accounts for 43 % of the total radioactivity dose from Area G.
- The tritium dose at the Area G MEI and the nearest facility receptor at White Rock are 78% and 68%, respectively, of the maximum tritium dose reported in the 1992 LANL ESR. Although the tritium emissions from Area G of 14 Ci/yr are small compared to the total tritium emissions from LANL of 1,298 Ci/yr², the proximity of receptors to Area G may account for the modeled results for this study.
- The tritium dose from Area G accounts for an extremely small fraction of the total EDE from all LANL sources.

6.2 Fugitive Dust Concentrations/EDE

Results are given below for air impacts of fugitive dust released from open areas and from materials handling operations, followed by a comparison of these results to results given in the 1992 LANL ESR.

6.2.1 Open Area Release

The atmospheric dispersion modeling provided ground-level ambient particulate matter concentrations at various locations which, when combined with contaminant levels in the surface soils, could be used to calculate an effective dose equivalent (EDE). The ground-level ambient concentrations and EDEs for the maximum exposed individuals (MEIs), the nearest facility receptor, and the maximum value from the 80-km grid for releases from open areas are given in Table 6-3. The same information is given in Table 6-4 for the boundary line receptors. As with the gaseous tritium concentrations and EDEs, the maximum concentration and EDEs occurred at 500m east of Area G. Secondary maximum values occurred at 500m east-northeast, northeast, north-northwest, and north of Area G. Again, the reasons for these maximum values are the short distance from the source to the receptors and the location of these receptors along the dominant wind directions from the south-southwest, southwest, and west (see annual wind rose). In all cases, the EDEs from the Area G Open Area release scenario are well below the 10 mrem/year standard.

6.2.2 Materials Handling Release

The ground-level activity and EDE for the MEI, nearest facility receptor, and 80 km grid for releases from materials handling are shown in Table 6-5. The ground-level activity and EDE for the boundary line receptors are listed in Table 6-6. All EDEs are 5 to 8 orders of magnitude below the national standard of 10 mrem/year. As with the gaseous tritium concentrations and EDEs, the maximum concentration and EDEs occurred at 500m

Table 6-3
Ambient Concentrations and EDEs for
Fugitive Dust Releases from Open Areas

Receptor Location	Concentration (pCi/m³)	EDE (mrem/year)	Distance (meters)	Direction (degrees)
MEI - LANL	5.9e-08	4.5e-05	4,956	NNW
Nearest Facility Receptor	1.2e-06	3.2e-04	1,957	ENE
Maximum for 80 km Grid	8.8e-07	1.2e-03	1,500	SE
MEI - Area G	2.4e-06	6.1e-04	1,200	NNE

Table 6-4
Open Area Fugitive Dust Concentration/EDE Result
for Property Line Receptors

Distance (meters)	Direction	Concentration (pCi/m ³)	EDE (mrem/year)
500	N	7.5e-06	1.8e-03
500	NNE	1.2e-05	2.8e-03
500	NE	1.5e-05	3.5e-03
500	ENE	1.8e-05	4.3e-03
500	E	2.3e-05	5.5e-03
1408.73	NNW	5.0e-07	1.5e-04
2080.89	ESE	2.3e-06	5.4e-04
3395.77	SE	1.2e-06	3.2e-04
4037.64	SE	9.5e-07	2.5e-04
4212.98	NW	6.6e-08	4.6e-05
4858.45	SE	7.2e-07	2.0e-04
5234.48	SW	2.0e-07	7.6e-05
5859.77	SSW	2.2e-07	8.1e-05
5923.90	WSW	7.2e-08	4.8e-05
7089.13	W	4.1e-08	4.0e-05
7333.48	SSE	2.3e-07	8.2e-05
7760.51	NW	2.5e-08	3.7e-05
8583.45	S	1.6e-07	6.5e-05
10232.04	NW	1.6e-08	3.5e-05
10475.41	WNW	1.6e-08	3.4e-05

Table 6-5
Ambient Concentrations and EDEs for
Fugitive Dust Releases from Materials Handling Operations

Receptor Location	Concentration (pCi/m³)	EDE (mrem/year)	Distance (meters)	Direction
MEI - LANL	1.3e-09	9.6e-07	4,956	NNW
Nearest Facility Receptor	2.6e-08	6.8e-06	1,957	ENE
Maximum for 80 km Grid	1.9e-08	2.6e-05	1,500	SE
MEI - Area G	5.2e-08	1.3e-05	1,200	NNE

Table 6-6
Materials Handling Fugitive Dust Concentration/EDE Result
for Property Line Receptors

Distance (meters)	Direction	Concentration (pCi/m ³)	EDE (mrem/year)
500	N	1.6e-07	3.9e-06
500	NNE	2.6e-07	6.0e-05
500	NE	3.2e-07	7.4e-05
500	ENE	3.9e-07	9.1e-05
500	E	5.0e-07	1.2e-04
1408.73	NNW	1.1e-08	3.2e-06
2080.89	ESE	4.8e-08	1.2e-05
3395.77	SE	2.7e-08	6.7e-06
4037.64	SE	1.7e-08	5.3e-06
4212.98	NW	1.4e-09	9.9e-07
4858.45	SE	1.6e-08	4.2e-06
5234.48	SW	4.3e-09	1.6e-06
5859.77	SSW	4.8e-09	1.7e-06
5923.90	WSW	1.6e-09	1.0e-06
7089.13	W	8.7e-10	8.6e-07
7333.48	SSE	5.0e-09	1.7e-06
7760.51	NW	5.4e-10	7.8e-07
8583.45	S	3.3e-09	1.4e-06
10232.04	NW	3.5e-10	7.4e-07
10475.41	WNW	3.4e-10	7.4e-07

east of Area G. Secondary maximum values occurred at 500m east-northeast, northeast, north-northwest, and north of Area G. The reasons for these maximum values are the short distance from the source to the receptors and the location of these receptors along the dominant wind directions from the south-southwest, southwest, and west (see annual wind rose).

6.2.3 Comparison with 1992 LANL ESR Data

The 1992 LANL ESR states that the highest measured off-site EDE for ^{238}Pu , $^{239,240}\text{Pu}$, ^{241}Am , uranium, ^{234}U , ^{235}U , and ^{238}U , at the Pajarito Acres monitoring station was 0.08 mrem/year. Pajarito Acres is located approximately southeast of Area G. The maximum Open Area and Materials Handling EDEs at the southeast boundary line receptor are 0.25% and 0.01%, respectively, of this measured EDE.

The estimated dose from exposure to dust released from Area G is compared to the total exposure from various sources at key receptor locations in Table 6-7. In all cases, the dose resulting from dust releases at Area G is small compared to the dose at the same location from all sources.

Results from comparing the EDEs for release of fugitive dust from Area G with the 1992 LANL ESR Data indicate that:

- EDEs from the Open Area and Materials Handling operations account for a small percentage of the total EDEs from Area G; and
 - EDEs from Open Area and Materials Handling operations are negligible when compared to EDEs resulting from all LANL operations.
-
- EDEs from the Open Area are greater than EDEs from Materials Handling, because the amount of dust released from the Open Area is greater than that released from Materials Handling;

Table 6-7
Comparison of Dose from Fugitive Dust Releases From Area G to Other Sources

Source	Receptor	Dose (mrem/year)	Dose From Area G Dust Releases as a Fraction of Total Dose at Source	
			Open Areas	Materials Handling
All Area G operations	Area G MEI	9.0e-03	6.8%	0.14%
All LANL operations	LANL MEI	7.9	0.0006%	1.22e-05%
All LANL operations	Persons living within 80 km	1.4 ^c	0.19% ^a	0.0041% ^b

Notes: a - The EDE for releases from open areas is 2.72e-03 persons-rem/year
b - The EDE for releases from materials handling is 5.73e-05 persons-rem/year
c - Units are person-rem/year

7.0 DISCUSSION

This section presents a discussion of the results. The uncertainties in the data are described below followed by the conclusions and recommendations.

7.1 Uncertainty in the Air Impact Estimates

The accuracy of the air impact estimates depends on the accuracy of the input data used to generate these estimates as well as on the accuracy of the methodology employed to generate the estimates. The tritium emissions are based on a very large set of field measurement data and therefore are considered to be reasonably certain. The largest uncertainty is believed to be in the soils data used to estimate exposure due to windblown dust. A limited amount of data were available providing data on the activity of various radioactive species in the surface soils. A greater uncertainty exists in the estimates of the amount of soil carried away by winds from open areas and from excavation activities. The total uncertainty, however, is certainly less than $\pm$ one order of magnitude.

Effect of Complex Terrain -

The complex, irregular terrain at Los Alamos can favorably and unfavorably influence atmosphere turbulence and the dispersion of contaminants released near TA-54, Area G. The complex terrain and surrounding forests present an aerodynamically rough surface which results in increased horizontal and vertical turbulence and dispersion. Although the dispersion decreases in general at the lower elevations where the terrain is smoother and less vegetated, the frequent clear skies and light

winds result in favorable daytime vertical dispersion, especially during the warm spring and summer days (thermals). The strong daytime heating during the summer can force strong vertical mixing up to 1200 to 2400 m above ground level. The TA-54 Area G daytime winds display the thermally driven SW upslope wind channeled through the Rio Grande Valley, away from White Rock.

Clear skies and light winds have a negative effect on night-time dispersion. Unfavorable turbulence/dispersion effects occur because the generally light winds are limited in diluting the contaminants horizontally.

In addition, strong, shallow surface inversions develop as a result of these meteorological conditions. These inversions severely reduce near surface horizontal and vertical dispersion, and tend to be strong in the winter. In addition, shallow drainage winds fill the lower elevation areas with cold air, resulting in deeper inversions, common toward the valley (White Rock) on clear nights with light winds. Nighttime drainage winds will tend to direct any release from Area G towards the White Rock area. The tritium dose in White Rock is negligible in this study, but a more realistic modeling scenario might result in higher concentrations, emphasizing the need to better understand the complex terrain effects. In addition, the canyon topography can limit dispersion by channeling the air around the mesa.⁴

Overall, dispersion is greatest in the spring during strong winds; although deep vertical mixing is greatest during the summer afternoons due to thermals. Low-level dispersion is generally lower during summer

and autumn when the winds are light, and even though low-level dispersion is generally greater in the winter, occasional intense surface inversions can greatly limit the low-level dispersion during nights and early mornings.

Dispersion modeling of complex terrain using the Gaussian approximation may produce results that are not representative of the actual dispersion conditions. The current models using the Gaussian approximation are not designed to resolve complex wind patterns and turbulence features that result from complex terrain, such as canyon channeling. Currently, there are studies ongoing at LANL to analyze the dispersion through canyons and other complex terrain features/phenomena using advanced Lagrangian particle models. These models read multiple point meteorological data and develop a grid, which can resolve the complex wind patterns. It also allows the modeler to account for various turbulence features, such as mechanical mixing or heat flux generated turbulence, that is not available in the Gaussian models, such as CAP-88 used in the present study.

The fact that correlations of wind speed and direction are not accounted for may give erroneous results. A maximum impact for dust emissions was seen in the SE direction. These winds are the night-time damage winds. However, night-time wind speeds are less than day-time speeds, so dust emissions would be smaller than predicted by the time-averaged values used in this study.

7.2 Conclusions

The overall conclusion from this exercise is that fugitive air emissions from

Area G do not pose a health threat to persons living or working downwind of the facility. The estimated impacts are several orders of magnitude below applicable regulatory levels.

7.3 Recommendations

Given the rather low impacts that are estimated, the only recommendation offered is that LANL should update the estimated air impacts as new data become available. The methodology should be re-evaluated in 2-3 years and brought up to date with regulation and guidance is available at that time.

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APPENDIX A

Selection of Fugitive Dust Model for Area G Technical Note

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1.0

INTRODUCTION

Los Alamos National Laboratory (LANL) has operated a solid, low-level radioactive disposal facility in Area G of Technical Area 54 (TA-54), since 1957. Area G occupies over 60 acres at the southern end of Mesita del Buey. A wide variety of waste has been disposed of underground at Area G, including the following categories: polychlorinated biphenyls (PCBs), low-level radioactive waste, mixed waste, transuranic waste (TRU), animal tissue, and tritium waste. Low-level waste has been disposed of in 30 pits and 209 shafts.

This technical note summarizes the results of an evaluation of various fugitive dust emission models to determine which model(s) is most appropriate to Area G. The U.S. EPA's "Unlimited Erosion Model" and "Limited Erosion Model," models currently being used by the U.S. NRC, and other appropriate models were evaluated. The fugitive dust emission model(s) determined to be appropriate to Area G will be used, along with surface isopleths showing concentrations of radionuclides in Area G soils, to model atmospheric releases of radioactive fugitive dust from Area G. Atmospheric transport models will be used to predict areas potentially affected by long-term dust deposition and atmospheric concentrations. The analysis is in support of the Radioactive Air Emissions Management (RAEM) program's characterization of radioactive air emissions from waste sites to assure compliance with the National Emission Standards for Hazardous Air Pollutants (NESHAP) for radionuclides.

The soil covering the mesa is classified as a Hackroy sandy loam. It varies in thickness from 3-4 feet at the interior of the mesa and thins out near the canyon rims. The layer of volcanic rock immediately underneath the surface soils is ashfall material called the Bandelier tuff that includes pumiceous tuff and weathered rhyolitic tuff. The disturbed tuff is subject to wind erosion when it is exposed. The tuff at the surface has a moisture range from 2% to 8% (by weight), with the moisture content decreasing with depth. Below 10 ft., the moisture content ranges from 0.5% to 2%. The mesa contains stands of pinion and juniper as well as some underbrush. Overall, the vegetation is relatively sparse.

The surface winds at the site are variable, but the most common meteorology is a moderate SW up-valley wind during the day and either a light NW to N drainage wind or a moderate SW wind at night. The average wind speed is 2.9 m/sec (6 mph), with the most prevalent wind direction being south to southwest. The LANL area is semi-arid. The area gets 18 in. of annual precipitation with 40% occurring during July and August.

2.0

DESCRIPTION of SOURCES

There are several potential sources of windblown dust at Area G, including:

- Surface soils;
- Materials handling activities;
- Unpaved roads; and
- Paved roads.

Of these, only the first two sources are considered to be potential sources of radionuclides. The roads would contribute to radionuclide emissions only to the extent that radioactive contamination has been spilled or tracked onto the roadways.

Surface soils, whether as bare soil and in storage piles, are a source of windblown dust. The magnitude of emissions from surface soils will depend on the type and amount of vegetative cover present and the particle size distribution of the soil, as well as other factors such as soil moisture and wind speed.

There are three accepted mechanisms of particle movement: surface creep, saltation, and airborne suspension (Momeni, et al., 1979). Surface creep involves relatively large particles (i.e., 500-1000 μm diameter) that move along the surface due to the force of strong winds and/or impact of smaller particles. Saltation involves smaller particles (100-500 μm) that move about within a few centimeters of the ground surface but are quickly brought down by gravity. This "skipping" action is considered to account for the movement of the greatest mass of soil (Nicholson, 1988). Particles smaller than 100 μm may be picked up by turbulent winds and transported through the atmosphere. The smallest of these particles (<10 μm) may be suspended for extended periods of time.

For estimation purposes, soils are divided into limited and unlimited reservoirs of erodible material. Soils that covered with vegetation, rocks, or other nonerodible material have a limited reservoir of erodible particles. It requires a high threshold wind speed for wind erosion to occur from such surfaces and the emission rates tend to decrease rapidly during an erosion event. Uncovered soils of relatively small particle size are considered to be an unlimited reservoir of erodible particles. It requires a lower wind speed for erosion to occur and the emission rates are fairly independent of time at a given wind speed. Over time, an area may become depleted of erodible particles and a crust form that limits further erosion (e.g., desert pavement). Such soils are considered to be limited reservoirs.

The types of materials handling operations performed at Area G include such activities as excavation, dumping, and grading. The preparation of disposal pits requires excavation of surface soils and large volumes of tuff. The excavated material typically is placed nearby in temporary storage piles. Ultimately, the excavated material may be used as fill in the disposal pits. Thus, the same soil may be handled several times and each handling step may involve dumping the material. Elevated levels of particulate matter (PM) emissions are possible each time the soil is handled. Information on typical equipment and operating practices for material handling operations are available (Church, 1981 and U.S. EPA, 1991).

Site preparation activities often involve some amount of excavation, grading, etc. to construct roadways and prepare areas for storage domes, buildings, and support equipment. While site preparation tends to be limited to non-contaminated areas, PM emissions are still likely to occur and some tracking of contaminated material into clean areas may inadvertently take place.

Multiple potential emission points exist for each of the various soils handling operations. For excavation, the main emission points of concern are emissions from:

- Exposed soil/tuff in the excavation pit;
- Material as it is dumped from the excavation bucket; and
- Soil/tuff in short-term storage piles.

In addition, emissions of particulate matter will also occur from the engines of the earth-moving equipment, but these are, of course, non-radioactive emissions.

Particulate matter (PM) emissions will depend primarily on the particle size distribution of the soil, its moisture content, the wind speed, and the operating practices that are followed. The magnitude of emissions from soils handling operations will vary with the operating conditions. The longer or more energetic the moving and handling, the greater likelihood that PM emissions will occur. The rate of excavation and dumping, the drop height, the amount of exposed surface area, the length of time that the soil is exposed, the shape of the storage piles, and the dryness of the surface soil layers will all influence the levels of PM emissions. As the volume of soil/tuff handled per handling step, the lower the emissions per ton of throughput (Vissler, 1992).

A number of methods are available for controlling particulate matter emissions from soils. Compared to point source controls, emission controls for excavation and other area sources are difficult to implement and only moderately effective. Emission controls for soil area sources include (Eklund, et al., 1992):

- Covers and physical barriers;
- Temporary and long-term foam covers;
- Water sprays;
- Water sprays with additives;
- Operational controls;
- Complete enclosures;
- Wind screens; and
- Collection hoods.

Control of emissions can also be achieved by controlling the operating conditions within preset parameters. Reductions in emissions can be achieved by identifying and operating within acceptable ranges of operating conditions.

3.0 ESTIMATION OF PARTICULATE MATTER AIR EMISSIONS

Available models were reviewed for applicability to Area G. One approach to estimating emissions of dust-borne radionuclides is through the use of resuspension factors (U.S. EPA, 1992). Measurements of the ambient concentration of a given contaminant at some height above the ground can be related to the measured concentration of that contaminant in the surface soil to develop a resuspension factor:

$$K = C_a/C_s \quad (\text{Eq. 1})$$

where: K = Resuspension factor (m-1);
 C_a = Concentration in air ($\mu\text{g}/\text{m}^3$ or pCi/m^3); and
 C_s = Concentration in soil ($\mu\text{g}/\text{m}^2$ or pCi/m^2).

Momeni, et al. report resuspension factors of $10^{-7}/\text{m}$ to $10^{-3}/\text{m}$ for freshly deposited contaminants and $10^{-9}/\text{m}$ for aged contaminants. Resuspension factors, however, have been found to vary over a very wide range; more than six orders of magnitude for wind erosion and over more than eight orders of magnitude for activities such as excavation (Nicholson, 1988). This large variability makes resuspension factors of dubious value for estimating emissions and, of course, the resuspension factor reflects the ratio of concentrations and does not provide any information about the rate of emissions.

In theory, one could develop a resuspension rate by ratioing the vertical flux of a contaminant (F_v , in $\text{g}/\text{m}^2\text{-sec}$) to the surface concentration. An emission rate could be determined in the surface area of the source is known:

$$E = R C_s A \quad (\text{Eq. 2})$$

where: E = Emission rate (g/sec);
 R = Resuspension rate (s^{-1}) = $F_v * C_s$; and
 A = Surface area of source (m^2).

Resuspension rates also have been found to vary over a very wide range (i.e., four to six orders of magnitude), even at a single field location (Nicholson, 1988). It should be noted that C_s will vary with the depth of soil sampled and there is no standard definition of what constitutes a "surface soil". Despite the limitations with this approach, the U.S. Nuclear Regulatory Commission (NRC, 1987) employs a resuspension rate in its guidance for estimating emissions from uranium milling operations.

An alternative approach is to use empirical emission factors or predictive equations based on measurements of wind erosion of soils. For agricultural soils, the U.S. Soil Conservation Service (SCS) has published an equation for estimating annual erosion losses using average annual climatic data (U.S. EPA, 1988). The SCS equation is based on several dimensionless factors - soil erodibility, soil ridge roughness factor, vegetative cover factor, climatic factor - that are read from tables or figures that are compilations of nationwide data. The SCS model estimates soil losses due to surface creep, saltation, and suspension and therefore the estimates include soil mass that would not be transportable over significant distances by wind. The SCS model appears to be best suited for determining the approximate amount of soil lost for different crop types or for different regions of the country. Its applicability is suspect for estimating dust emissions from localized areas such as Area G.

The U.S. EPA has developed a series of predictive equations for estimating fugitive particulate matter emissions based on field studies performed by Cowherd and co-workers. These equations have become the standard predictive tool for regulatory purposes.

For estimating emissions from wind erosion, emission flux models are available for both unlimited and limited reservoirs. The unlimited reservoir model is:

Emission flux for respirable particles $\leq 10\mu\text{m}$ (PM_{10}):

$$E_{10} = 0.036 (1-V) \left(\frac{[u]}{u_t} \right)^3 F(X) C \quad (\text{Eq.3})$$

where

E_{10}	=	PM_{10} annual average emission flux of component i, $\text{g/m}^2\text{-h}$
V	=	Fraction of contaminated surface with continuous vegetative cover (equals 0 for bare soil)
$[u]$	=	Mean annual windspeed at 10 m anemometer height, m/s (from local climatological data)
u_t	=	Equivalent threshold value of windspeed at 7 m anemometer height, m/s (Equation No. 4)
C	=	Fractional percent by weight of component i from bulk samples of surface material
$F(x)$	=	Function obtained from the relationship in Figure 1 ($x=0.886 u_t/[u]$, dimensionless ratio).

Calculation of the equivalent threshold value of windspeed at a 7 m anemometer height (u_t):

$$u_t = 18.1 (u^*_t)/100 \quad (\text{Eq. 4})$$

where

u_t	=	Equivalent threshold value of windspeed at a 7 m anemometer height, m/s
(u^*_t)	=	Threshold friction velocity corrected for nonerodible elements, cm/s

A different set of equations are used for a finite reservoir of erodible material. The applicable equation from AP-42 is:

$$P = 58 (u^* - u^*_t)^2 + 25 (u^* - u^*_t) \quad (\text{Eq. 5})$$

where:

P	=	erosion potential (g/m^2);
u^*	=	friction velocity (m/sec); and
u^*_t	=	threshold friction velocity (m/sec).

Equation 5 yields the erosion potential between disturbance episodes. Each time the soil surface is disturbed, an emission event can occur. The friction velocity term in Equation 5 can be calculated as follows:

NOTE: If $x > 2$,
 $F(x) = 0.18 (8x^3 + 12x) e^{-x^2}$

Figure 1. Function curve used in "unlimited reservoir" model.

$$u^* = u^{10+} (0.053) \quad (\text{Eq. 6})$$

where: u^{10+} = fastest mile wind speed between disturbances (m/sec).

The mean atmospheric wind speeds typically are insufficient to sustain wind erosion from flat surfaces, but wind gust may quickly erode a substantial portion of the erodible material (U.S. EPA, 1985). The fastest mile is the meteorological variable that best approximates the magnitude of wind gusts.

The threshold friction velocity is dependent on the particle size distribution and can be determined from Figure 2.

The particle size multiplier, k, for several sizes of particles for use with Equation 5 are:

size (microns)	multiplier, k
< 30	1.0
< 15	0.6
< 10	0.5
< 2.5	0.2

Figure 3 illustrates the decisions required to choose between the finite and infinite models. AP-42 provides more detailed information on the finite and infinite models and should be reviewed if further information is needed.

The finite model is considered applicable for Area G given the presence of a crust and the particle size distribution of the surface soils. Like most soils in arid climates, the surface soils at Area G have become depleted of smaller size soil particles and a crust has formed that limits further erosion. An extreme example of this phenomena is "desert pavement" where winds strip away all small soil particles and the resulting soil surface closely resembles concrete pavement.

The emissions of PM from all drop operations, such as adding to storage piles or truck dumping, are expressed in Equation 7 (Eklund, et al., 1993):

$$E = \frac{k (0.0016)(M) \left(\frac{U}{2.2} \right)^{1.3}}{\left(\frac{X_{H_2O}}{2} \right)^{1.4}} \quad (\text{Eq. 7})$$

where E = PM emissions [g];
k = particle size multiplier [unitless];

Figure 2. Threshold friction velocity versus aggregate size distribution.

Figure 3. Decision flowchart.

0.0016 = empirical constant [g/Kg]; and
 M = mass of waste handled [Kg];
 U = mean wind speed [m/sec];
 2.2 = empirical constant [m/sec]; and
 X_{H2O} = percent moisture content [%].

The particle size multiplier, k, for several sizes of particles for use with Equation 7 are:

size (microns)	multiplier, k
< 30	0.74
< 15	0.48
< 10	0.35
< 5	0.20
< 2.5	0.11

Total suspended particulates (TSP) from wind erosion of continuously active piles can be estimated as:

$$EF = 1.9 \left(\frac{s}{15} \right) \frac{(365 - p)}{235} \left(\frac{f}{15} \right) \quad (\text{Eq. 8})$$

where EF = PM emission factor (g/m²-day);
 0.19 = empirical constant (g/m²-day);
 s = percentage silt of aggregate (%);
 1500 = empirical constant (unitless);
 365 = no. of days/year (days);
 p = number of days of precipitation > 0.01 inch per year (days);
 235 = empirical constant (days);
 f = fraction of time wind > 5.4 m/sec at mean pile height (unitless); and
 15 = empirical constant (unitless).

The fraction of TSP that is PM₁₀ can be assumed to be 50%. The number of days of precipitation (p) for the Los Alamos area is about 90. Equation 8 is valid for piles that are active at least once per day.

For soil graded by a bulldozer or any other tractor with a blade, the following equation should be used to predict the PM₁₀ (particulate matter of less than 10 microns) emissions (Eklund and Albert, 1993):

$$ER = \frac{0.094 s^{1.5}}{X_{H_2O}^{1.4}} \quad (\text{Eq. 9})$$

where ER = PM₁₀ emission rate [g/sec];
 0.094 = empirical constant [g/sec];
 s = percent silt content [%]; and
 X_{H2O} = percent moisture content [%].

The emission rate of traffic on paved roads in grams per vehicle kilometers traveled (VKT) is given by:

$$EF = 220 \left(\frac{sL}{12} \right)^{0.3} \quad (\text{Eq. 10})$$

where EF = PM₁₀ emission factor [g/VKT];
 220 = empirical constant [g/VKT];
 sL = silt surface loading [g/m²];
 12 = empirical constant [g/m²]; and
 0.3 = empirical constant [unitless].

For unpaved roads, the PM₁₀ emission model is given by:

$$EF = 610 \left(\frac{s}{12} \right) \left(\frac{S}{48} \right) \left(\frac{W}{2.7} \right)^{0.7} \left(\frac{w}{4} \right)^{0.5} \frac{(365 - p)}{365} \quad (\text{Eq. 11})$$

where EF = PM₁₀ emission factor [g/VKT];
 610 = empirical constant [g/VKT];
 s = percent silt content of road surface [%];
 12 = empirical constant [unitless];
 S = mean vehicle speed [km/hr];
 48 = empirical constant [km/hr];
 W = mean vehicle weight [Mg];
 2.7 = empirical constant [Mg];
 w = mean number of wheels per vehicle [unitless];
 4 = empirical constant [unitless];
 365 = no. of days per year [days]; and
 p = number of days with < 0.01 inches precipitation [days] = 90 for Los Alamos based on the information given in AP-42.

The emission factors can be converted into a total mass emitted if multiplied by the number of vehicle kilometers traveled or they can be readily converted to an emission rate.

Default values for use with the above equations are given in Tables 1 and 2. The default values should be used only when site-specific data are unavailable. The fraction of TSP made up of PM₁₀ can be estimated to be 0.5.

If the dust is contaminated, the PM or PM₁₀ emission rates given in this document may be translated to emission rates of the contaminant as follows:

$$EF_i = X_i EF \quad (\text{Eq. 12})$$

where EF_i = emission factor of contaminant i [g/VKT]; and
 X_i = fraction of contaminant i in particulate matter [unitless].

In general, the dust and silt at a site will contain a higher fraction of the metal species than the bulk soil at the site; i.e. the particulate matter is enriched with the metals. Therefore, X_i is equal to:

$$X_i = C Z 10^{-6} \quad (\text{Eq. 13})$$

where C = concentration of metal in the bulk soil [$\mu\text{g/g}$];
 Z = enrichment factor [unitless]; and
 10^{-6} = conversion factor [$\text{g}/\mu\text{g}$].

Table 1.
Default Values for Estimating Emissions from Materials Handling

Parameter	Symbol	Units	Default Value	Expected Range	Reference
Mean wind speed	U	m/sec	4.4	0 - 4.47	*
Moisture content	X _{H2O}	%	10	--	*
Silt content	s	%	8 (< 75 μ m)	2 - 20	7
Silt surface loading	sL	g/m ²	5	0.3 - 30	7
Mean vehicle speed	S	km/hr	20	8 - 45	7
Mean vehicle weight	W	Mg	3 (plant vehicle)	2 - 9	7
			20 (Commercial haulers)	9 - 45	7
			30 (plant haul trucks)	20 - 50	7
Mean # of wheels	w	unitless	10	4 - 18	7

* = Author's estimate.

Table 2.
Default Values for Estimating PM Emissions from Other Area Sources

Parameter	Symbol	Units	Default Value	Expected Range	Reference
Erosion potential	P _t	g/m ²	33	0 - 525	7
Percentage of silt	s	%	2.2	0.44 - 19	7
Fraction of time with high winds	f	unitless	20	Site specific	--
Wind speed	U	m/sec	4.4	0.6 - 6.7	7

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APPENDIX B

Example Calculations of Fugitive Dust Emissions

[40] From: Bart Eklund 10/27/94 1:18PM (6711 bytes: 165 ln)
To: Bart Eklund
Subject: Example Calculations - LANL Area G dust emissions estimates
----- Message Contents -----

1. Dust from paved roads - Ignore. Assume road dust has no radionuclides.
2. Dust from unpaved roads - Ignore. Assume dust has no radionuclides.
3. Dust from open areas -

Given particle size distribution and presence of crust, the EPA finite reservoir of erodible material model is applicable.

$$P \text{ (g/m}^2\text{)} = 58(u^* - u^*_t)\exp^2 + 25(u^* - u^*_t)$$

u^* = friction velocity (m/sec)

u^*_t = threshold friction velocity (m/sec)

$$u^* = u_{10+}(0.053)$$

u_{10+} = fastest mile wind speed between disturbances
(m/sec)

LANL previously supplied a fastest mile wind speed value of 25.4 m/sec.

$$u^* = (25.4 \text{ m/sec})(0.053) = 1.35 \text{ m/sec}$$

u^*_t is dependent on the particle size distribution. Looking at a PSD for the surface soil samples collected by me in Sept '93, the mean particle size is 26 μm (0.026 mm). Looking at Cowherd's look-up chart, this corresponds to a u^*_t value of about 15 cm/sec or 0.15 m/sec.

So, we can plug in the values and find the erosion potential:

$$\begin{aligned} P &= 58(1.35-0.15)\exp^2 + 25(1.35-0.15) \\ &= 114 \text{ g/m}^2 \end{aligned}$$

Now estimate the time between disturbances and the fraction of Area G that is covered with "non-erodible elements" such as buildings, plants, and large rocks. How often does someone drive over the average open space off-road? I assume once per year on average for the full 60 acre site. I also assume that 50% of Area G is covered with roads, buildings, rocks, and plants. So, the emission estimate is:

$$\begin{aligned} &(114 \text{ g/m}^2)(60 \text{ acres})(4047 \text{ m}^2/\text{acre})(1 \text{ disturb/yr})(0.50 \text{ open}) \\ &= 13,800,000 \text{ g/yr} = 0.438 \text{ g/sec} \end{aligned}$$

13,800 kg/yr equals about 9.2 cubic meters of soil.

Obviously, the estimate is highly dependent on the assumption of one disturbance episode per year. If this were one per month, the dust emissions would be 12x higher.

According to the 1993 soil sampling results provided by LANL, 42 samples were collected and results are reported for tritium in each sample and for uranium and cesium-137 in 22 of the samples (it is not clear if the others were analyzed and had ND, or weren't analyzed). The average values are:

tritium = 19,500 pCi/L = 0.975 pCi/g
uranium = 1.62 ug/g
cesium-137 = 0.213 pCi/g

Note the units differ. My conversion of the tritium units assumes the soil is 5% moisture. Also, this tritium spread via windblown dust is separate and distinct from the emissions of tritiated water we measured w/flux chambers. Both contribute to air impacts.

What else is in the soil? Work previously summarized by Mike Porto of Radian is given below (except where they have been superseded by the '93 soils data):

Pu-238 = 0.005 pCi/g
Pu-239,240 = 0.025 pCi/g
Sr-90 = 0.88 pCi/g

For comparison to the '93 soils data, the old values were tritium at 7,200 pCi/L, Cs-137 at 1.09 pCi/g and uranium at 3.4 uCi/g.

These above concs. can be multiplied by the erosion potential to get the avg. emission rate. For example, for Pu-238 we get (0.438 g/sec)(0.005 pCi/g) = 0.00219 pCi/sec. The input data are:

@@

input data EMISSION RATES

tritium = 0.427 pCi/sec
Uranium = 0.710 ug/sec (=1.49 uCi/sec using old
soils data)
Cesium-137 = 0.0933 pCi/sec
Pu-238 = 0.0022 pCi/sec
Pu-239,240 = 0.011 pCi/sec
Sr-90 = 0.39 pCi/sec

Note different units for uranium (even for old soils data)

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With about 3.15exp07 sec/yr, the emissions appear to be well under a Curie.

4. Dust emissions from Materials Handling (excavation, dumping, etc.

Using the AP-42 factor:

$$E \text{ (lb/ton)} = k(0.0032) (U/5) \exp 1.3 / \{ (M/2) \exp 1.4 \} * (V)$$

k = particle size multiplier = 0.74 for TSP

U = wind speed (mph)

M = moisture content of material (%)

V = amount of material dropped/moved (tons)

Average wind speed is 6.3 mph according to '92 Env. Surveillance report. Typical moisture content of tuff is very low, I assume 2% (below 10' below ground, the tuff averages even lower 0.5 - 2%). So, the emissions are:

$$E \text{ (lb/ton)} = (0.74) (0.0032) (6.3/5) \exp 1.3 / (2/2) \exp 1.4 * V \\ = 0.00320 * V$$

$$E \text{ (g/ton)} = (0.00320) (454 \text{ g/lb}) * V = 1.45 * V$$

Given the large amount of activity going on at the site at present, I estimate the activity rate at 100,000 tons/yr. I then doubled it to 200,000 tons/yr to account for the fact that the soil tends to be dumped twice before it reaches its final resting place.

$$E \text{ (g/ton)} = 1.45 * 200,000 = 290,000 \text{ g} = 290 \text{ kg}$$

290 kg over one year = 0.00920 g/sec. Using the same soil concentrations as above, the emission rates are:

@@

input data Emission Rates for Excavation

Dust 0.0092 g/sec

Tritium = 0.00897 pCi/sec

Uranium = 0.0149 ug/sec (0.0313 uCi/g using
old soils data)

Cs-137 = 0.00196 pCi/sec

Pu-238 = 0.000046 pCi/sec

Pu-239,240 = 0.00023 pCi/yr

Sr-90 = 0.0081 pCi/yr

Note different units for uranium, even when using old soils data.

@@

APPENDIX C

Output for CAP88 Modeling Runs

Normalized tritium concentration data ("Chi/Q") for the receptor grid surrounding Area G are shown in Table C-1. Tables C-2, C-4, and C-6 contain normalized particulate matter concentrations for the receptor grid surrounding Area G for Pa-234, Ba-137, and all other particulate matter, respectively. The normalized concentrations are the actual concentrations predicted by the model divided by the initial emission rate. The resulting normalized concentrations can be used to determine the downwind concentrations for any emission rate. The CAP88-PC model determines different Chi/Q values for Ba-137M and Pa-234 because these are daughter products with relatively short half-lives. Therefore, it is not expected that these materials will have a significant effect over long travel times or distances.

Normalized deposition values (D/Q) for particulate matter are shown in Tables C-3, C-5, and C-7 for Pa-234, Ba-137, and all other particulate matter, respectively. The CAP88-PC model assumes no deposition for any gaseous material, therefore, there are no D/Q values for tritium. However, for all particulate matter except iodine, CAP88-PC applies a deposition velocity of $1.8\text{E-}03$ m/s, to determine the deposition values from the Chi/Q values. The iodine deposition velocity is $3.5\text{E-}02$ m/s. As with the particulate Chi/Q values, and for the same reasons, CAP88-PC determines different D/Q values for Ba-137M and Pa-234.

Table C-1

Normalized Concentrations for Tritium

(sec/m³)

Dist. (m)	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	E	ENE	NE	NNE
500	5.593e-06	3.338e-06	2.589e-06	2.965e-06	3.766e-06	5.946e-06	8.900e-06	1.220e-05	1.473e-05	1.995e-05	2.381e-05	2.372e-05	1.786e-05	1.354e-05	1.088e-05	8.802e-06
1200	1.006e-06	5.206e-07	4.785e-07	4.956e-07	7.251e-07	9.288e-07	1.858e-06	2.386e-06	2.927e-06	3.398e-06	5.563e-06	4.689e-06	3.582e-06	2.210e-06	2.342e-06	1.826e-06
1409	7.581e-07	3.853e-07	3.597e-07	3.675e-07	5.449e-07	6.865e-07	1.418e-06	1.819e-06	2.238e-06	2.566e-06	4.306e-06	3.586e-06	2.742e-06	1.661e-06	1.799e-06	1.394e-06
1957	4.367e-07	2.195e-07	2.043e-07	2.064e-07	3.073e-07	3.894e-07	8.171e-07	1.057e-06	1.305e-06	1.498e-06	2.516e-06	2.094e-06	1.600e-06	9.681e-07	1.047e-06	8.074e-07
2081	3.939e-07	1.976e-07	1.838e-07	1.854e-07	2.762e-07	3.502e-07	7.372e-07	9.555e-07	1.180e-06	1.355e-06	2.275e-06	1.893e-06	1.447e-06	8.752e-07	9.459e-07	7.290e-07
3396	1.776e-07	8.750e-08	8.135e-08	8.044e-08	1.207e-07	1.541e-07	3.337e-07	4.389e-07	5.449e-07	6.265e-07	1.055e-06	8.770e-07	6.701e-07	4.044e-07	4.349e-07	3.313e-07
4038	1.371e-07	6.705e-08	6.241e-08	6.113e-08	9.208e-08	1.177e-07	2.585e-07	3.426e-07	4.267e-07	4.911e-07	8.281e-07	6.880e-07	5.256e-07	3.168e-07	3.396e-07	2.569e-07
4213	1.287e-07	6.282e-08	5.850e-08	5.717e-08	8.619e-08	1.102e-07	2.428e-07	3.224e-07	4.019e-07	4.627e-07	7.804e-07	6.483e-07	4.953e-07	2.984e-07	3.197e-07	2.414e-07
4858	1.041e-07	5.052e-08	4.710e-08	4.570e-08	6.910e-08	8.846e-08	1.969e-07	2.630e-07	3.287e-07	3.787e-07	6.395e-07	5.310e-07	4.056e-07	2.441e-07	2.609e-07	1.959e-07
4956	1.011e-07	4.900e-08	4.570e-08	4.429e-08	6.699e-08	8.577e-08	1.912e-07	2.556e-07	3.196e-07	3.683e-07	6.219e-07	5.164e-07	3.944e-07	2.373e-07	2.536e-07	1.902e-07
5234	9.321e-08	4.508e-08	4.207e-08	4.066e-08	6.157e-08	7.886e-08	1.765e-07	2.364e-07	2.959e-07	3.411e-07	5.763e-07	4.784e-07	3.654e-07	2.197e-07	2.346e-07	1.756e-07
5860	7.881e-08	3.795e-08	3.546e-08	3.408e-08	5.173e-08	6.629e-08	1.496e-07	2.012e-07	2.523e-07	2.910e-07	4.921e-07	4.084e-07	3.119e-07	1.874e-07	1.997e-07	1.488e-07
5924	7.755e-08	3.733e-08	3.488e-08	3.351e-08	5.087e-08	6.519e-08	1.472e-07	1.981e-07	2.485e-07	2.866e-07	4.847e-07	4.022e-07	3.072e-07	1.846e-07	1.966e-07	1.465e-07
7089	5.943e-08	2.842e-08	2.662e-08	2.535e-08	3.863e-08	4.952e-08	1.132e-07	1.534e-07	1.929e-07	2.227e-07	3.772e-07	3.129e-07	2.389e-07	1.433e-07	1.523e-07	1.126e-07
7333	5.665e-08	2.723e-08	2.566e-08	2.457e-08	3.741e-08	4.760e-08	1.080e-07	1.462e-07	1.840e-07	2.125e-07	3.598e-07	2.984e-07	2.279e-07	1.367e-07	1.452e-07	1.073e-07
7760	5.213e-08	2.506e-08	2.368e-08	2.266e-08	3.452e-08	4.383e-08	9.955e-08	1.349e-07	1.699e-07	1.962e-07	3.325e-07	2.757e-07	2.105e-07	1.263e-07	1.340e-07	9.879e-08
8583	4.497e-08	2.162e-08	2.052e-08	1.963e-08	2.992e-08	3.785e-08	8.606e-08	1.169e-07	1.474e-07	1.704e-07	2.889e-07	2.395e-07	1.828e-07	1.096e-07	1.161e-07	8.530e-08
10232	3.484e-08	1.677e-08	1.606e-08	1.535e-08	2.344e-08	2.942e-08	6.704e-08	9.151e-08	1.158e-07	1.340e-07	2.275e-07	1.885e-07	1.438e-07	8.609e-08	9.088e-08	6.622e-08
10475	3.377e-08	1.625e-08	1.560e-08	1.490e-08	2.277e-08	2.853e-08	6.508e-08	8.892e-08	1.126e-07	1.304e-07	2.214e-07	1.834e-07	1.399e-07	8.374e-08	8.832e-08	6.420e-08

Table C-2
Normalized Concentrations for Pa-234 Particulate Matter
 (sec/m³)

Dist.	(m)	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	E	ENE	NE	NNE
500	5.179e-06	3.036e-06	2.312e-06	2.607e-06	3.305e-06	5.202e-06	7.800e-06	1.067e-05	1.289e-05	1.753e-05	2.088e-05	2.085e-05	1.583e-05	1.228e-05	1.002e-05	8.143e-06	8.143e-06
1200	8.905e-07	4.552e-07	3.940e-07	4.124e-07	5.860e-07	7.621e-07	1.517e-06	1.962e-06	2.381e-06	2.789e-06	4.601e-06	3.779e-06	3.020e-06	1.923e-06	2.063e-06	1.645e-06	1.645e-06
1409	6.634e-07	3.332e-07	2.904e-07	3.009e-07	4.311e-07	5.534e-07	1.137e-06	1.473e-06	1.788e-06	2.072e-06	3.508e-06	2.834e-06	2.281e-06	1.430e-06	1.567e-06	1.247e-06	1.247e-06
1957	3.732e-07	1.847e-07	1.583e-07	1.623e-07	2.320e-07	3.010e-07	6.297e-07	8.252e-07	1.003e-06	1.165e-06	1.977e-06	1.588e-06	1.289e-06	8.118e-07	8.903e-07	7.078e-07	7.078e-07
2081	3.352e-07	1.654e-07	1.414e-07	1.446e-07	2.066e-07	2.686e-07	5.639e-07	7.406e-07	9.002e-07	1.046e-06	1.776e-06	1.426e-06	1.158e-06	7.303e-07	8.010e-07	6.367e-07	6.367e-07
3396	1.445e-07	6.944e-08	5.779e-08	5.792e-08	8.227e-08	1.087e-07	2.365e-07	3.176e-07	3.864e-07	4.510e-07	7.708e-07	6.125e-07	5.058e-07	3.214e-07	3.520e-07	2.787e-07	2.787e-07
4038	1.089e-07	5.170e-08	4.244e-08	4.214e-08	5.966e-08	7.939e-08	1.757e-07	2.386e-07	2.906e-07	3.400e-07	5.830e-07	4.606e-07	3.836e-07	2.449e-07	2.681e-07	2.117e-07	2.117e-07
4213	1.017e-07	4.814e-08	3.942e-08	3.903e-08	5.524e-08	7.361e-08	1.636e-07	2.229e-07	2.715e-07	3.179e-07	5.456e-07	4.305e-07	3.592e-07	2.295e-07	2.511e-07	1.980e-07	1.980e-07
4858	8.072e-08	3.783e-08	3.068e-08	3.011e-08	4.251e-08	5.695e-08	1.285e-07	1.768e-07	2.156e-07	2.529e-07	4.353e-07	3.421e-07	2.873e-07	1.840e-07	2.012e-07	1.582e-07	1.582e-07
4956	7.813e-08	3.656e-08	2.961e-08	2.903e-08	4.096e-08	5.491e-08	1.242e-07	1.711e-07	2.086e-07	2.448e-07	4.216e-07	3.311e-07	2.783e-07	1.784e-07	1.950e-07	1.532e-07	1.532e-07
5234	7.145e-08	3.331e-08	2.686e-08	2.624e-08	3.698e-08	4.968e-08	1.130e-07	1.563e-07	1.906e-07	2.238e-07	3.860e-07	3.026e-07	2.551e-07	1.637e-07	1.789e-07	1.405e-07	1.405e-07
5860	5.927e-08	2.740e-08	2.188e-08	2.123e-08	2.982e-08	4.026e-08	9.272e-08	1.292e-07	1.576e-07	1.854e-07	3.204e-07	2.501e-07	2.123e-07	1.367e-07	1.494e-07	1.172e-07	1.172e-07
5924	5.821e-08	2.689e-08	2.144e-08	2.079e-08	2.921e-08	3.944e-08	9.094e-08	1.268e-07	1.547e-07	1.820e-07	3.147e-07	2.455e-07	2.085e-07	1.344e-07	1.468e-07	1.151e-07	1.151e-07
7089	4.299e-08	1.958e-08	1.530e-08	1.469e-08	2.048e-08	2.792e-08	6.557e-08	9.262e-08	1.128e-07	1.331e-07	2.312e-07	1.789e-07	1.540e-07	1.000e-07	1.094e-07	8.575e-08	8.575e-08
7333	4.073e-08	1.863e-08	1.464e-08	1.415e-08	1.970e-08	2.660e-08	6.196e-08	8.750e-08	1.065e-07	1.257e-07	2.185e-07	1.689e-07	1.457e-07	9.474e-08	1.036e-07	8.124e-08	8.124e-08
7760	3.707e-08	1.691e-08	1.326e-08	1.280e-08	1.778e-08	2.399e-08	5.603e-08	7.939e-08	9.657e-08	1.141e-07	1.986e-07	1.532e-07	1.327e-07	8.645e-08	9.454e-08	7.411e-08	7.411e-08
8583	3.129e-08	1.421e-08	1.107e-08	1.067e-08	1.476e-08	1.988e-08	4.667e-08	6.653e-08	8.082e-08	9.562e-08	1.669e-07	1.282e-07	1.119e-07	7.323e-08	8.013e-08	6.280e-08	6.280e-08
10232	2.319e-08	1.044e-08	8.023e-09	7.715e-09	1.058e-08	1.421e-08	3.365e-08	4.856e-08	5.885e-08	6.985e-08	1.226e-07	9.327e-08	8.273e-08	5.463e-08	5.987e-08	4.690e-08	4.690e-08
10475	2.235e-08	1.005e-08	7.720e-09	7.415e-09	1.016e-08	1.364e-08	3.236e-08	4.682e-08	5.678e-08	6.744e-08	1.185e-07	9.004e-08	8.000e-08	5.285e-08	5.788e-08	4.524e-08	4.524e-08

Table C-3

Normalized Depositions for Pa-234 Particulate Matter

(m⁻²)

Dist. (m)	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSe	SE	ESE	E	ENE	NE	NNE
500	9.322e-09	5.465e-09	4.162e-09	4.693e-09	5.949e-09	9.364e-09	1.404e-08	1.921e-08	2.320e-08	3.155e-08	3.758e-08	3.753e-08	2.849e-08	2.210e-08	1.804e-08	1.466e-08
1200	1.603e-09	8.194e-10	7.092e-10	7.423e-10	1.055e-09	1.372e-09	2.731e-09	3.532e-09	4.286e-09	5.020e-09	8.282e-09	6.802e-09	5.436e-09	3.461e-09	3.713e-09	2.961e-09
1409	1.194e-09	5.998e-10	5.227e-10	5.416e-10	7.760e-10	9.961e-10	2.047e-09	2.651e-09	3.218e-09	3.730e-09	6.314e-09	5.101e-09	4.106e-09	2.574e-09	2.821e-09	2.245e-09
1957	6.718e-10	3.325e-10	2.849e-10	2.921e-10	4.176e-10	5.418e-10	1.133e-09	1.485e-09	1.805e-09	2.097e-09	3.559e-09	2.858e-09	2.320e-09	1.461e-09	1.603e-09	1.274e-09
2081	6.034e-10	2.977e-10	2.545e-10	2.603e-10	3.719e-10	4.835e-10	1.015e-09	1.333e-09	1.620e-09	1.883e-09	3.197e-09	2.567e-09	2.084e-09	1.315e-09	1.442e-09	1.146e-09
3396	2.601e-10	1.250e-10	1.040e-10	1.043e-10	1.481e-10	1.957e-10	4.257e-10	5.717e-10	6.955e-10	8.118e-10	1.387e-09	1.103e-09	9.104e-10	5.785e-10	6.336e-10	5.017e-10
4038	1.960e-10	9.306e-11	7.639e-11	7.585e-11	1.074e-10	1.429e-10	3.163e-10	4.295e-10	5.231e-10	6.120e-10	1.049e-09	8.291e-10	6.905e-10	4.408e-10	4.826e-10	3.811e-10
4213	1.831e-10	8.665e-11	7.096e-11	7.025e-11	9.943e-11	1.325e-10	2.945e-10	4.012e-10	4.887e-10	5.722e-10	9.821e-10	7.749e-10	6.466e-10	4.131e-10	4.520e-10	3.564e-10
4858	1.453e-10	6.809e-11	5.522e-11	5.420e-11	7.652e-11	1.025e-10	2.313e-10	3.182e-10	3.881e-10	4.552e-10	7.835e-10	6.158e-10	5.171e-10	3.312e-10	3.622e-10	2.848e-10
4956	1.406e-10	6.581e-11	5.330e-11	5.225e-11	7.373e-11	9.884e-11	2.236e-10	3.080e-10	3.755e-10	4.406e-10	7.589e-10	5.960e-10	5.009e-10	3.211e-10	3.510e-10	2.758e-10
5234	1.286e-10	5.996e-11	4.835e-11	4.723e-11	6.656e-11	8.942e-11	2.034e-10	2.813e-10	3.431e-10	4.028e-10	6.948e-10	5.447e-10	4.592e-10	2.947e-10	3.220e-10	2.529e-10
5860	1.067e-10	4.932e-11	3.938e-11	3.821e-11	5.368e-11	7.247e-11	1.669e-10	2.326e-10	2.837e-10	3.337e-10	5.767e-10	4.502e-10	3.821e-10	2.461e-10	2.689e-10	2.110e-10
5924	1.048e-10	4.840e-11	3.859e-11	3.742e-11	5.258e-11	7.099e-11	1.637e-10	2.282e-10	2.785e-10	3.276e-10	5.665e-10	4.419e-10	3.753e-10	2.419e-10	2.642e-10	2.072e-10
7089	7.738e-11	3.524e-11	2.754e-11	2.644e-11	3.686e-11	5.026e-11	1.180e-10	1.667e-10	2.030e-10	2.396e-10	4.162e-10	3.220e-10	2.772e-10	1.800e-10	1.969e-10	1.544e-10
7333	7.331e-11	3.353e-11	2.635e-11	2.547e-11	3.546e-11	4.788e-11	1.115e-10	1.575e-10	1.917e-10	2.263e-10	3.933e-10	3.040e-10	2.623e-10	1.705e-10	1.865e-10	1.462e-10
7760	6.673e-11	3.044e-11	2.387e-11	2.304e-11	3.200e-11	4.318e-11	1.009e-10	1.429e-10	1.738e-10	2.054e-10	3.575e-10	2.758e-10	2.389e-10	1.556e-10	1.702e-10	1.334e-10
8583	5.632e-11	2.558e-11	1.993e-11	1.921e-11	2.657e-11	3.578e-11	8.401e-11	1.198e-10	1.455e-10	1.721e-10	3.004e-10	2.308e-10	2.014e-10	1.318e-10	1.442e-10	1.130e-10
10232	4.174e-11	1.879e-11	1.444e-11	1.389e-11	1.904e-11	2.558e-11	6.057e-11	8.741e-11	1.059e-10	1.257e-10	2.207e-10	1.679e-10	1.489e-10	9.833e-11	1.078e-10	8.442e-11
10475	4.023e-11	1.809e-11	1.390e-11	1.335e-11	1.829e-11	2.455e-11	5.825e-11	8.428e-11	1.022e-10	1.214e-10	2.133e-10	1.621e-10	1.440e-10	9.513e-11	1.042e-10	8.143e-11

Table C-4

Normalized Concentrations for Ba-137

(sec/m³)

Dist. (m)	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	E	ENE	NE	NNE
500	2.233e-06	1.045e-06	5.305e-07	4.063e-07	4.498e-07	9.268e-07	1.861e-06	2.794e-06	3.364e-06	4.616e-06	5.470e-06	5.805e-06	4.909e-06	4.631e-06	4.244e-06	3.584e-06
1200	1.821e-07	6.642e-08	2.634e-08	1.973e-08	1.574e-08	2.720e-08	1.195e-07	2.353e-07	2.404e-07	2.334e-07	4.035e-07	3.114e-07	3.526e-07	2.793e-07	3.583e-07	3.555e-07
1409	1.114e-07	3.975e-08	1.525e-08	1.182e-08	9.189e-09	1.511e-08	7.022e-08	1.462e-07	1.502e-07	1.378e-07	2.380e-07	1.849e-07	2.069e-07	1.602e-07	2.143e-07	2.194e-07
1957	3.834e-08	1.377e-08	5.117e-09	4.092e-09	3.175e-09	5.209e-09	2.277e-08	5.094e-08	5.489e-08	4.732e-08	7.617e-08	6.301e-08	6.485e-08	4.906e-08	6.817e-08	7.357e-08
2081	3.086e-08	1.112e-08	4.122e-09	3.317e-09	2.572e-09	4.221e-09	1.821e-08	4.120e-08	4.488e-08	3.834e-08	6.102e-08	5.094e-08	5.159e-08	3.873e-08	5.407e-08	5.888e-08
3396	4.306e-09	1.628e-09	6.072e-10	5.053e-10	3.819e-10	6.355e-10	2.567e-09	6.143e-09	7.304e-09	5.986e-09	9.003e-09	7.749e-09	7.119e-09	4.933e-09	6.789e-09	7.760e-09
4038	1.904e-09	7.383e-10	2.782e-10	2.317e-10	1.719e-10	2.889e-10	1.168e-09	2.816e-09	3.435e-09	2.802e-09	4.184e-09	3.587e-09	3.244e-09	2.190e-09	2.930e-09	3.350e-09
4213	1.539e-09	6.010e-10	2.271e-10	1.891e-10	1.396e-10	2.353e-10	9.536e-10	2.301e-09	2.823e-09	2.301e-09	3.433e-09	2.939e-09	2.651e-09	1.779e-09	2.359e-09	2.692e-09
4858	7.208e-10	2.887e-10	1.103e-10	9.149e-11	6.649e-11	1.130e-10	4.631e-10	1.119e-09	1.396e-09	1.137e-09	1.693e-09	1.443e-09	1.292e-09	8.520e-10	1.095e-09	1.234e-09
4956	6.443e-10	2.591e-10	9.909e-11	8.216e-11	5.958e-11	1.014e-10	4.163e-10	1.006e-09	1.258e-09	1.024e-09	1.524e-09	1.298e-09	1.162e-09	7.646e-10	9.784e-10	1.100e-09
5234	4.706e-10	1.913e-10	7.343e-11	6.077e-11	4.380e-11	7.481e-11	3.086e-10	7.462e-10	9.373e-10	7.635e-10	1.136e-09	9.651e-10	8.626e-10	5.649e-10	7.139e-10	7.967e-10
5860	2.363e-10	9.829e-11	3.801e-11	3.131e-11	2.229e-11	3.834e-11	1.600e-10	3.868e-10	4.900e-10	3.992e-10	5.937e-10	5.024e-10	4.485e-10	2.914e-10	3.591e-10	3.933e-10
5924	2.206e-10	9.193e-11	3.558e-11	2.929e-11	2.083e-11	3.584e-11	1.497e-10	3.621e-10	4.590e-10	3.739e-10	5.561e-10	4.704e-10	4.199e-10	2.726e-10	3.353e-10	3.665e-10
7089	6.495e-11	2.813e-11	1.098e-11	8.960e-12	6.252e-12	1.087e-11	4.622e-11	1.119e-10	1.430e-10	1.165e-10	1.733e-10	1.456e-10	1.303e-10	8.408e-11	9.985e-11	1.051e-10
7333	5.075e-11	2.219e-11	8.749e-12	7.171e-12	5.076e-12	8.699e-12	3.651e-11	8.826e-11	1.129e-10	9.195e-11	1.369e-10	1.149e-10	1.028e-10	6.629e-11	7.826e-11	8.166e-11
7760	3.307e-11	1.465e-11	5.802e-12	4.751e-12	3.362e-12	5.750e-12	2.417e-11	5.844e-11	7.486e-11	6.100e-11	9.085e-11	7.613e-11	6.818e-11	4.390e-11	5.137e-11	5.281e-11
8583	1.473e-11	6.677e-12	2.661e-12	2.175e-12	1.540e-12	2.623e-12	1.104e-11	2.673e-11	3.430e-11	2.796e-11	4.168e-11	3.483e-11	3.125e-11	2.010e-11	2.320e-11	2.322e-11
10232	3.076e-12	1.445e-12	5.816e-13	4.740e-13	3.358e-13	5.672e-13	2.392e-12	5.811e-12	7.465e-12	6.093e-12	9.100e-12	7.568e-12	6.819e-12	4.388e-12	4.982e-12	4.753e-12
10475	2.458e-12	1.161e-12	4.678e-13	3.811e-13	2.698e-13	4.552e-13	1.924e-12	4.679e-12	6.017e-12	4.917e-12	7.347e-12	6.107e-12	5.502e-12	3.537e-12	4.009e-12	3.793e-12

Table C-5

Normalized Depositions for Ba-137 Particulate Matter

(m⁻²)

Dist. (m)	N	NNW	NW	NNW	W	WSW	SW	SSW	S	SSE	SE	ESE	E	ENE	NE	NNE
500	4.019e-09	1.881e-09	9.549e-10	7.313e-10	8.096e-10	1.668e-09	3.350e-09	5.029e-09	6.055e-09	8.309e-09	9.846e-09	1.045e-08	8.836e-09	8.336e-09	7.639e-09	6.451e-09
1200	3.278e-10	1.196e-10	4.741e-11	3.551e-11	2.833e-11	4.896e-11	2.151e-10	4.235e-10	4.327e-10	4.201e-10	7.263e-10	5.605e-10	6.347e-10	5.027e-10	6.449e-10	6.399e-10
1409	2.005e-10	7.155e-11	2.745e-11	2.128e-11	1.654e-11	2.720e-11	1.264e-10	2.632e-10	2.704e-10	2.480e-10	4.284e-10	3.328e-10	3.724e-10	2.884e-10	3.857e-10	3.949e-10
1957	6.901e-11	2.479e-11	9.211e-12	7.366e-12	5.715e-12	9.376e-12	4.099e-11	9.169e-11	9.880e-11	8.518e-11	1.371e-10	1.134e-10	1.167e-10	8.831e-11	1.227e-10	1.324e-10
2081	5.555e-11	2.002e-11	7.420e-12	5.971e-12	4.630e-12	7.598e-12	3.278e-11	7.416e-11	8.078e-11	6.901e-11	1.098e-10	9.169e-11	9.286e-11	6.971e-11	9.733e-11	1.060e-10
3396	7.751e-12	2.930e-12	1.093e-12	9.095e-13	6.874e-13	1.144e-12	4.621e-12	1.106e-11	1.315e-11	1.077e-11	1.621e-11	1.395e-11	1.281e-11	8.879e-12	1.222e-11	1.397e-11
4038	3.427e-12	1.329e-12	5.008e-13	4.171e-13	3.094e-13	5.200e-13	2.102e-12	5.069e-12	6.183e-12	5.044e-12	7.531e-12	6.457e-12	5.839e-12	3.942e-12	5.274e-12	6.030e-12
4213	2.770e-12	1.082e-12	4.088e-13	3.404e-13	2.513e-13	4.235e-13	1.716e-12	4.142e-12	5.081e-12	4.142e-12	6.179e-12	5.290e-12	4.772e-12	3.202e-12	4.246e-12	4.846e-12
4858	1.297e-12	5.197e-13	1.985e-13	1.647e-13	1.197e-13	2.034e-13	8.336e-13	2.014e-12	2.513e-12	2.047e-12	3.047e-12	2.597e-12	2.326e-12	1.534e-12	1.971e-12	2.221e-12
4956	1.160e-12	4.664e-13	1.784e-13	1.479e-13	1.072e-13	1.825e-13	7.493e-13	1.811e-12	2.264e-12	1.843e-12	2.743e-12	2.336e-12	2.092e-12	1.376e-12	1.761e-12	1.980e-12
5234	8.471e-13	3.443e-13	1.322e-13	1.094e-13	7.884e-14	1.347e-13	5.555e-13	1.343e-12	1.687e-12	1.374e-12	2.045e-12	1.737e-12	1.553e-12	1.017e-12	1.285e-12	1.434e-12
5860	4.253e-13	1.769e-13	6.842e-14	5.636e-14	4.012e-14	6.901e-14	2.880e-13	6.962e-13	8.820e-13	7.186e-13	1.069e-12	9.043e-13	8.073e-13	5.245e-13	6.464e-13	7.079e-13
5924	3.971e-13	1.655e-13	6.404e-14	5.272e-14	3.749e-14	6.451e-14	2.695e-13	6.518e-13	8.262e-13	6.730e-13	1.001e-12	8.467e-13	7.558e-13	4.907e-13	6.035e-13	6.597e-13
7089	1.169e-13	5.063e-14	1.976e-14	1.613e-14	1.125e-14	1.957e-14	8.320e-14	2.014e-13	2.574e-13	2.097e-13	3.119e-13	2.621e-13	2.345e-13	1.513e-13	1.797e-13	1.892e-13
7333	9.135e-14	3.994e-14	1.575e-14	1.291e-14	9.137e-15	1.566e-14	6.572e-14	1.589e-13	2.032e-13	1.655e-13	2.464e-13	2.068e-13	1.850e-13	1.193e-13	1.409e-13	1.470e-13
7760	5.953e-14	2.637e-14	1.044e-14	8.552e-15	6.052e-15	1.035e-14	4.351e-14	1.052e-13	1.347e-13	1.098e-13	1.635e-13	1.370e-13	1.227e-13	7.902e-14	9.247e-14	9.506e-14
8583	2.651e-14	1.202e-14	4.790e-15	3.915e-15	2.772e-15	4.721e-15	1.987e-14	4.811e-14	6.174e-14	5.033e-14	7.502e-14	6.269e-14	5.625e-14	3.618e-14	4.176e-14	4.180e-14
10232	5.537e-15	2.601e-15	1.047e-15	8.532e-16	6.044e-16	1.021e-15	4.306e-15	1.046e-14	1.344e-14	1.097e-14	1.638e-14	1.362e-14	1.227e-14	7.898e-15	8.968e-15	8.555e-15
10475	4.424e-15	2.090e-15	8.420e-16	6.860e-16	4.856e-16	8.194e-16	3.463e-15	8.422e-15	1.083e-14	8.851e-15	1.322e-14	1.099e-14	9.904e-15	6.367e-15	7.216e-15	6.827e-15

Table C-6

Normalized Concentrations for All Other Particulate Matter^a(Sec/m³)

Dist. (m)	N	NNW	NW	NNW	W	WSW	SW	SSW	S	SSE	SE	ESE	E	ENE	NE	NNE
500	5.216e-06	3.064e-06	2.340e-06	2.643e-06	3.353e-06	5.271e-06	7.891e-06	1.079e-05	1.303e-05	1.771e-05	2.109e-05	2.105e-05	1.598e-05	1.238e-05	1.009e-05	8.197e-06
1200	9.062e-07	4.657e-07	4.059e-07	4.262e-07	6.079e-07	7.889e-07	1.560e-06	2.012e-06	2.446e-06	2.864e-06	4.712e-06	3.880e-06	3.083e-06	1.957e-06	2.097e-06	1.670e-06
1409	6.772e-07	3.422e-07	3.007e-07	3.128e-07	4.502e-07	5.766e-07	1.175e-06	1.516e-06	1.846e-06	2.137e-06	3.607e-06	2.924e-06	2.337e-06	1.460e-06	1.598e-06	1.269e-06
1957	3.840e-07	1.916e-07	1.662e-07	1.713e-07	2.464e-07	3.186e-07	6.594e-07	8.591e-07	1.048e-06	1.216e-06	2.055e-06	1.659e-06	1.333e-06	8.351e-07	9.143e-07	7.249e-07
2081	3.454e-07	1.720e-07	1.488e-07	1.531e-07	2.203e-07	2.853e-07	5.922e-07	7.730e-07	9.429e-07	1.095e-06	1.851e-06	1.493e-06	1.200e-06	7.526e-07	8.240e-07	6.531e-07
3396	1.516e-07	7.396e-08	6.282e-08	6.355e-08	9.137e-08	1.200e-07	2.562e-07	3.404e-07	4.167e-07	4.859e-07	8.242e-07	6.601e-07	5.359e-07	3.375e-07	3.686e-07	2.903e-07
4038	1.153e-07	5.569e-08	4.685e-08	4.705e-08	6.760e-08	8.934e-08	1.931e-07	2.590e-07	3.178e-07	3.716e-07	6.313e-07	5.034e-07	4.109e-07	2.596e-07	2.831e-07	2.222e-07
4213	1.079e-07	5.202e-08	4.370e-08	4.379e-08	6.293e-08	8.326e-08	1.806e-07	2.428e-07	2.981e-07	3.488e-07	5.928e-07	4.724e-07	3.859e-07	2.438e-07	2.658e-07	2.083e-07
4858	8.642e-08	4.136e-08	3.455e-08	3.438e-08	4.942e-08	6.565e-08	1.440e-07	1.951e-07	2.401e-07	2.813e-07	4.790e-07	3.807e-07	3.120e-07	1.974e-07	2.148e-07	1.677e-07
4956	8.376e-08	4.004e-08	3.343e-08	3.323e-08	4.776e-08	6.349e-08	1.395e-07	1.892e-07	2.328e-07	2.729e-07	4.648e-07	3.692e-07	3.027e-07	1.916e-07	2.084e-07	1.626e-07
5234	7.688e-08	3.665e-08	3.052e-08	3.027e-08	4.350e-08	5.792e-08	1.278e-07	1.738e-07	2.140e-07	2.511e-07	4.278e-07	3.395e-07	2.788e-07	1.765e-07	1.919e-07	1.496e-07
5860	6.431e-08	3.049e-08	2.524e-08	2.490e-08	3.577e-08	4.780e-08	1.063e-07	1.454e-07	1.793e-07	2.107e-07	3.595e-07	2.845e-07	2.345e-07	1.488e-07	1.616e-07	1.256e-07
5924	6.321e-08	2.995e-08	2.477e-08	2.444e-08	3.510e-08	4.692e-08	1.044e-07	1.430e-07	1.763e-07	2.072e-07	3.535e-07	2.796e-07	2.306e-07	1.463e-07	1.589e-07	1.235e-07
7089	4.738e-08	2.225e-08	1.817e-08	1.781e-08	2.551e-08	3.437e-08	7.728e-08	1.068e-07	1.318e-07	1.554e-07	2.656e-07	2.089e-07	1.736e-07	1.107e-07	1.202e-07	9.326e-08
7333	4.505e-08	2.127e-08	1.750e-08	1.728e-08	2.473e-08	3.299e-08	7.345e-08	1.013e-07	1.251e-07	1.476e-07	2.523e-07	1.983e-07	1.649e-07	1.052e-07	1.142e-07	8.862e-08
7760	4.123e-08	1.946e-08	1.601e-08	1.582e-08	2.262e-08	3.012e-08	6.706e-08	9.272e-08	1.145e-07	1.351e-07	2.312e-07	1.815e-07	1.512e-07	9.659e-08	1.048e-07	8.123e-08
8583	3.518e-08	1.659e-08	1.364e-08	1.349e-08	1.926e-08	2.557e-08	5.691e-08	7.894e-08	9.753e-08	1.153e-07	1.974e-07	1.545e-07	1.293e-07	8.277e-08	8.978e-08	6.948e-08
10232	2.661e-08	1.255e-08	1.029e-08	1.021e-08	1.453e-08	1.919e-08	4.257e-08	5.945e-08	7.356e-08	8.725e-08	1.497e-07	1.165e-07	9.821e-08	6.319e-08	6.851e-08	5.285e-08
10475	2.573e-08	1.213e-08	9.958e-09	9.878e-09	1.406e-08	1.854e-08	4.118e-08	5.759e-08	7.134e-08	8.468e-08	1.454e-07	1.130e-07	9.534e-08	6.134e-08	6.645e-08	5.114e-08

^a These are individual normalized concentrations for Cs-137, Pu-238, Pu-240, Sr-90, U-238, Th-234, and U-234.

Table C-7

Normalized Depositions for All Other Particulate Matter^a(m⁻²)

Dist. (m)	N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	E	ENE	NE	NNE
500	9.389e-09	5.515e-09	4.212e-09	4.757e-09	6.035e-09	9.488e-09	1.420e-08	1.942e-08	2.345e-08	3.188e-08	3.796e-08	3.789e-08	2.876e-08	2.228e-08	1.816e-08	1.475e-0
1200	1.631e-09	8.383e-10	7.306e-10	7.672e-10	1.094e-09	1.420e-09	2.808e-09	3.622e-09	4.403e-09	5.155e-09	8.482e-09	6.984e-09	5.549e-09	3.523e-09	3.775e-09	3.006e-0
1409	1.219e-09	6.160e-10	5.413e-10	5.630e-10	8.104e-10	1.038e-09	2.115e-09	2.729e-09	3.323e-09	3.847e-09	6.493e-09	5.263e-09	4.207e-09	2.628e-09	2.876e-09	2.284e-0
1957	6.912e-10	3.449e-10	2.992e-10	3.083e-10	4.435e-10	5.735e-10	1.187e-09	1.546e-09	1.886e-09	2.189e-09	3.699e-09	2.986e-09	2.399e-09	1.503e-09	1.646e-09	1.305e-0
2081	6.217e-10	3.096e-10	2.678e-10	2.756e-10	3.965e-10	5.135e-10	1.066e-09	1.391e-09	1.697e-09	1.971e-09	3.332e-09	2.687e-09	2.160e-09	1.355e-09	1.483e-09	1.176e-0
3396	2.729e-10	1.331e-10	1.131e-10	1.144e-10	1.645e-10	2.160e-10	4.612e-10	6.127e-10	7.501e-10	8.746e-10	1.484e-09	1.188e-09	9.646e-10	6.075e-10	6.635e-10	5.225e-1
4038	2.075e-10	1.002e-10	8.433e-11	8.469e-11	1.217e-10	1.608e-10	3.476e-10	4.662e-10	5.720e-10	6.689e-10	1.136e-09	9.061e-10	7.396e-10	4.673e-10	5.096e-10	4.000e-1
4213	1.942e-10	9.364e-11	7.866e-11	7.882e-11	1.133e-10	1.499e-10	3.251e-10	4.370e-10	5.366e-10	6.278e-10	1.067e-09	8.503e-10	6.946e-10	4.388e-10	4.784e-10	3.749e-1
4858	1.556e-10	7.445e-11	6.219e-11	6.188e-11	8.896e-11	1.182e-10	2.592e-10	3.512e-10	4.322e-10	5.063e-10	8.622e-10	6.853e-10	5.616e-10	3.553e-10	3.866e-10	3.019e-1
4956	1.508e-10	7.207e-11	6.017e-11	5.981e-11	8.597e-11	1.143e-10	2.511e-10	3.406e-10	4.190e-10	4.912e-10	8.366e-10	6.646e-10	5.449e-10	3.449e-10	3.751e-10	2.927e-1
5234	1.384e-10	6.597e-11	5.494e-11	5.449e-11	7.830e-11	1.043e-10	2.300e-10	3.128e-10	3.852e-10	4.520e-10	7.700e-10	6.111e-10	5.018e-10	3.177e-10	3.454e-10	2.693e-1
5860	1.158e-10	5.488e-11	4.543e-11	4.482e-11	6.439e-11	8.604e-11	1.913e-10	2.617e-10	3.227e-10	3.793e-10	6.471e-10	5.121e-10	4.221e-10	2.678e-10	2.909e-10	2.261e-1
5924	1.138e-10	5.391e-11	4.459e-11	4.399e-11	6.318e-11	8.446e-11	1.879e-10	2.574e-10	3.173e-10	3.730e-10	6.363e-10	5.033e-10	4.151e-10	2.633e-10	2.860e-10	2.223e-1
7089	8.528e-11	4.005e-11	3.271e-11	3.206e-11	4.592e-11	6.187e-11	1.391e-10	1.922e-10	2.372e-10	2.797e-10	4.781e-10	3.760e-10	3.125e-10	1.993e-10	2.164e-10	1.679e-1
7333	8.109e-11	3.829e-11	3.150e-11	3.110e-11	4.451e-11	5.938e-11	1.322e-10	1.823e-10	2.252e-10	2.657e-10	4.541e-10	3.569e-10	2.968e-10	1.894e-10	2.056e-10	1.595e-1
7760	7.421e-11	3.503e-11	2.882e-11	2.848e-11	4.072e-11	5.422e-11	1.207e-10	1.669e-10	2.061e-10	2.432e-10	4.162e-10	3.267e-10	2.722e-10	1.739e-10	1.886e-10	1.462e-1
8583	6.332e-11	2.986e-11	2.455e-11	2.428e-11	3.467e-11	4.603e-11	1.024e-10	1.421e-10	1.756e-10	2.075e-10	3.553e-10	2.781e-10	2.327e-10	1.490e-10	1.616e-10	1.251e-1
10232	4.790e-11	2.259e-11	1.852e-11	1.838e-11	2.615e-11	3.454e-11	7.663e-11	1.070e-10	1.324e-10	1.571e-10	2.695e-10	2.097e-10	1.768e-10	1.137e-10	1.233e-10	9.513e-1
10475	4.631e-11	2.183e-11	1.792e-11	1.778e-11	2.531e-11	3.337e-11	7.412e-11	1.037e-10	1.284e-10	1.524e-10	2.617e-10	2.034e-10	1.716e-10	1.104e-10	1.196e-10	9.205e-1

^a These are individual normalized deposition values for Cs-137, Pu-238, Pu-240, Sr-90, U-238, Th-234, and U-234.