Title
Radionuclide Air Emission Report for 2008

Author
Wahl, Linnea

Publication Date
2009-07-28

Radionuclide Air Emission Report for 2008

Prepared by
Environment, Health, and Safety Division
Environmental Services Group

May 21, 2009

Ernest Orlando Lawrence Berkeley National Laboratory
Berkeley, CA 94720

This work was supported by the U.S. Department of Energy under Contract No. DE- AC02-05CH11231.

U.S. Department of Energy

Radionuclide Air Emission Report for 2008

(in compliance with 40 CFR 61, Subpart H)

Site Name: Ernest Orlando Lawrence Berkeley National Laboratory

Operation Office Information

Office: U.S. Department of Energy
Berkeley Site Office

Address: MS 90R1023
One Cyclotron Road
Berkeley, CA 94720

Contact: Kim Abbott **Phone**: (510) 486-7909

Site Information

Operator: University of California

Address: MS 85B0198
One Cyclotron Road
Berkeley, CA 94720

Contact: Linnea Wahl, CHP **Phone**: (510) 486-7623

Table of Contents

LIST OF TABLES

LIST OF FIGURES

Preface

As a U.S. Department of Energy (DOE) facility whose operations involve the use of radionuclides, Berkeley Lab is subject to the requirements of the U.S. EPA's 40 CFR 61, National Emission Standards for Hazardous Air Pollutants (NESHAP) (EPA 1989). Subpart H of this regulation (subsequently referred to as NESHAP) establishes standards for exposure of the public to radionuclides (other than radon) released from DOE facilities. This regulation limits the emission of radionuclides to ambient air from DOE facilities. Such emissions may not exceed amounts that would cause any member of the public to receive an effective dose equivalent (subsequently referred to as dose) of 10 mrem/yr (0.1 mSv/yr).

Under the NESHAP regulation, DOE facilities are required to submit an annual report each year. The NESHAP regulation specifies the content of the report and DOE provides further guidance (DOE 1994). This document is Berkeley Lab's annual report on radionuclide air emissions and meets the NESHAP requirements for reporting. This report can be found on the Laboratory's website at http://www.lbl.gov/ehs/esg/Reports/tableforreports.htm.

Executive Summary

Berkeley Lab operates facilities where radionuclides are handled and stored. These facilities are subject to the U.S. Environmental Protection Agency (EPA) radioactive air emission regulations in Code of Federal Regulations (CFR) Title 40, Part 61, Subpart H (EPA 1989). Radionuclides may be emitted from stacks or vents on buildings where radionuclide production or use is authorized or they may be emitted as diffuse sources. In 2008, all Berkeley Lab sources were minor sources of radionuclides (sources resulting in a potential dose of less than 0.1 mrem/yr [0.001 mSv/yr]). These minor sources include more than 100 stack sources and one source of diffuse emissions. There were no unplanned emissions from the Berkeley Lab site. Emissions from minor sources (stacks and diffuse emissions) either were measured by sampling or monitoring or were calculated based on quantities used, received for use, or produced during the year. Using measured and calculated emissions, and building-specific and common parameters, Laboratory personnel applied the EPA-approved computer code, CAP88-PC, to calculate the effective dose equivalent to the maximally exposed individual (MEI). The effective dose equivalent from all sources at Berkeley Lab in 2008 is 5.2×10^{-3} mrem/yr (5.2×10^{-5} mSv/yr) to the MEI, well below the 10 mrem/yr (0.1 mSv/yr) dose standard. The location of the MEI is at the University of California (UC) Lawrence Hall of Science, a public science museum about 1500 ft (460 m) east of Berkeley Lab's Building 56. The estimated collective effective dose equivalent to persons living within 50 mi (80 km) of Berkeley Lab is 1.1×10^{-1} person-rem (1.1×10^{-3} person-Sv) attributable to the Lab's airborne emissions in 2008.

Acronyms

ALS	Advanced Light Source
CAP88-PC	EPA-approved dose calculation software
CFR	Code of Federal Regulations
COMPLY	EPA-approved dose calculation software
DOE	U. S. Department of Energy
EPA	U. S. Environmental Protection Agency
HEPA	High-efficiency particulate air
JBEI	Joint BioEnergy Institute
LHS	Lawrence Hall of Science
MEI	Maximally exposed individual
NESHAP	National Emission Standards for Hazardous Air Pollutants
TEDA	Triethylene diamine
TEDA-DAC	Triethylene-diamine-doped activated carbon
UC	University of California

1

Facility Information

Lawrence Berkeley National Laboratory was founded by Ernest O. Lawrence in 1931. Lawrence received the 1939 Nobel Prize in physics for his invention of the cyclotron particle accelerator, and he is generally credited with the modern concept of interdisciplinary science, in which scientists, engineers, and technicians from different fields work together on complex scientific projects addressing national needs and programs. Lawrence's pioneering work established a great tradition of scientific inquiry and discovery at the Laboratory.

The Laboratory supports work in such diverse fields as genomics, physical biosciences, nanoscience, life sciences, fundamental physics, accelerator physics and engineering, energy conservation technology, and materials science. Through its fundamental research in these fields, Berkeley Lab has achieved international recognition for its leadership and made numerous contributions to national programs. Berkeley Lab's research embraces the following concepts to align with the DOE mission:

- Explore the complexity of energy and matter
- Advance the science needed to attain abundant clean energy
- Understand energy impacts on our living planet
- Provide extraordinary tools for multidisciplinary research

1.1 SITE DESCRIPTION

Berkeley Lab is located about 3 mi (5 km) east of San Francisco Bay (see Figure 1) on land owned by UC. The Laboratory's main site is situated on approximately 202 acres (82 hectares) of this land. University of California provides long-term land leases to the DOE for the buildings at the Laboratory.

The main site lies in the hills above the UC Berkeley campus, on the ridges and draws of Blackberry Canyon (which forms the western part of the site) and adjacent Strawberry Canyon (which forms the eastern part of the site). Elevations across the site range from 450 to 1,150 ft (135 to 350 m) above sea level. The western portion of the site is in Berkeley, with the eastern portion in Oakland (see Figure 2). The population of Berkeley is estimated at 100,000 and that of Oakland at 400,000 (MTC/ABAG 2000).

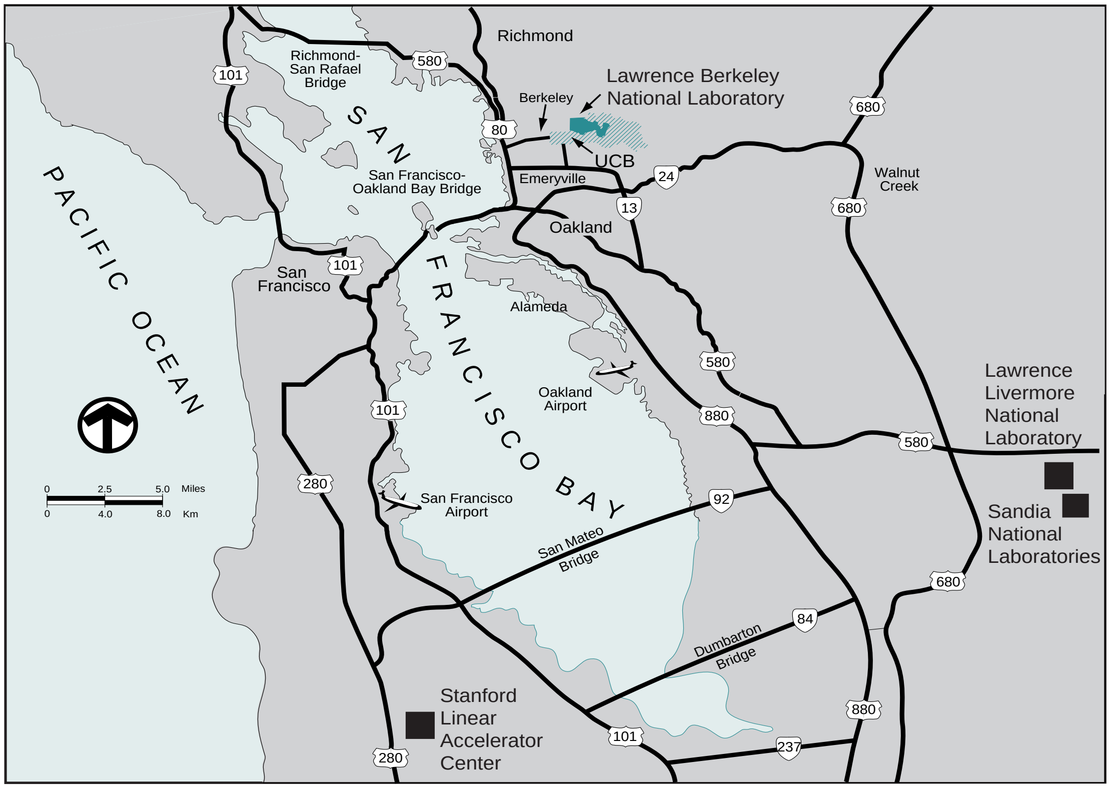

Figure 1. San Francisco Bay Area Map

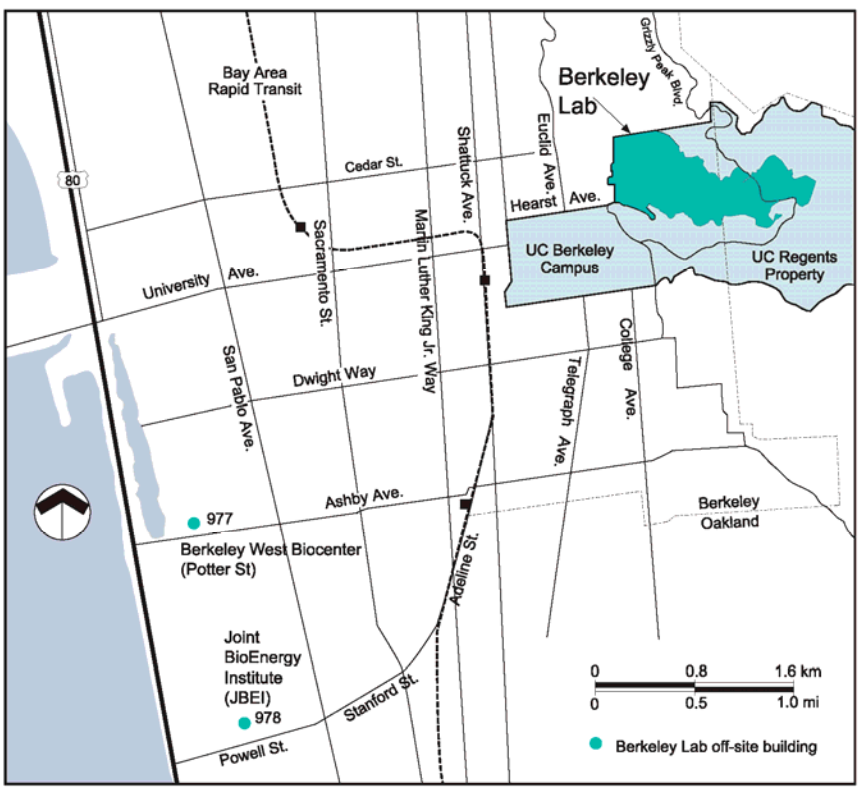

Figure 2. Vicinity Map

Adjacent land use consists of residential, institutional, and recreational areas. The area to the south and east of the Laboratory, which is UC land, is maintained largely in a natural state but includes UC Berkeley's Strawberry Canyon Recreational Area and Botanical Garden. Northeast of the Laboratory are the university's Lawrence Hall of Science, Space Sciences Laboratory, and Mathematical Sciences Research Institute. Berkeley Lab is bordered on the north by a residential neighborhood and on the west by the UC Berkeley campus, as well as by multiunit dwellings, student residence halls, and private homes. The area to the west of Berkeley Lab is highly urbanized.

The climate of the site is temperate, influenced by the moderating effects of nearby San Francisco Bay and the Pacific Ocean to the west, and on the east by the East Bay hills paralleling the eastern shore of this same bay. These physical barriers contribute significantly to the relatively warm, wet winters and cool, dry summers of the site. In 2008, precipitation totaled 21.8 in. (55.3 cm), absolute humidity averaged 7.5 g/m^3, and ambient temperature averaged 55.4°F (13.0°C).

On-site wind patterns change little from one year to the next. The most prevalent wind pattern occurs during fair weather, with daytime westerly winds blowing off the bay, followed by lighter nighttime southeasterly drainage winds of the East Bay hills. The other predominant wind pattern is associated with storm systems passing through the region, which usually occur during the winter months. South-to-southeast winds in advance of each storm are followed by a shift to west or northwest winds after passage of the system.

Vegetation on the Berkeley Lab site is a mixture of native plants, naturalized exotics, and ornamental species. The site was intensively grazed and farmed for approximately 150 years before the development of the Laboratory at this site in the 1930s. At the main site, the Laboratory manages on-site vegetation so that it is coordinated with the local natural succession of native plant communities. Berkeley Lab also works to maintain a wooded and savanna character in the areas surrounding buildings and roads. Ornamental species are generally restricted to public spaces and courtyards and to areas adjacent to buildings. The site has no rare, threatened, or endangered species of plants.

1.2 SOURCE DESCRIPTION

Berkeley Lab operates facilities subject to the EPA's NESHAP regulations where radionuclides are produced, handled, and stored (EPA 1989). Figure 3 illustrates the Berkeley Lab general site configuration, including locations of buildings where radionuclides are used or produced, the former location of Building 10 (a source of diffuse emissions in 2008), and the Lawrence Hall of Science (or LHS, the location of the MEI). Building 977, the Berkeley West Biocenter on Potter Street, and Building 978, the Joint BioEnergy Institute, are shown on Figure 2.

Researchers at the Lab use a wide variety of liquid and solid radionuclides in their research programs. Work with radioactive material may be conducted on laboratory bench tops, in fumehoods, in gloveboxes, and/or under ultra-high vacuum. In addition, radioactive gases are a by-product of charged-particle accelerator operations in Buildings 6, 56, and 88 include ^{11}C, ^{13}N, ^{15}O, and ^{18}F, which are short-lived radionuclides.

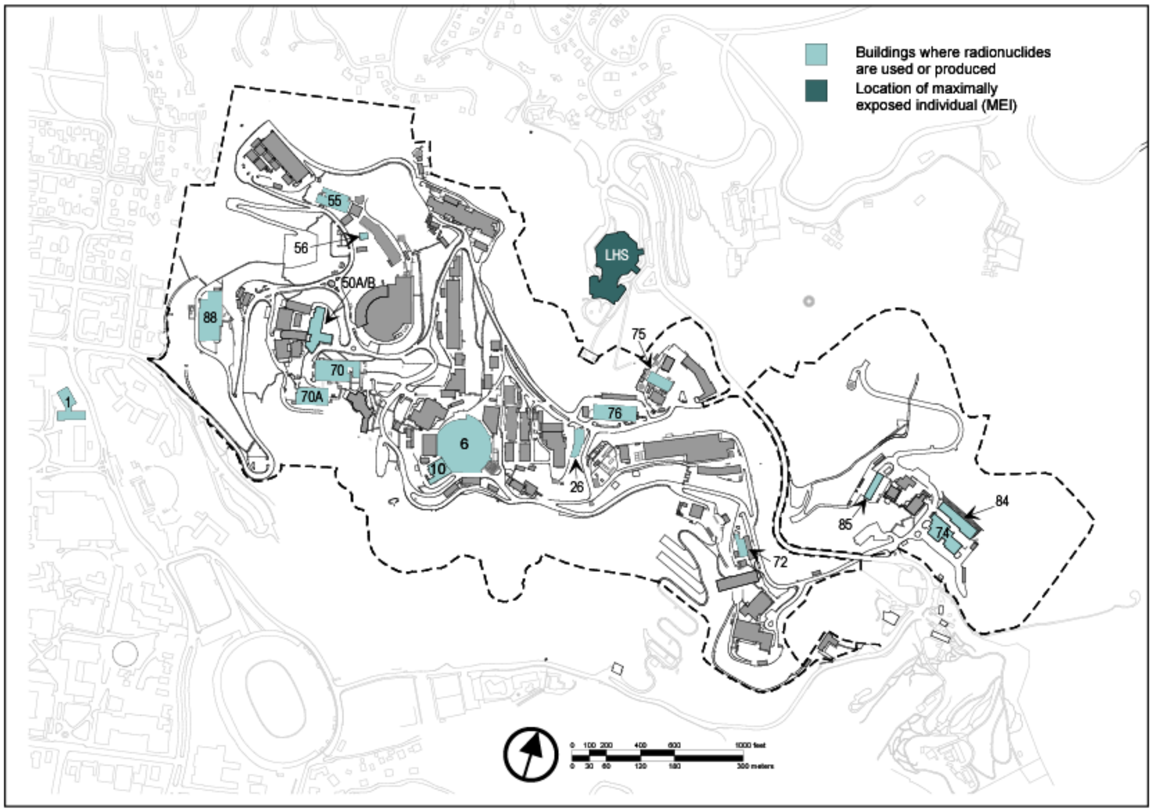

Figure 3. Berkeley Lab Buildings Where Radionuclides are Used or Produced

Radiochemical and radiobiological studies performed at Berkeley Lab typically use microcurie to tens of millicurie quantities of a variety of radionuclides. All use of radioactive material must be conducted in accordance with a Lab authorization or permit. An authorization or permit establishes the location of radioactive material areas (work areas where unsealed radioactive material is handled) and radioactive material storage areas (controlled areas where radioactive material is stored only, with no direct manipulation of the material), the required handling procedures, and appropriate work enclosures for each project.

Table 1 identifies buildings at Berkeley Lab where use or production of unsealed radioactive material was authorized in 2008 and the radionuclides that were authorized for use. Note that not all authorized radionuclides were necessarily used during the year.

Table 1. Buildings Where Unsealed Radionuclide Use or Production is Authorized by Berkeley Lab

Building	Building Name/ Function	Radionuclides Authorized by Berkeley Lab
1	Donner Laboratory	C-14, H-3, I-125, P-32, U-238
6	Advanced Light Source (ALS)	Activation products,[a] Am-241, Am-243, Cm-243, Cm-246, Cm-248, Eu-152, Eu-154, H-3, I-129, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Sr-90, Tc-99, Th-232, U-233, U-235, U-238
26	Radioanalytical Laboratory	Am-241, Am-243, Cm-243, Cm-246, Cm-248, Eu-152, Eu-154, H-3, I-129, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Sr-90, Tc-99, Th-232, U-233, U-235, U-238
50A/B	Physics Research	Ag-106m, Au-194, Co-56, Co-57, Co-58, Co-60, Mn-52, Na-22, Ni-57, Re-184m, Sc-48, Se-75, Ta-182, V-48, Zn-65, Be-7, Sc-46, Ag-105, Mn-54
55	Center for Functional Imaging	Activation products,[a] C-11, C-14, Ce-141, Co-55, Co-57, Cu-64, F-17, F-18, Ge-68, H-3, I-123, I-125, I-131, N-13, Nb-95, O-14, O-15, Ru-103, Sc-46, Sr-85, Tc-99m, Tl-201
56	Biomedical Isotope Facility	Activation products,[a] C-11, Co-55, Co-57, F-18, N-13, O-14, O-15, F-17
70	Environmental Energy Technology, Nuclear Science, and Earth Sciences Research	Activation products,[a] alpha, Am-241, Am-243, Ba-133, beta-gamma, Bi-207, Ce-141, Ce-144, Cf-249, Cf-252, Cm-243, Cm-248, Er-165, Er-169, Er-171, Es-253, Eu-152, Fe-59, H-3, Hf-172, Hf-175, Hf-181, Ho-166, Ho-166m, I-129, K-40, Na-22, Nb-95, Np-237, P-32, Pa-233, Pu-238, Pu-239, Ra-226, Re-189, Rh-101, Sc-46, Sm-153, Sr-89, Ta-179, Ta-182, Tb-160, Tc-99, Te-125m, Th-228, Th-229, Th-230, Th-232, U-234, U-235, U-238, Yb-169, Zn-65
70A	Nuclear, Chemical, and Life Sciences Research	Activation products,[a] Am-241, Am-243, Ba-133, Bk-249, C-11, C-14, Cf-249, Cf-250, Cf-252, Cl-36, Cm-243, Cm-245, Cm-246, Cm-248, Co-60, Es-253, Es-254, Eu-152, Eu-154, Eu-155, Fe-59, fission products, H-3, Ni-65, Np-237, Np-239, P-32, P-33, Pa-231, Pb-205, Pb-210, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Pu-244, Ra-226, Ra-228, Ru-106, Sr-90, Tc-99, Th-228, Th-229, Th-230, Th-232, U-232, U-233, U-234, U-235, U-238, U-natural
72	Low-Background Facility	Ac-227, activation products,[a] alpha, Am-241, Au-198, Be-10, Be-7, C-11, Cf-249, Cf-252, Co-56, Co-57, Co-58, Co-60, Cr-51, Cs-134, Eu-152, Eu-154, Fe-55, Fe-59, fission products, H-3, I-129, Na-22, Np-237, Np-239, P-32, Pu-238, Pu-239, Sb-124, Sc-46, Se-75, Sr-90, U-238, U-238, Zn-65
74	Life Sciences Research	C-11, C-14, Ce-141, Cu-64, F-18, Ge-68, H-3, I-123, I-125, I-131, N-13, Nb-95, O-15, P-32, Ru-103, S-35, Sc-46, Sr-85, Tc-99m, Tl-201
75	Radioanalytical Laboratory	Ac-227, activation products,[a] alpha, Am-241, Am-243, beta-gamma, C-11, C-14, F-18, Fe-55, H-3, I-125, I-129, I-131, Np-237, Pb-210, Pu-238, Pu-239, Pu-242, S-35, Sr-90, Th-229, Th-230, Th-232, U-232, U-natural
76	Radioanalytical Laboratory	Am-241, Am-243, Cm-243, Cm-246, Cm-248, Eu-152, Eu-154, H-3, I-129, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Sr-90, Tc-99, Th-232, U-233, U-235, U-238
84	Life Sciences Research	H-3, P-32, S-35
85	Hazardous Waste Handling Facility	Alpha, beta-gamma, C-14, H-3
88	88-Inch Cyclotron	Ac-227, activation products,[a] actinide tracers, alpha, Am-241, Au-198, Be-7, Be-10, beta-gamma, C-11, Cf-249, Cf-252, Cm-248, Co-56, Co-57, Co-58, Co-60, Cr-51, Cs-134, Eu-152, Eu-154, Fe-55, Fe-59, fission products, gamma tracers, Gd-148, H-3, N-13, Na-22, Ne-18, Ne-19, Np-237, Np-239, O-14, P-32, P-33, Pb-212, Pu-238, Pu-239, Pu-242, Pu-244, Sb-124, Sc-46, Se-75, Th-228, Th-229, Th-232, U-234, U-235, U-236, U-238, U-natural, Zn-65

[a] Produced when materials such as air, water, and metals are bombarded by neutrons, protons, or other accelerated particles

Table 1. (continued) Buildings Where Unsealed Radionuclide Use or Production is Authorized by Berkeley Lab

Building	Building Name/ Function	Radionuclides Authorized by Berkeley Lab
977	Berkeley West Biocenter (Potter Street Facility)	C-11, C-14, H-3, P-32, S-35
978	Joint BioEnergy Institute (JBEI)	C-14, Cd-109, H-3, P-32, S-35

[a] Produced when materials such as air, water, and metals are bombarded by neutrons, protons, or other accelerated particles

2
Air Emissions Data

At Berkeley Lab, radionuclides may be emitted from stacks or other exhaust points (such as vents) on the buildings where radionuclide use is authorized (see Table 1). Alternatively, radionuclides may be uniformly released from an area or emanate from a number of points randomly distributed over an area; this is a diffuse source.

If the radionuclides emitted from any type of source could result in a potential dose of 0.1 mrem/yr (0.001 mSv/yr) or more to a member of the public at an off-site point where there is a residence, school, business, or office, it is considered a major source, and the EPA requires the Lab to measure its emissions continuously. Berkeley Lab has no major sources.

If emitted radionuclides could result in a potential dose of less than 0.1 mrem/yr (0.001 mSv/yr), the source of the radionuclides is considered a minor source. The EPA requires the Lab to perform periodic confirmatory measurements on such sources. In 2008, all Berkeley Lab sources were minor sources of radionuclides. Emissions from minor sources were either measured by real-time monitoring, continuous sampling with monthly analysis of the samples, or sampling for one month at a time four times a year; or were calculated based on quantities received, used, or produced during the year.

The approach to measuring radionuclides from Berkeley Lab sources is summarized in Table 2, which EPA Region 9 approved in 2005 (Jordan 2005).

Table 2. EPA-Approved Radionuclide Emissions Measurement Approach

Potential Dose (mrem/yr)[a]	Category	Requirements
dose ≥ 10.0	Non-compliant	Reduction or relocation of source term and reevaluation prior to authorization.
10.0 > dose ≥ 1.0	1	• Continuous sampling with weekly collection and analysis AND • Real-time monitoring with alarming telemetry for short-lived ($t_{1/2}$< 100 h) radionuclides resulting in >10% of potential dose to the maximally exposed individual.
1.0 > dose ≥ 0.1	2	• Continuous sampling with monthly collection and analysis OR • Real-time monitoring for short-lived ($t_{1/2}$ < 100 h) radionuclides resulting in >10% of potential dose to the maximally exposed individual.
0.1 > dose ≥ 0.01	3	Periodic sampling 25% of the year.
dose < 0.01	4	Potential dose evaluation before project starts and when annual radionuclide use limits (as authorized by internal Lab documents) are revised; no sampling or monitoring required.

[a] 1 mrem = 0.01 mSv

Among the minor sources at Berkeley Lab are a few stacks, or point sources, where the emissions are measured. There are many more radioactive material areas, or group sources, where emissions are calculated.

Occasionally, activities at the Laboratory result in a diffuse source of radionuclide emissions. Diffuse sources are not actively ventilated and their emissions may be measured or calculated, depending on potential dose from those emissions (Table 2). In 2008, Berkeley Lab had one minor diffuse source, created by construction activities at the site of the former Building 10.

A single building may have all three types of sources: point (measured stacks [typically Category 3]), group (calculated emissions [Category 4]), and diffuse (calculated wide-area emissions [Category 3 or 4]) sources (Table 3). The total activity of each radionuclide from stack air measurements and calculations is shown in Table 4.

2.1 POINT SOURCES: MEASURED EMISSIONS

In accordance with the EPA-approved approach (Table 2), Berkeley Lab measures emissions from stacks or other exhaust points if the potential dose from the sources could exceed 0.01 mrem/yr (0.0001 mSv/yr); these are Category 3 sources (recall that Berkeley Lab has no major [Category 1 or 2] sources). Additionally, Berkeley Lab may choose to measure emissions from stacks with less dose impact (Category 4) to ensure that those emissions are well understood. Thus stacks where emissions are measured include both Category 3 and Category 4 sources (Table 5).

At sampled stacks, a representative sample of the exhaust air passes through the appropriate collection medium (silica gel for ^{3}H, sodium hydroxide solution for ^{14}C, activated carbon for ^{125}I, and fiberglass filter for particulate alpha- and beta-emitting radionuclides). Each medium is

Table 3. Measurement Category of Sources

Building	Category 1	Category 2	Category 3	Category 4	Total
1	0	0	0	5	5
6	0	0	0	9	9
10 (diffuse)	0	0	0	1	1
26	0	0	0	4	4
50A/B	0	0	0	3	3
55	0	0	0	8	8
56	0	0	2	0	2
70	0	0	0	10	10
70A	0	0	2	22	24
72	0	0	0	3	3
74	0	0	0	10	10
75	0	0	1	1	2
76	0	0	0	1	1
84	0	0	0	10	10
85	0	0	2	0	2
88	0	0	3	12	15
977	0	0	0	4	4
978	0	0	0	1	1
Total	0	0	10	104	114

Table 4. Total Activity Emitted in 2008

Radio-nuclide	Activity (Ci/yr)[a]	Radio-nuclide	Activity (Ci/yr)	Radio-nuclide	Activity (Ci/yr)	Radio-nuclide	Activity (Ci/yr)
F-18	1.56E+00	Pu-239	5.43E-08	Sr-90	4.27E-10	Th-229	1.83E-14
H-3	4.23E-01	U-238	5.26E-08	Ag-108m	2.01E-10	Na-22	9.98E-15
C-11	1.08E-02	Np-237	4.64E-08	Br-82	1.12E-10	Cf-249	3.90E-15
C-14	1.90E-03	Pu-242	4.12E-08	Co-60	9.55E-11	Cr-51	3.73E-15
Tc-99m	5.56E-05	U-235	2.72E-08	Ra-226	7.65E-11	Co-58	2.13E-15
P-32	3.08E-05	U-234	1.20E-08	Eu-155	6.00E-11	Th-227	1.70E-15
N-13	1.80E-05	Pu-241	1.20E-08	Ge-75	5.00E-11	Co-56	1.58E-15
Tl-201	4.60E-06	Am-241	8.52E-09	Cm-244	2.57E-11	Hg-194	1.00E-15
Ge-68	8.00E-07	I-125	6.49E-09	Co-57	1.03E-11	Au-195	6.31E-16
Beta (Sr-90)	6.19E-07	Pa-231	4.00E-09	I-129	1.00E-11	Cm-243	3.10E-16
Fe-59	5.00E-07	I-131	3.00E-09	Fe-55	8.96E-12	Ba-133	2.10E-16
Sc-46	4.64E-07	Cm-248	1.67E-09	Zn-65	8.32E-12	Cd-109	2.00E-16
Ge-77	3.00E-07	Eu-152	1.67E-09	Sb-125	8.00E-12	Zr-88	1.95E-16
Pu-238	1.85E-07	Th-232	1.31E-09	Ni-63	7.58E-12	Ag-105	1.86E-16
U-233	1.76E-07	Cs-137	1.13E-09	Cs-134	5.33E-12	Rb-83	1.05E-16
Am-243	1.01E-07	Tc-99	1.00E-09	Mn-54	3.69E-12	Be-7	2.00E-17
Ar-41	1.00E-07	As-76	1.00E-09	Th-230	5.96E-13		
O-15	9.40E-08	Cf-252	6.45E-10	Ra-228	6.00E-14		
Alpha (Th-232)	6.39E-08	Eu-154	5.76E-10	Th-228	3.49E-14		
Total	2.00E+00						

[a] 1 Ci = 3.7×10^{10} Bq

Table 5. Stacks Where Radionuclide Emissions are Measured

Building	Number of Stacks	Stack Identification	Measurement Category	Emissions Control	Efficiency (%)
55	1	55-128H	4	HEPA [a] TEDA-DAC [b]	> 99 > 75
56	2	56-Accelerator 56-Glovebox	3 3	None [c]	NA
70	1	70-147A	4	HEPA	> 99
70A	2	70A-1129P/RT 70A-1129H	3 3	HEPA	> 99
75	1	75-127H	3	HEPA	> 99
85	2	85-Fumehood 85-Glovebox	3 3	HEPA	> 99
88	3	88-135H 88-Cave0 88-RT	3 3 3	HEPA	> 99

[a] High-efficiency particulate air filter
[b] Triethylene-diamine-doped activated carbon trap
[c] Radionuclides emitted from accelerators are short-lived, gaseous, activation products, for which emission control is impractical

changed out after a month, and the radionuclides collected on the media are analyzed at a commercial laboratory. At sites that are continuously monitored in real time, a sample of the exhaust air is passed through or over detectors that provide a nearly instantaneous measurement of positron-emitting radionuclides (at Buildings 56 and 88) or alpha-emitting radionuclides (at Building 70A). Real-time measurements are recorded and archived.

Many stacks and vents at Berkeley Lab have effluent controls; that is, a filter to collect particulates or gases before they are released to the atmosphere. For example, the measured stacks (point sources) on Building 70A have high-efficiency particulate air filters to prevent small particles from entering the atmosphere. Where effluent controls are in place, samples are collected downstream from the filter. Table 5 shows effluent controls on sampled and monitored stacks.

2.2 GROUP SOURCES: CALCULATED EMISSIONS

In accordance with the EPA-approved approached (Table 2), Berkeley Lab calculates emissions from stacks or other exhaust points if the potential dose from the sources is less than 0.01 mrem/yr (0.0001 mSv/yr). These Category 4 sources (typically radioactive material areas where small amounts of radionuclides are authorized for use) are grouped by building, as shown in Table 6, to simplify reporting (DOE 1994). The amount of each radionuclide emitted is calculated by multiplying the entire quantity of that radionuclide received, used, or produced during the year by the appropriate EPA-specified release factor based on the radionuclide's physical state (provided in 40 CFR Part 61, Appendix D). This method provides a conservative, upper-bound estimate of the annual emissions.

Table 6. Sources for Which Radionuclide Emissions are Calculated

Building	Number of Radioactive Material Areas	Emissions Control	Efficiency (%)
1	5	None	NA[a]
6	9	None	NA
26	4	None	NA
50A/B	3	None	NA
55	8	None	NA
70	10	None	NA
70A	22	None	NA
72	3	None	NA
74	10	HEPA[b] None	> 99 NA
75	1	None	NA
76	1	None	NA
84	10	None	NA
88	12	HEPA	> 99
977	4	None	NA
978	1	None	NA

[a] Not applicable
[b] High-efficiency particulate air filter

Emissions are typically calculated assuming that all radionuclides received during the year are used in areas where stacks are not sampled or monitored. In fact, some received radionuclides may be emitted through sampled or monitored stacks. Emissions of these radionuclides are thus overestimated because they are accounted for as both calculated and measured emissions. For group sources there typically are no effluent controls because the emissions from these sources are very low activity.

2.3 NONPOINT SOURCES: DIFFUSE EMISSIONS

Berkeley Lab had one source of diffuse emissions in 2008 created by construction activities at the site of former Building 10. The soil at this site was found to be contaminated with low levels of natural uranium and was disposed of off-site at a low-level radioactive waste disposal site. Emissions from soil-handling activities were estimated using methods described in the EPA document, *Methods for Estimating Fugitive Air Emissions of Radionuclides from Diffuse Sources at DOE Facilities* (EPA 2004).

3

Dose Assessment

3.1 DOSE MODEL

To comply with NESHAP regulations and DOE guidance, the EPA-approved atmospheric dispersion and radiation dose calculation computer code, CAP88-PC, Versions 2.0 and 3.0, was used to calculate the dose at various distances and from various release points (EPA 2006). For buildings 1, 977, and 978, where the nearest member of the public was much less than 328 ft (100 m) from the source, the EPA-approved dose model COMPLY was used for that location; CAP88-PC was used for doses at all other distances from the building. Doses to members of the public nearest each building were compared, and the location where the dose was greatest was determined to be the Laboratory MEI.

Dose from emissions from individual Laboratory buildings was calculated and summed for the entire facility. As identified in Figures 2 and 3, Buildings 1, 977 (the Berkeley West Biocenter), and 978 (the Joint BioEnergy Institute) are located outside of Berkeley Lab's main perimeter and could be considered separate facilities since they are not on one contiguous site. However, Building 1 is located on the adjacent UC Berkeley campus and is within walking distance of the main Berkeley Lab site. Buildings 977 and 978 are located about 3 mi (5 km) southwest of the main Laboratory site. Annual radioactive air emissions from these off-site buildings and the associated dose to each nearest member of the public are much less than the highest building emissions and doses at the main Berkeley Lab site, and it would be inappropriate and misleading to model and report these much lower doses in separate reports. Therefore, for reporting and dose-modeling purposes, all off-site buildings are considered along with buildings on the Berkeley Lab site and all contribute to the potential dose received by the Laboratory MEI.

3.2 INPUT PARAMETERS

Input parameters to CAP88-PC include the emissions discussed in Section 2, and building-specific and common parameters, discussed below. To estimate dose, CAP88-PC, Version 3, provides a library of 825 radionuclides, which includes data for all of the radionuclides listed in Table 4 except ^{252}Cf and ^{248}Cm. For these two radionuclides, Version 2 of CAP88-PC was used. (Note that the dose from ^{252}Cf and ^{248}Cm to the sitewide MEI is very low—less than 0.1% of the total dose from all radionuclides.)

In addition, when calculating dose from particulate alpha- and beta-emitting radionuclides, Berkeley Lab assigns gross alpha and gross beta measurements to the high-hazard alpha-emitting radionuclide, ^{232}Th, and the high-hazard beta-emitting radionuclide, ^{90}Sr, respectively. The use of the high-hazard radionuclides ^{232}Th and ^{90}Sr to represent alpha and beta emissions provides an upper-bound estimate of the dose.

3.2.1 Building-Specific Parameters

For dose assessment, some Berkeley Lab buildings can be combined because they are near each other and similar operations are performed there (DOE 1994). For combined buildings and buildings with many unsampled stacks, average stack height and conservative stack diameter (0.1 m), exit velocity (0 m/s), and receptor distance (from nearest edge of building) values are typically used (Table 7). These values overestimate the impact of air emissions on a nearby person and are chosen to ensure that stack emissions are not underestimated.

For Buildings 56 and 85, where individual stacks correlate to a single operation, the actual stack diameter and exit velocity were used and modeled separately (Stacks 1, 2, and 3). The input parameters that vary with building are shown in Table 7.

3.2.2 Common Parameters

The input parameters that are common among Berkeley Lab sources include meteorological data and agricultural data. Meteorological data were compiled from on-site data for 2008. Berkeley Lab collects this data from a 66-ft (20-m) tower located in the central portion of the Laboratory. Site-specific values for annual precipitation (21.8 in. [55.3 cm]), average ambient temperature (55.4°F [13.0°C]), and average absolute humidity (7.5 g/m^3) were used. The default value for lid (mixing) height, 3300 ft (1000 m), was chosen. The 2008 wind data are provided in Attachment A.

Table 7. Building-Specific Input Parameters

Building Number	Stack Height (m)[a]	Stack Diameter (m)	Exit Velocity (m/s)	Nearest Member of Public	MEI Location	Farm Location [b]
1	18	0.1	0	10 m ESE	990 m ENE	4200 m N
6	9	0.1	0	350 m NNE	370 m NNE	3200 m N
10 (diffuse)	0	194.45[c]	0	350 m NNE	370 m NNE	3200 m N
26/76	8	0.1	0	250 m N	250 m N	3200 m N
55/56				250 m NNW	460 m E	3200 m N
Stack 1	16	0.3	3.66			
Stack 2	16	0.46	2.19			
Stack 3	12	0.1	0			
70/70A/50A/B	16	0.1	0	270 m WSW	530 m ENE	3200 m N
72	3	0.1	0	230 m SSW	500 m NW	3200 m N
74/84	7	0.1	0	160 m SSE	690 m WNW	3200 m N
75	7.4	0.35	9.1	110 m NW	110 m NW	3200 m N
85				210 m SSE	570 m WNW	3200 m N
Stack 1	16	0.23	7.24			
Stack 2	16	0.46	7.62			
Stack 3	16	0.1	0			
88	13	0.1	0	110 m W	690 m ENE	3200 m N
977	16	0.1	0	30 m N	5000 m N	8200 m N
978	28	0.26	0	19 m E	5700 m NE	8200 m N

[a] 1 m = 3.281 ft
[b] Approximate distance to Wildcat Canyon Regional Preserve where cattle graze
[c] Area of diffuse source estimated to be 194.45 m^2

Agricultural data were obtained from the California Department of Food and Agriculture and the urban scenario was chosen (Wahl 2004). The values include the following.

- Vegetables, fraction home-produced: 0.076
- Vegetables, fraction from assessment area: 0.924
- Milk, fraction from assessment area: 1
- Meat, fraction home-produced: 0.008
- Meat, fraction from assessment area: 0.992
- Beef cattle density: 1.9 per km^2
- Milk cattle density: 4.0 per km^2
- Land fraction cultivated for vegetable crops: 4.6%

3. 3 COMPLIANCE ASSESSMENT

3.3.1 MEI Dose and Location

Doses from Berkeley Lab's airborne emissions are well below the 10 mrem/yr (0.1 mSv/yr) NESHAP dose standard. As shown in Table 8, the sum of doses from all sources at Berkeley Lab in 2008 is 5.2×10^{-3} mrem/yr (5.2×10^{-5} mSv/yr) to the MEI. The location of this hypothetical person is the UC Lawrence Hall of Science, about 1500 ft (460 m) east of Buildings 55 and 56.

Although no one actually lives at the Hall of Science, the EPA-approved software calculates the dose assuming a person resides there 24 hours a day for the entire year, eats meat and vegetables grown at the Hall of Science or nearby (see the agricultural parameters in Section 3.2.2), and drinks water from local wells contaminated with deposited airborne radionuclides. Thus the calculated dose to this hypothetical person, the MEI, is greater than the dose to an actual visitor to the Hall of Science.

Fluorine-18 emitted from Building 56 stacks accounts for about 81% of the dose to the Berkeley Lab MEI. Another 6% of the dose is due to operations with ^{3}H at the Building 85 Hazardous Waste Handling Facility, and about 4% of the dose is due to ^{99}Tc used in Building 55 laboratories.

Annual ^{18}F emissions from Building 56 stacks are believed to be overestimated because false-positive results occur when ^{18}F adsorbs onto the real-time detectors. These false positive measurements are included in the calculation of annual ^{18}F emissions. As a result, the calculated dose represents an upper-bound estimate of dose from ^{18}F.

The CAP88-PC code was validated by performing a sample assessment. The output of the sample assessment was compared to output provided in the CAP88-PC, Version 3.0, users' guide (EPA 2007). The two outputs are identical, indicating that the code performed as intended.

Table 8 Dose Assessment Results

Building	Primary Radionuclides Contributing to MEI Dose[a]	Dose to MEI (mrem/yr)[b]	Percent of Total Dose (%)
1	P-32	1.3E-7	< 0.1
6	Th-232	2.7E-7	< 0.1
10 (diffuse)	U-238	4.0E-6	< 0.1
26/76	Np-237, Pa-231, Pu-239, Th-229	3.6E-5	0.7
55/56	F-18, Tc-99[c]	4.4E-3	85.3
70/70A/50A/B	Np-237, Pu-238, Pu-239	3.5E-4	6.8
72	Ge-77	6.4E-9	< 0.1
74/84	P-32	9.7E-6	0.2
75	Alpha	1.4E-5	0.3
85	H-3	3.1E-4	6.0
88	C-11, U-235, U-238	3.8E-5	0.7
977	P-32	1.3E-8	< 0.1
978	P-32	5.8E-9	< 0.1
Total		5.2E-3	100

[a] Radionuclides that contribute more than 10% of the potential dose to the MEI from this source
[b] Dose from all radionuclides emitted; 1 mrem = 0.01 mSv
[c] Contributes 4% of the potential dose to the MEI from this source

3.3.2 Certification

I certify under penalty of law that I have personally examined and am familiar with the information submitted herein, and based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the submitted information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment (see 18 U.S.C. 1001).

Certified By: Date:

Howard Hatayama, Division Director
EH&S Division. Lawrence Berkeley National Lab

Certified By: Date:

Aundra Richards, Site Manager
DOE Berkeley Site Office

4

Additional Information

4.1 ADDITIONS OR MODIFICATIONS

There was no facility construction or modification (fabrication, erection, or installation) in 2008 relevant to the NESHAP regulation. Changes in work authorized included

- termination of radionuclide use in Building 52 and Building 64 in 2007 and
- authorization of radionuclide use in Building 978, the Joint BioEnergy Institute, in 2008.

4.2 UNPLANNED RELEASES

There were no unplanned releases in 2008 from the Berkeley Lab site.

4.3 DIFFUSE EMISSIONS

Berkeley Lab had one source of diffuse emissions in 2008 resulting from construction activities at the site of former Building 10. The soil at this site was found to be contaminated with low levels of natural uranium and was disposed of off-site at a low-level radioactive waste disposal site. Emissions from soil-handling activities were estimated using methods described in the EPA document, *Methods for Estimating Fugitive Air Emissions of Radionuclides from Diffuse Sources at DOE Facilities* (EPA 2004). The calculated dose from this diffuse source was very low, 4.0×10^{-6} mrem/y, which is less than 0.1% of the total dose to the Laboratory MEI.

5

Supplemental Information

5.1 COLLECTIVE DOSE ESTIMATE

Collective population dose is calculated as the average radiation dose to a person in a specified area, multiplied by the number of people in that area. In accordance with DOE and EPA guidance documents, all radionuclides potentially emitted in 2008 (shown in Table 4) were assumed to be released from a hypothetical, centrally located stack that is 52 ft (16 m) high, is 1 ft (0.3 m) in diameter, and has an exit velocity of 13.5 ft/s (4.1 m/s) (Wahl 2003). The total population within 50 mi (80 km) of the Laboratory is approximately 6,615,000 based on the LandScan Global Population Database (Dobson and Bright 2002; Gallegos 2002). The population file is provided in Attachment B. The estimated collective dose to persons living within 50 mi (80 km) of Berkeley Lab is 1.1×10^{-1} person-rem (1.1×10^{-3} person-Sv) attributable to Berkeley Lab airborne emissions in 2008.

5.2 40 CFR 61 SUBPARTS Q AND T

Subparts Q and T of 40 CFR 61 are not applicable to Berkeley Lab, as the Laboratory does not operate a storage and disposal facility for radium-containing material or uranium mill tailings.

5.3 RADON EMISSIONS

The Laboratory does not process, manage, or possess ^{232}U or ^{232}Th in quantities that could produce an impact of 0.1 mrem/yr (0.001 mSv/yr) or 10% of the nonradon dose to the public from ^{220}Rn. The Laboratory does not maintain nondisposal or nonstorage sources of ^{222}Rn emissions in quantities that could produce an impact of 0.1 mrem/yr (0.001 mSv/yr) or 10% of the nonradon dose to the public.

5.4 FACILITY COMPLIANCE

In 2008, no release points produced emissions exceeding 0.1 mrem/yr (0.001 mSv/yr) and no sources were subject to continuous monitoring requirements. Periodic confirmatory measurements were conducted in accordance with the EPA-approved measurement approach (Table 2).

References

DOE 1994: U.S. Department of Energy, "Calendar Year 1993 Radionuclide Air Emissions Annual Reports for DOE Sites," memo to DOE site offices providing guidance for report preparation (March 22, 1994).

Dobson and Bright 2002: Dobson, J. E., and E. A. Bright, *Landscan Global Population 1998 Database*, www.ornl.gov/gist/projects/LandScan/landscan_doc.htm (August 2002).

EPA 1989: U.S. Environmental Protection Agency, National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities, 40 CFR Part 61, Subpart H (1989, as amended).

EPA 2004: US Environmental Protection Agency, *Methods for Estimating Fugitive Air Emissions of Radionuclides from Diffuse Sources at DOE Facilities*, Final Report, Eastern Research Group, Inc. (September 3, 2004).

EPA 2006: U.S. Environmental Protection Agency, National Emission Standards for Hazardous Air Pollutants (Radionuclides), Availability of Updated Compliance Model, Federal Register, Vol. 71, No. 34, p. 8854 (February 21, 2006).

EPA 2007: U.S. Environmental Protection Agency, *CAP88-PC Version 3.0 User Guide*, Trinity Engineering Associates, Inc. (December 2007).

Gallegos 2002: Gallegos, G., "Estimating Populations for Collective Dose Calculations," *Health Physics*, Volume 83, Number 2, pages 283–286 (August 2002).

Jordan 2005: Jordan, D., "Request for Approval for LBNL to Revise Its Radionuclide NESHAP Monitoring Approach," memo from EPA Region 9 to R. Pauer, LBNL, documenting approval of monitoring approach (April 5, 2005).

MTC/ABAG 2000: Metropolitan Transportation Commission/Association of Bay Area Governments, *Bay Area Census*, 2000 census data website, http://www.bayareacensus.ca.gov/cities/cities.htm (accessed April 23, 2009).

Wahl 2003: Wahl, L., "Annual Calculation of Collective Dose from Airborne Radionuclides," memo ES-03-037 to file documenting stack parameters for collective dose calculations (October 9, 2003).

Wahl 2004: Wahl, L., "Agricultural Data Used in CAP88-PC," memo ES-05-003 to file documenting source of agricultural values used for collective dose calculations (October 26, 2004).

Appendix A

Meteorological Data

Wind Direction	Stability Category	2008 Average Wind Frequency at Given Speed					
		1-3 knots	4-6 knots	7-10 knots	11-16 knots	17- 21 knots	> 21 knots
N	A	.00148	.00091	.00000	.00000	.00000	.00000
NNE	A	.00114	.00046	.00000	.00000	.00000	.00000
NE	A	.00148	.00080	.00000	.00000	.00000	.00000
ENE	A	.00171	.00114	.00000	.00000	.00000	.00000
E	A	.00114	.00125	.00000	.00000	.00000	.00000
ESE	A	.00125	.00137	.00000	.00000	.00000	.00000
SE	A	.00137	.00046	.00000	.00000	.00000	.00000
SSE	A	.00080	.00068	.00000	.00000	.00000	.00000
S	A	.00228	.00103	.00000	.00000	.00000	.00000
SSW	A	.00228	.00160	.00000	.00000	.00000	.00000
SW	A	.00490	.00125	.00000	.00000	.00000	.00000
WSW	A	.00296	.00057	.00000	.00000	.00000	.00000
W	A	.00444	.00046	.00000	.00000	.00000	.00000
WNW	A	.00262	.00011	.00000	.00000	.00000	.00000
NW	A	.00103	.00171	.00000	.00000	.00000	.00000
NNW	A	.00091	.00148	.00000	.00000	.00000	.00000
N	B	.00046	.00023	.00000	.00000	.00000	.00000
NNE	B	.00046	.00011	.00000	.00000	.00000	.00000
NE	B	.00011	.00011	.00023	.00000	.00000	.00000
ENE	B	.00000	.00068	.00057	.00000	.00000	.00000
E	B	.00034	.00114	.00137	.00000	.00000	.00000
ESE	B	.00034	.00057	.00000	.00000	.00000	.00000
SE	B	.00125	.00137	.00023	.00000	.00000	.00000
SSE	B	.00786	.00649	.00125	.00000	.00000	.00000
S	B	.00581	.00490	.00011	.00000	.00000	.00000
SSW	B	.00570	.00376	.00011	.00000	.00000	.00000
SW	B	.00718	.00604	.00023	.00000	.00000	.00000

Wind Direction	Stability Category	2008 Average Wind Frequency at Given Speed					
		1-3 knots	4-6 knots	7-10 knots	11-16 knots	17- 21 knots	> 21 knots
WSW	B	.00581	.00775	.00057	.00000	.00000	.00000
W	B	.00581	.00330	.00023	.00000	.00000	.00000
WNW	B	.00216	.00057	.00000	.00000	.00000	.00000
NW	B	.00103	.00194	.00182	.00000	.00000	.00000
NNW	B	.00023	.00057	.00011	.00000	.00000	.00000
N	C	.00046	.00011	.00000	.00000	.00000	.00000
NNE	C	.00011	.00000	.00000	.00000	.00000	.00000
NE	C	.00011	.00000	.00000	.00000	.00000	.00000
ENE	C	.00046	.00023	.00103	.00080	.00000	.00000
E	C	.00023	.00046	.00205	.00080	.00000	.00000
ESE	C	.00046	.00023	.00057	.00046	.00000	.00000
SE	C	.00365	.00570	.00342	.00080	.00000	.00000
SSE	C	.00433	.00148	.00046	.00000	.00000	.00000
S	C	.00535	.00273	.00046	.00000	.00000	.00000
SSW	C	.00365	.00046	.00000	.00000	.00000	.00000
SW	C	.00399	.00239	.00000	.00000	.00000	.00000
WSW	C	.01151	.01823	.00467	.00000	.00000	.00000
W	C	.02017	.02962	.01310	.00011	.00000	.00000
WNW	C	.01060	.01276	.00251	.00046	.00000	.00000
NW	C	.00114	.00160	.00251	.00000	.00000	.00000
NNW	C	.00000	.00057	.00023	.00000	.00000	.00000
N	D	.00148	.00262	.00216	.00000	.00000	.00000
NNE	D	.00057	.00023	.00034	.00000	.00000	.00000
NE	D	.00080	.00011	.00023	.00000	.00000	.00000
ENE	D	.00046	.00046	.00296	.00182	.00034	.00000
E	D	.00570	.00228	.00308	.00273	.00046	.00011
ESE	D	.01424	.01618	.01401	.00308	.00046	.00000
SE	D	.00695	.01196	.00980	.00558	.00114	.00000

Wind Direction	Stability Category	2008 Average Wind Frequency at Given Speed					
		1-3 knots	4-6 knots	7-10 knots	11-16 knots	17- 21 knots	> 21 knots
SSE	D	.00194	.00000	.00046	.00057	.00000	.00000
S	D	.00308	.00011	.00011	.00011	.00000	.00000
SSW	D	.00148	.00000	.00023	.00000	.00000	.00000
SW	D	.00148	.00000	.00000	.00000	.00000	.00000
WSW	D	.00570	.00103	.00091	.00011	.00000	.00000
W	D	.02609	.01025	.00524	.00034	.00000	.00000
WNW	D	.02199	.02245	.01436	.00319	.00011	.00000
NW	D	.01253	.01276	.00479	.00000	.00000	.00000
NNW	D	.00456	.00968	.00923	.00000	.00000	.00000
N	E	.00148	.00194	.00034	.00000	.00000	.00000
NNE	E	.00160	.00034	.00000	.00000	.00000	.00000
NE	E	.00080	.00011	.00000	.00000	.00000	.00000
ENE	E	.00125	.00068	.00046	.00000	.00000	.00000
E	E	.00615	.00125	.00068	.00000	.00000	.00000
ESE	E	.00980	.00592	.00068	.00000	.00000	.00000
SE	E	.01037	.00695	.00023	.00000	.00000	.00000
SSE	E	.00342	.00000	.00023	.00000	.00000	.00000
S	E	.00034	.00000	.00000	.00000	.00000	.00000
SSW	E	.00011	.00000	.00000	.00000	.00000	.00000
SW	E	.00011	.00000	.00011	.00000	.00000	.00000
WSW	E	.00091	.00251	.00023	.00000	.00000	.00000
W	E	.00285	.00798	.00023	.00000	.00000	.00000
WNW	E	.00809	.00444	.00023	.00000	.00000	.00000
NW	E	.01037	.00399	.00011	.00000	.00000	.00000
NNW	E	.00467	.00752	.00205	.00000	.00000	.00000
N	F	.01071	.00262	.00000	.00000	.00000	.00000
NNE	F	.00501	.00103	.00000	.00000	.00000	.00000
NE	F	.00661	.00091	.00000	.00000	.00000	.00000

Wind Direction	Stability Category	2008 Average Wind Frequency at Given Speed					
		1-3 knots	4-6 knots	7-10 knots	11-16 knots	17- 21 knots	> 21 knots
ENE	F	.00524	.00194	.00000	.00000	.00000	.00000
E	F	.01344	.00353	.00023	.00000	.00000	.00000
ESE	F	.01937	.00160	.00000	.00000	.00000	.00000
SE	F	.02245	.00809	.00000	.00000	.00000	.00000
SSE	F	.02643	.00672	.00034	.00000	.00000	.00000
S	F	.01367	.00296	.00011	.00000	.00000	.00000
SSW	F	.01253	.00228	.00011	.00000	.00000	.00000
SW	F	.01390	.00513	.00000	.00000	.00000	.00000
WSW	F	.01276	.00991	.00000	.00000	.00000	.00000
W	F	.01561	.00444	.00000	.00000	.00000	.00000
WNW	F	.01527	.00171	.00000	.00000	.00000	.00000
NW	F	.01812	.00330	.00011	.00000	.00000	.00000
NNW	F	.01413	.00376	.00000	.00000	.00000	.00000

Appendix B

Population Data

Direction	Population at Given Distance from Center from Berkeley Lab												
	0.5 km	1 km	2 km	3 km	4 km	5 km	10 km	20 km	30 km	40 km	50 km	60 km	80 km
N	0	0	419	0	0	0	359	30398	98105	32491	68070	24776	1797
NNW	0	0	808	2443	2430	2793	2484	52319	0	993	11808	26337	116202
NW	0	2291	1278	1627	3649	3453	36003	78123	1753	43472	15539	61782	148052
WNW	0	0	3813	6632	7002	7163	22596	15684	91680	35109	2452	2444	987
W	0	0	0	6789	6941	3885	14	6636	45790	1780	588	0	0
WSW	0	0	4181	2416	7039	2982	24	158141	158570	0	0	0	0
SW	0	4530	4402	2967	7448	8834	5707	123614	429877	77558	8	0	0
SSW	0	0	3345	1553	8699	5591	51318	12682	26539	143163	20902	1540	218
S	0	0	2912	2404	6515	2818	107157	64082	0	120732	209651	39481	6338
SSE	0	1270	1096	716	3089	3224	41486	188837	171923	161075	158439	272632	1153570
SE	0	0	0	1122	796	1867	11308	12453	74898	49162	77674	9220	45859
ESE	0	0	51	189	0	0	4648	11966	64845	64822	69656	8301	38140
E	0	0	0	19	130	37	8755	61557	15866	2791	21010	12024	42996
ENE	0	0	40	2	98	1982	6467	76620	121897	96518	87328	10455	12356
NE	0	0	0	0	22	17	908	46933	19832	6565	727	1675	1447
NNE	346	0	0	0	0	6	19	5603	28838	7625	99040	93357	42715