Radionuclide Air Emission Report for 2005

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Environmental Services Group
Environment, Safety, and Health Division

Ernest Orlando Lawrence Berkeley National Laboratory

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Radionuclide Air Emission Report for 2005

(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: Carl Schwab **Phone**:(510) 486-4298

Site Information

Operator: University of California

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

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

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Synopsis

Berkeley Lab operates facilities where radionuclides are handled and stored that 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 2005, 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]), there were no diffuse emissions, and there were no unplanned emissions. Emissions from minor sources either were measured by sampling or monitoring or were calculated based on quantities received for use or produced during the year. Using measured and calculated emissions, and building-specific and common parameters, Laboratory personnel applied the EPA computer code, CAP88-PC, Version 2.0, to calculate the effective dose equivalent to the maximally exposed individual (MEI). The effective dose equivalent from all sources at Berkeley Lab is 0.019 mrem/yr (1.9×10^{-4} mSv/yr) to the MEI, well below the 10 mrem/yr (0.1 mSv/yr) dose standard. The location of the MEI is the University of California (UC) Lawrence Hall of Science, 1509 ft (460 m) east of Building 56. The estimated collective effective dose equivalent to persons living within 50 mi (80 km) of Berkeley Lab is 0.17 person-rem (0.0017 person-Sv) attributable to the Lab's airborne emissions.

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/tableforreports/tableforreports.htm.

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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, leading to the awarding of Nobel Prizes to eight more Berkeley Lab scientists.

The Laboratory supports work in such diverse fields as genomics, physical biosciences, 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. Its 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 203 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), with elevations ranging 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 102,743 and that of Oakland at 370,736.

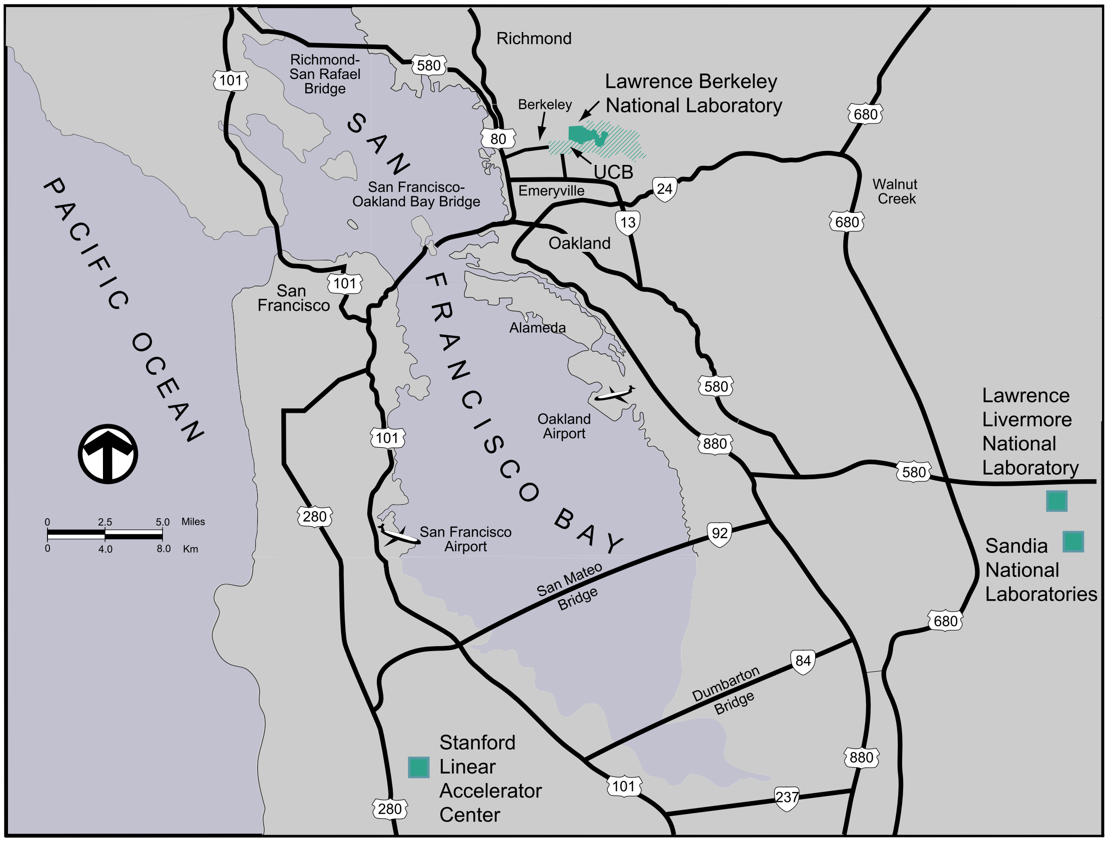

Figure 1 San Francisco Bay Area Map

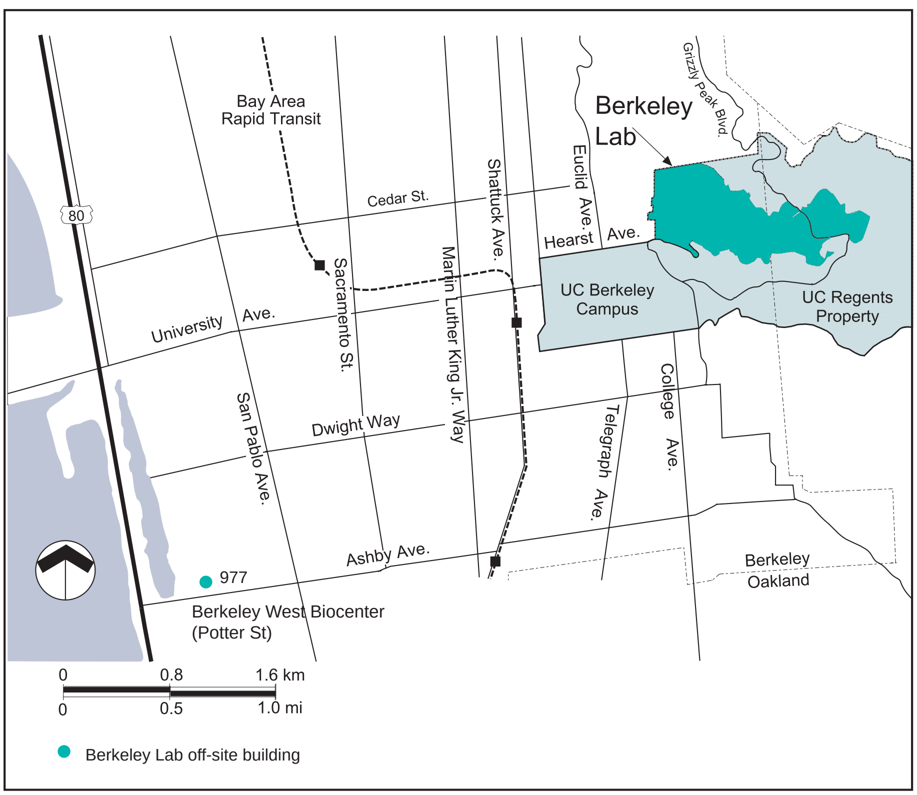

Figure 2 Vicinity Map

Adjacent land use consists of residential, institutional, and recreation 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 single-family homes 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 2005, precipitation totaled 43.4 in. (110.2 cm) and ambient temperature averaged 55.9°F (13.3°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 winds originating in 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 late 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 does not have any rare, threatened, or endangered species of plants present.

1.2 SOURCE DESCRIPTION

Berkeley Lab operates facilities where radionuclides are handled and stored that are subject to the EPA's NESHAP regulations. Figure 3 illustrates the Berkeley Lab general site configuration and locations of buildings (note that Building 977, the Berkeley West Biocenter on Potter Street, is off-site, as shown on Fig. 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, and in gloveboxes. In addition, radioactive gases are a by-product of charged-particle

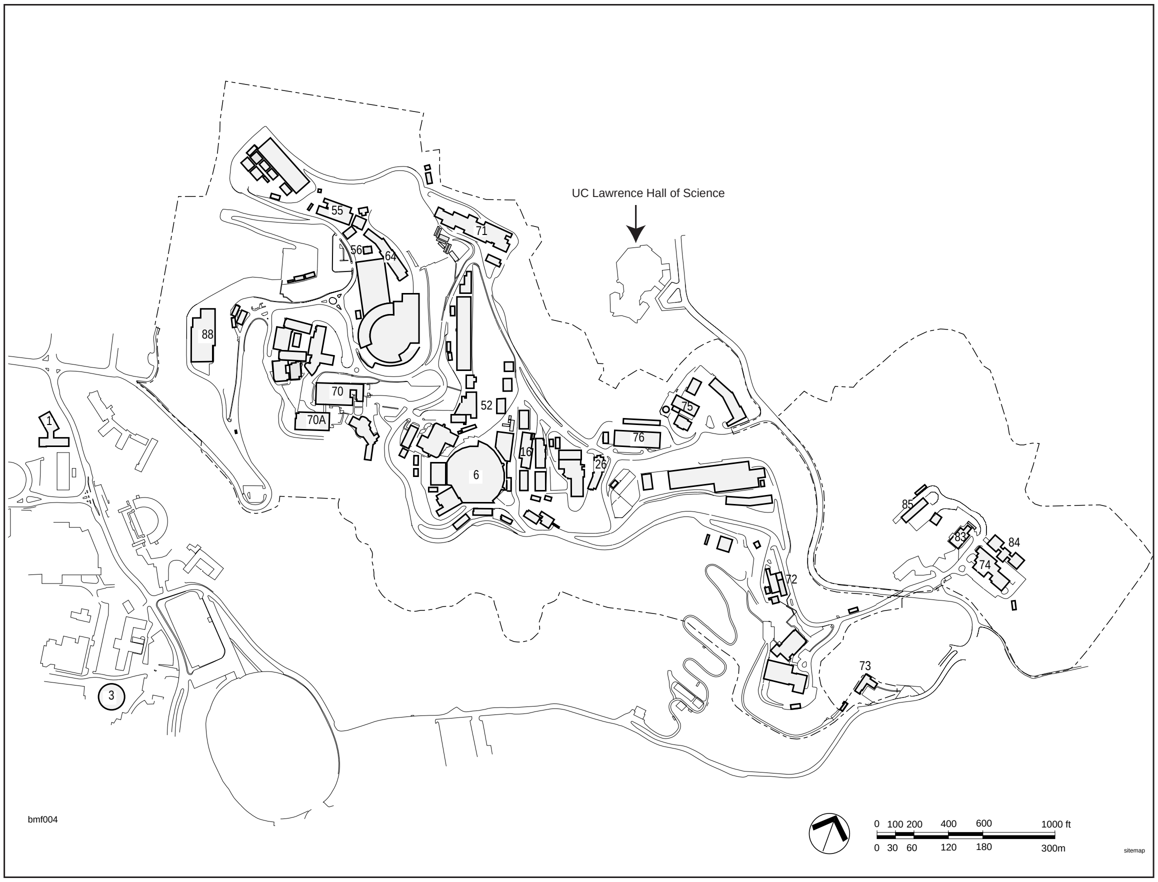

Figure 3 Berkeley Lab Buildings

accelerator operations. Radioactive gases produced by accelerator operations in Buildings 6, 56, and 88 include ^{11}C, ^{13}N, ^{15}O, and ^{18}F, which are short-lived radionuclides.

Radiochemical and radiobiological studies performed at Berkeley Lab typically use microcurie or 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 2005 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, P-33, S-35
3	Calvin Laboratory	C-14, H-3, P-32, P-33, S-35
6	Advanced Light Source (ALS)	Am-241, Am-243, Cm-243, Cm-246, Cm-248, Eu-152, Eu-154, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Pu-242, Sr-90, Tc-99, Th-232, U-233, U-235, U-238
16	Accelerator and Fusion Research	U-234, U-235, U-238
26	Radioanalytical Laboratory	Ac-227, activation products[a], Al-26, alpha, Am-241, As-74, Au-195, Au-198, Be-7, beta-gamma, Br-77, C-11, C-14, Cf-249, Cf-252, Co-56, Co-57, Co-58, Co-60, Cr-51, Cs-134, Cs-137, Cu-60, Eu-152, Eu-154, F-18, Fe-55, Fe-59, fission products, Ga-67, Ge-69, H-3, I-125, I-129, I-131, In-111, Mg-28, Mn-52, Mn-54, Na-21, Na-22, Ni-57, Np-237, Np-239, P-32, Pa-231, Pa-233, Pu-238, Pu-239, S-35, Sb-124, Sc-46, Sc-93, Se-75, Sr-90, U-232, V-48, Y-88, Zn-62, Zn-63, Zn-65, Zr-88
50B	Physics Research	Ag-105, Ag-106m, Au-194, Be-7, Co-56, Co-57, Co-58, Co-60, Mn-52, Mn-54, Na-22, Ni-57, Re-184m, Sc-46, Sc-48, Se-75, Ta-182, V-48, Zn-65
52	Accelerator and Fusion Research	Activation products, Am-241, Cf-250, Cm-243, Cm-248, Np-237, Pu-239, Pu-244, Th-229, Th-230, Th-232, U-232, U-235, U-236, U-238, Pu-242
55	Center for Functional Imaging	Activation products, C-11, C-14, Ce-141, Co-55, Co-57, Cr-51, Cu-64, F-17, F-18, 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, Zr-89
56	Biomedical Isotope Facility	Activation products, C-11, Co-55, Co-57, F-17, F-18, N-13, O-15, O-14, Zr-89
64	Life Sciences Research	P-32
70	Environmental Energy Technology, Nuclear Science, and Earth Sciences Research	Activation products, Am-241, Am-243, Bi-207, Bk-249, Ce-141, Ce-144, Cf-249, Cf-252, Cm-244, Cm-248, Er-165, Er-169, Er-171, Es-253, Es-254, Eu-152, Fe-59, fission products, Fm-257, H-3, Hf-172, Hf-175, Hf-181, Ho-166, Ho-166m, Mn-54, Na-22, Nb-95, Np-237, P-32, Pa-233, Pu-238, Pu-239, Ra-226, Rh-101, Rh-102, Sc-46, Sm-153, Sr-90, Ta-182, Tb-160, Tc-199, Te-125m, Th-229, Tl-204, Tm-170, U-233, U-235, U-238, Y-90, Yb-169, Zn-65, Zr-88, Zr-95
70A	Nuclear, Chemical, and Life Sciences Research	Activation products, Am-241, Am-243, Bk-249, C-11, C-14, Cf-249, Cf-250, Cf-252, Cm-243, Cm-244, Cm-245, Cm-246, Cm-248, Co-60, Cs-137, Es-253, Es-254, Eu-152, Eu-154, Eu-155, Fe-59, fission products, H-3, Kr-81, Kr-85, Ni-63, Ni-65, Np-237, Np-239, P-32, P-33, Pa-231, Pa-233, Pb-205, Pb-210, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Pu-244, Ra-226, Ru-106, S-35, Sr-90, Tc-99, Th-228, Th-229, Th-230, Th-232, U-232, U-233, U-234, U-235, U-236, U-238

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

Building	Building name/function	Radionuclides authorized by Berkeley Lab
72	Low-Background Facility	Ac-227, activation products[a], alpha, Am-241, Au-198, Be-7, C-11, Cf-249, Cf-252, Co-56, Co-57, Co-58, Co-60, Cr-51, Cs-134, Cs-137, Cu-60, Eu-152, Eu-154, Fe-55, Fe-59, fission products, Mn-54, Na-21, Na-22, Ni-57, Np-237, Np-239, P-32, Pa-231, Pa-233, Pu-239, Sb-124, Sc-46, Sc-93, Se-75, U-238, Zn-62, Zn-63, Zn-65
73	Life Sciences Research	H-3
74	Life Sciences Research	Am-241, C-11, C-14, Ce-141, Cu-64, F-18, Fe-59, H-3, I-123, I-131, N-13, Nb-95, Np-237, P-32, Pb-210, Pu-238, Ru-103, S-35, Sc-46, Sr-85, Tc-99, Tc-99m, Th-232, Tl-201, U-233, U-234/235, U-238
75	Radioanalytical Laboratory	Ac-227, activation products, Al-26, alpha, Am-241, As-74, Au-195, Au-198, Be-7, beta-gamma, Br-77, C-11, C-14, Cf-249, Cf-252, Co-56, Co-57, Co-58, Co-60, Cr-51, Cs-134, Cs-137, Cu-60, Eu-152, Eu-154, F-18, Fe-55, Fe-59, fission products, Ga-67, Ge-69, H-3, I-125, I-129, I-131, In-111, Mg-28, Mn-52, Mn-54, Na-21, Na-22, Ni-57, Np-237, Np-239, P-32, Pa-231, Pa-233, Pu-238, Pu-239, S-35, Sb-124, Sc-46, Sc-93, Se-75, Sr-90, U-232, V-48, Y-88, Zn-62, Zn-63, Zn-65, Zr-88
76	Radioanalytical Laboratory	Ac-227, activation products, Al-26, alpha, Am-241, As-74, Au-195, Au-198, Be-7, beta-gamma, Br-77, C-11, C-14, Cf-249, Cf-252, Co-56, Co-57, Co-58, Co-60, Cr-51, Cs-134, Cs-137, Cu-60, Eu-152, Eu-154, F-18, Fe-55, Fe-59, fission products, Ga-67, Ge-69, H-3, I-125, I-129, I-131, In-111, Mg-28, Mn-52, Mn-54, Na-21, Na-22, Ni-57, Np-237, Np-239, P-32, Pa-231, Pa-233, Pu-238, Pu-239, S-35, Sb-124, Sc-46, Sc-93, Se-75, Sr-90, U-232, V-48, Y-88, Zn-62, Zn-63, Zn-65, Zr-88
83	Life Sciences Research	C-14, H-3, P-32, P-33, S-35
84	Life Sciences Research	C-14, H-3, P-32, S-35
85	Hazardous Waste Handling Facility	Alpha, beta-gamma, C-14, H-3
88	88-Inch Cyclotron	Ac-227, actinide tracers, activation products, alpha, Am-241, Am-243, Au-198, Be-7, beta-gamma, C-11, C-14, Cd-109, Cf-249, Cf-252, Cm-246, Cm-248, Co-56, Co-57, Co-58, Co-60, Cr-51, Cs-134, Cs-137, Cu-60, Eu-152, Eu-154, F-17, F-18, Fe-55, Fe-59, fission products, gamma tracers, Gd-148, H-3, Mn-54, N-13, Na-21, Na-22, Ne-18, Ne-19, Ni-57, Np-237, Np-239, O-14, O-15, P-32, P-33, Pa-231, Pa-233, Pb-212, Pu-238, Pu-239, Pu-241, Pu-242, Pu-244, S-35, Sb-124, Sc-46, Sc-93, Se-75, Th-228, Th-229, Th-232, U (natural), Zn-62, Zn-63, Zn-65, Zr-89
977	Berkeley West Biocenter (Potter Street Facility)	C-14, Cd-109, H-3, P-32, P-33, 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). If the radionuclides emitted 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, the stack is considered a major source, and the EPA requires the Lab to measure its emissions continuously. Berkeley Lab has no major sources.

If the 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 2005, 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
- calculated based on quantities received for use 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.

Table 2 EPA-Approved Radionuclide Emissions Measurement Approach

Potential Dose (mrem/yr)[a]	Category	Requirements
dose $\geq$ 10.0	Non-compliant	Reduction or relocation of source term and reevaluation prior to authorization.
10.0 > dose $\geq$ 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 $\geq$ 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 $\geq$ 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. A third type of source is the diffuse source, a source of radionuclide emissions that are uniformly released from an area or emanate from a number of points randomly distributed over an area. Diffuse sources are not actively ventilated and their emissions may be measured or calculated, depending on potential dose from those emissions. 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). Note, however, that in 2005, Berkeley Lab had no diffuse sources. The total activity of each radionuclide from stack air measurements and calculations is shown in Table 4.

Table 3 Measurement Category of Sources

Building	Category 1	Category 2	Category 3	Category 4	Total
1	0	0	0	4	4
3	0	0	0	1	1
6	0	0	0	9	9
16	0	0	0	1	1
26	0	0	0	3	3
50B	0	0	0	1	1
52	0	0	0	0	0
55	0	0	0	10	10
56	0	0	2	0	2
64	0	0	0	1	1
70	0	0	0	9	9
70A	0	0	2	23	25
72	0	0	0	9	9
73	0	0	0	1	1
74	0	0	0	11	11
75	0	0	1	5	6
76	0	0	0	1	1
83	0	0	0	1	1
84	0	0	0	8	8
85	0	0	2	0	2
88	0	0	3	10	13
977	0	0	0	3	3
Total	**0**	**0**	**10**	**111**	**121**

Table 4 Total Activity Emitted in 2005

Radionuclide	Activity (Ci/yr)[a]	Radionuclide	Activity (Ci/yr)	Radionuclide	Activity (Ci/yr)
F-18	3.93E+00	U-232	1.35E-07	Ca-45	3.00E-11
C-11	2.42E+00	Pu-239	1.16E-07	Th-232	1.13E-11
H-3	1.16E-01	Ar-41	1.00E-07	Cf-252	1.08E-11
I-125	1.63E-03	O-15	9.40E-08	Ce-144	5.20E-12
I-123	8.00E-04	Am-243	5.40E-08	Co-58	5.20E-12
Tc-99m	2.25E-04	Pu-238	4.39E-08	Nb-97	5.20E-12
P-32	1.07E-04	Cm-244	1.63E-08	Pb-212	5.20E-12
S-35	5.73E-05	U-238	8.20E-09	Rb-83	5.20E-12
Tc-99	5.17E-05	U-235	8.03E-09	Xe-133	5.20E-12
N-13	1.80E-05	U-238	7.25E-09	Xe-135	5.20E-12
P-33	4.75E-06	Cm-243	1.33E-09	Y-91m	5.20E-12
Tl-201	4.00E-06	Np-239	1.16E-09	Eu-154	3.81E-12
I-131	2.00E-06	Fe-55	1.05E-09	Sr-90	2.70E-12
Ta-182	1.33E-06	Cf-249	2.97E-10	Th-229	2.00E-12
Fe-59	1.02E-06	Pu-239	2.61E-10	As-76	1.89E-12
Beta	8.11E-07	Th-232	2.11E-10	Ba-133	5.54E-13
Alpha	5.38E-07	Co-60	1.25E-10	U-234	4.05E-13
Np-237	3.95E-07	Cs-134	9.05E-11	La-140	1.58E-13
C-14	2.89E-07	Cs-137	8.29E-11	K-42	1.40E-13
Sc-46	2.51E-07	Th-228	7.00E-11	Zr-95	6.77E-14
Nb-95	2.50E-07	Mn-54	6.45E-11	Zr-97	8.75E-15
Ce-141	2.50E-07	Cd-109	6.24E-11	Na-24	5.24E-15
Ru-103	2.50E-07	Co-57	6.21E-11	Zn-69m	1.17E-15
Pu-242	2.22E-07	Zn-65	5.42E-11		
Am-241	1.99E-07	Ni-63	5.41E-11		
Total					6.47E+00

[a] 1 Ci = 3.7×10^{10} Bq

2.1 POINT SOURCES: MEASURED EMISSIONS

Berkeley Lab measures emissions from stacks or other exhaust points if the potential dose from the sources could exceed 0.01 mrem/yr (1.0×10^{-4} mSv/yr). Additionally, Berkeley Lab may choose to measure emissions from stacks with less dose impact 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 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 changed out after a month, and the radionuclides collected on the media are analyzed either at a commercial laboratory or an on-site laboratory.

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 TEDA-DAC[a]	> 99 > 75
56	2	56-Accelerator 56-Glovebox	3 3	None[b]	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] Triethylene diamine (TEDA)-doped activated carbon traps
[b] Radionuclides emitted from accelerators are short-lived activation products, for which emission control is impractical

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).

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. Table 5 shows effluent controls on sampled and monitored stacks.

2.2 GROUP SOURCES: CALCULATED EMISSIONS

Berkeley Lab calculates emissions from stacks or other exhaust points if the potential dose from the sources is less than 0.01 mrem/yr (1.0×10^{-4} mSv/yr). These Category 4 sources (typically radioactive material areas where small amounts of radionuclides are authorized for use) are grouped by building to simplify reporting, as shown in Table 6 (DOE 1994). The amount of each radionuclide emitted is calculated by multiplying the entire quantity of that radionuclide received 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.

Emissions are 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

Table 6 Sources for Which Radionuclide Emissions are Calculated

Building	Number of Radioactive Material Areas	Emissions control	Efficiency (%)
1	4	None	NA[a]
3	1	None	NA
6	9	None	NA
16	1	None	NA
26	3	None	NA
50B	1	None	NA
52	0	None	NA
55	10	None	NA
64	1	None	NA
70	9	None	NA
70A	23	None	NA
72	9	None	NA
73	1	None	NA
74	11	HEPA None	> 99 NA
75	5	None	NA
76	1	None	NA
83	1	HEPA TEDA-DAC[b]	> 99 > 75
84	8	None	NA
88	10	HEPA	> 99
977	3	None	NA

[a] Not applicable
[b] TEDA-doped activated carbon traps

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 no diffuse emissions in 2005.

3

Dose Assessment

3.1 DOSE MODEL

To comply with NESHAP regulations and DOE guidance, the EPA atmospheric dispersion and radiation dose calculation computer code, CAP88-PC, Version 2.0, was used to calculate the dose at various distances and from various release points (Chaki 1999). For buildings 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 was calculated for individual Laboratory buildings and summed for the entire facility. As identified in Figures 2 and 3, Buildings 1, 3, and 977 (the Berkeley West Biocenter on Potter Street) are located outside of Berkeley Lab's main perimeter and could be considered separate facilities since they are not on one contiguous site. However, Buildings 1 and 3 are located on the adjacent UC Berkeley campus and are within walking distance of the main Berkeley Lab site. Building 977 is located about 3.1 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. Thus, it would be inappropriate and misleading to model and report these much lower doses separately. Therefore, for reporting and dose-modeling purposes, all of these off-site buildings are considered as being on one contiguous Berkeley Lab site.

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 2, provides a library of 265 radionuclides; however, this library does not include all of the radionuclides listed in Table 4. For radionuclides not included in the library, EPA has approved the interim use of surrogates at Berkeley Lab (Attachment A). The Laboratory selects a surrogate radionuclide that is similar to the actual radionuclide in its metabolic behavior, mode of decay, and decay energy. Note that the dose from surrogates to the sitewide MEI is very low: in 2005, the dose from surrogates is about 0.004% 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.

Input to the CAP88-PC dose calculations were reviewed and verified by an internal peer reviewer. The reviewer followed EHS Procedure 217, *Auditing Radionuclide NESHAP Compliance*, to verify source terms used as input into CAP88-PC and to check accuracy and completeness of CAP88-PC output data presented in this report. The reviewer determined that doses were calculated in compliance with Berkeley Lab procedures and with NESHAP regulations.

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. For combined buildings and buildings with many unmeasured stacks, average stack height and conservative stack diameter (0.1 m), exit velocity (0 m/s), and distance (from nearest edge of building) values are used (Table 7). These values overestimate the impact of air emissions on a nearby resident and are chosen to ensure that stack emissions are not underestimated.

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
3	15	0.1	0	30 m S	1060 m NE	4200 m N
6/16/52	9	0.1	0	350 m NNE	350 m NNE	3200 m N
26/76	8	0.1	0	250 m N	250 m N	3200 m N
55/56/64	16	0.1	0	250 m NNW	460 m E	3200 m N
70/70A/50B	16	0.1	0	200 m NW	530 m ENE	3200 m N
72	3	0.1	0	230 m SSW	500 m NW	3200 m N
73/74/83/84	7	0.1	0	160 m SSE	690 m WNW	3200 m N
75				110 m NW	110 m NW	3200 m N
Stack 1	8.5	0.91	7.0			
Stack 2	6.7	0.53	7.7			
Stack 3	7.4	0.35	6.5			
85	16	0.1	0	210 m SSE	570 m WNW	3200 m N
88	13	0.1	0	110 m W	690 m ENE	3200 m N
977	16	0.1	0	30 m	5000 m NE	8200 m N

[a] 1 m = 3.281 ft
[b] Approximate distance to Wildcat Canyon Regional Preserve where cattle graze

For Building 75, where each stack correlates to a single operation, the actual stack diameter and exit velocity for stacks 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 2005. 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 (43.4 in. [110.2 cm]) and annual ambient temperature (55.9°F [13.3°C]) were used. The default value for lid (mixing) height, 3281 ft (1000 m), was chosen. The 2005 wind data are provided in Attachment B.

Agricultural data were obtained from the California Department of Food and Agriculture and the urban scenario was chosen, thereby overestimating the impact of air emissions on a resident of Berkeley Lab site (Wahl 2004). The values include

- 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 is 0.019 mrem/yr (1.9×10^{-4} mSv/yr) to the MEI. The location of this hypothetical person is the UC Lawrence Hall of Science, 1509 ft (460 m) east of Buildings 55 and 56.

Although no one actually lives at the Hall of Science, the dose is calculated 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 contaminated water. Thus the calculated dose to this hypothetical person, the MEI, is greater than the dose to an actual Berkeley resident.

Table 8 Dose Assessment Results

Building	Primary radionuclides emitted[a]	Dose to MEI (mrem/yr)[b]	Percent of total dose (%)
1	P-32, S-35	1.1E-6	< 0.1
3	P-32, P-33, S-35	1.9E-6	< 0.1
6/16/52	U-235, U-238	4.9E-6	< 0.1
26/76	Am-241, Np-237, Pu-238, Pu-239	3.8E-4	2.0
55/56/64	I-125, F-18	1.7E-2	89.3
70/70A/50B	Am-241, Np-237, Pu-242, Alpha, U-238	5.9E-4	3.1
72	U-238	3.0E-5	0.2
73/74/83/84	P-32	2.2E-5	0.1
75	H-3, Alpha	5.0E-4	2.6
85	H-3, Alpha	1.1E-4	0.6
88	C-11	4.0E-4	2.1
977	P-32	7.6E-8	< 0.1
Total		1.9E-2	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 = 0.1 mSv

Fluorine-18 emitted from Building 56 stacks accounts for about 58% of the dose to the Berkeley Lab MEI; about 32% of the dose is due to ^{125}I 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 absorbs onto the real-time detectors, causing over-measurement and calculated doses that are not correlated with laboratory activities. These false positive measurements are included in the calculation of annual ^{18}F emissions.

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 2, users' guide (EPA 2000). The two outputs are identical, indicating that the code performed as intended.

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).

Signature: [signature] for Date: 5/23/06

Howard Hatayama
Acting Director of Environment, Health, and Safety Division
Lawrence Berkeley National Laboratory

Signature: Aundra Richards Date: 5/23/06

Aundra Richards
Director
DOE Berkeley Site Office

4

Additional Information

4.1 ADDITIONS OR MODIFICATIONS

There were no facility additions or modifications in 2005. There were, however, changes in emissions measurement and reporting in 2005, based primarily on a revised approach to measuring emissions approved by EPA on April 5, 2005 (see Table 2). Changes from last year's report include deletion and addition of stack sampling locations and decreases in sampling frequency.

At the following Category 4 sampling locations, potential doses were less than 0.01 mrem/yr (1.0×10^{-4} mSv/yr) so sampling was not required under the revised measurement approach and was discontinued.

- 70-103, -203, and -209 fumehood stacks
- 70A-1129 and -1145 storage cabinet stacks
- 70A-2211 and -2217 fumehood and glovebox stacks
- 75-103 and -107 stacks
- Building 88 East Alley Mezzanine fumehood stack

The following sampling locations were sampled less frequently, in accordance with the revised approach to emissions measurements.

- 70A-1129 fumehood stack (from weekly to monthly sampling)
- 70A-1129, -1145, -1149 glovebox stack (from weekly to monthly sampling)
- 75-127 fumehood stack (from monthly to quarterly sampling)
- Building 85 glovebox and fumehood stacks (from weekly to quarterly sampling)
- 88-135 fumehood stack (from monthly to quarterly sampling)
- Building 88 cave glovebox stack (from weekly to quarterly sampling)

Other changes in 2005 included authorization for use of radionuclides in Building 50B (grouped with Buildings 70 and 70A for dose calculation purposes), Building 73 (grouped with Buildings 74, 83, and 84), and Building 977 (the Berkeley West Biocenter on Potter Street). No work with radionuclides was performed in Building 71 in 2005.

4.2 UNPLANNED RELEASES

There were no unplanned releases in 2005.

4.3 DIFFUSE EMISSIONS

In 2005, no area sources were identified that potentially presented a source of fugitive emissions to the public.

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 2005 (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). Because CAP88-PC, Version 2.0, can only model 36 radionuclides at a time, the population dose assessment was performed in three runs, and the results of the three runs were summed. 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 C. The estimated collective dose to persons living within 50 mi (80 km) of Berkeley Lab is 0.17 person-rem (0.0017 person-Sv) attributable to Berkeley Lab airborne emissions.

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 (1×10^{-6} Sv/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 (1×10^{-6} Sv/yr) or 10% of the nonradon dose to the public.

5.4 FACILITY COMPLIANCE

In 2005, no release points produced emissions exceeding 0.1 mrem/yr (1.0×10^{-3} 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).

Chaki 1999: "CAP88-PC Windows Version 2.0," memo to F. Marcionwski, U.S. Environmental Protection Agency, documenting approval of CAP88-PC Version 2.0 (October 25, 1999).

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 Standard for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities*, 40 CFR Part 61, Subpart H (1989, as amended).

EPA 2000: U.S. Environmental Protection Agency, *Updated Users' Guide for CAP88-PC, Version 2.0*, EPA report 402-R-00-004 (March 2000).

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

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).

Acronyms and Abbreviations

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
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

Attachments

ATTACHMENT A: EPA APPROVAL OF SURROGATES

ATTACHMENT B: METEOROLOGICAL DATA

ATTACHMENT C: POPULATION DATA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

APR 13 2006

OFFICE OF
AIR AND RADIATION

Ron Pauer
Environmental Services Group Leader
Lawrence Berkeley National Laboratory
One Cyclotron Road
Berkeley, CA 94720

Dear Mr. Pauer:

Linnea Wahl of your staff has been in discussions with EPA Region IX and headquarters regarding the use of the CAP88-PC model to estimate dose from the Lawrence Berkeley National Lab's (LBNL) operations. A draft proposal dated March 7, 2006 was sent by you to Dick Lessler of EPA, Region IX and Behram Shroff at EPA, HQ.

Your proposal states that LBNL uses certain radionuclides for research purposes that are not found in the suite of radionuclides available within CAP88-PC version 2. In order to calculate the facility's dose consistent with subpart H of 40 CFR Part 61, LBNL's proposal seeks to use surrogates for those radionuclides not found in CAP88-PC version 2. We understand these surrogates are being used to prepare the 2005 Annual National Emission Standards for Hazardous Air Pollutants (NESHAP) Report, which is due at EPA in June 2006.

EPA agrees with LBNL's proposal to use the identified surrogates in place of those radionuclides not currently found in CAP-88 version 2. These radionuclides and their associated surrogates can be found in the attachment to LBNL's draft proposal and as Table 1 to this letter. EPA understands the choice of surrogates to be based on similarities in biological, chemical and radiological properties to those radionuclides not currently found in the model. Based on an independent scientific evaluation, EPA believes these surrogates reasonably capture the expected dose contribution from the radionuclides being represented. The doses attributable to these surrogates are expected to be very low compared to the regulatory standard.

As you know, EPA has been developing a more comprehensive version of the CAP-88 model (version 3) which will include most, if not all, of these identified radionuclides. It is still being checked for errors and will be available for use in Fall, 2006.

In light of the limitations of CAP88-PC version 2 and the adequacy of the surrogates proposed by LBNL for estimating dose, EPA approves LBNL's use of surrogates for regulatory compliance regarding the 2005 Annual NESHAP Report. Should you or your staff have any questions, please contact Behram Shroff at 202-343-9707.

Sincerely,

Bonnie Gitlin, Acting Director
Radiation Protection Division

Table 1: Table of Surrogates

cc: Susan Stahle, OGC
Dick Lessler, R9

Table I. Surrogates for Radionuclides Used at Berkeley Lab in 2005

Radio-nuclide	Half-Life[a]	Decay Mode[b]	Lung Class[c]	DAC[d] (μCi/cm^3)	DCF[e] (mrem/μCi)	Limiting Organ	Surrogate	Half-Life	Decay Mode	Lung Class	DAC (μCi/cm^3)	DCF[f] (mrem/μCi)	Limiting Organ
New Surrogates													
^{42}K	12.4 h	beta, gamma	D	2.00E-06	1.36E+00	whole body	^{40}K	1.3E9 y	beta, gamma	D	2.00E-07	1.20E+01	whole body
^{83}Rb	86.2 d	gamma	D	4.00E-07	4.92E+00	whole body	^{86}Rb	18.7 d	beta, gamma	D	3.00E-07	6.62E+00	whole body
Previously Approved Surrogates													
Activation products	NA[g]	beta, gamma	NA	NA	NA	NA	^{60}Co	5.3 y	beta, gamma	Y	1.00E-08	2.19E+02	whole body
Alpha	NA	alpha	NA	NA	NA	NA	^{232}Th	1.5E10 y	alpha	W	5.00E-13	4.11E+07	bone
^{108}Ag	2.4 m	beta, gamma	NA	NA	1.24E+04[h]	submersion	^{111}Ag	7.5 d	beta, gamma	W	4.00E-07	1.72E+04[h]	submersion
^{195}Au	183.0 d	EC, gamma	Y	2.00E-07	1.30E+01	whole body	^{58}Co	70.9 d	pos, gamma, EC	Y	3.00E-07	1.09E+01	whole body
^{198}Au	2.7 d	beta, gamma	Y	7.00E-07	3.28E+00	whole body	^{192}Ir	73.8 d	beta, gamma	Y	9.00E-08	2.93E+01	whole body
Beta	NA	beta	NA	NA	NA	NA	^{90}Sr	28.8 y	beta	Y	2.00E-09	1.30E+03	whole body
^{207}Bi	38.0 y	gamma	W	1.00E-07	2.00E+01	whole body	^{181}Hf	42.4 d	beta, gamma	W	2.00E-07	1.29E+01	whole body
^{249}Bk	320.0 d	beta	W	7.00E-10	1.39E+03	bone	^{241}Pu	14.4 y	beta	W	1.00E-10	8.25E+03	bone
^{76}Br	16.0 h	pos, gamma	D	2.00E-06	1.24E+00	whole body	^{82}Br	1.471 d	beta, gamma	D	2.00E-06	1.22E+00	whole body
^{77}Br	2.4 d	EC, gamma	W	8.00E-06	2.76E-01	whole body	^{64}Cu	12.7 h	EC, beta, pos, gamma	W	1.00E-05	2.56E-01	whole body
^{45}Ca	162.7 d	beta	W	4.00E-07	6.62E+00	whole body	^{90}Sr	28.8 y	beta	Y	2.00E-09	1.30E+03	whole body
^{49}Ca	8.7 m	beta, gamma	NA	NA	NA	NA	^{92}Sr	2.7 h	beta, gamma	Y	3.00E-06	8.10E-01	whole body
^{109}Cd	464.0 d	gamma, EC	Y	5.00E-08	4.51E+01	whole body	^{60}Co	5.3 y	beta, gamma	Y	1.00E-08	2.19E+02	whole body
^{249}Cf	350.6 y	alpha, gamma	Y	4.00E-12	4.81E+06	bone	^{245}Cm	8500 y	alpha, gamma	W	3.00E-12	8.29E+06	bone
^{250}Cf	13.1 y	alpha, gamma	W	4.00E-12	5.40E+06	bone	^{241}Am	432 y	alpha, gamma	W	3.00E-12	8.03E+06	bone
^{251}Cf	900 y	alpha, gamma	W	2.00E-12	1.25E+07	bone	^{241}Am	432 y	alpha, gamma	W	3.00E-12	8.03E+06	bone
^{55}Co	17.5 h	pos, gamma, EC	Y	1.00E-06	2.09E+00	whole body	^{58}Co	70.9 d	pos, gamma, EC	Y	3.00E-07	1.09E+01	whole body
^{56}Co	78.8 d	pos, gamma, EC	Y	8.00E-08	3.96E+01	whole body	^{60}Co	5.3 y	beta, gamma	Y	1.00E-08	2.19E+02	whole body

Radio-nuclide	Half-Life[a]	Decay Mode[b]	Lung Class[c]	DAC[d] (μCi/cm³)	DCF[e] (mrem/μCi)	Limiting Organ	Surrogate	Half-Life	Decay Mode	Lung Class	DAC (μCi/cm³)	DCF[f] (mrem/μCi)	Limiting Organ
^{62}Cu	9.7 m	pos, EC, gamma	NA	NA	NA	NA	^{64}Cu	12.7 h	EC, beta, pos, gamma	W	1.00E-05	2.56E-01	whole body
^{165}Er	10.4 h	EC	W	8.00E-05	2.99E-02	whole body	^{181}W	121.2 d	EC, gamma	D	1.00E-05	1.51E-01	whole body
^{169}Er	9.4 d	beta	W	1.00E-06	2.09E+00	whole body	^{151}Pm	28.4 h	beta, gamma	W	1.00E-06	1.62E+00	whole body
^{171}Er	7.5 h	beta, gamma	W	4.00E-06	5.62E-01	whole body	^{152m}Eu	9.3 h	beta, gamma	W	3.00E-06	8.18E-01	whole body
^{253}Es	20.5 d	alpha	W	6.00E-10	3.96E+03	whole body	^{236}U	2.3E7 y	alpha	W	3.00E-10	7.44E+03	whole body
^{254}Es	275.7 d	alpha, gamma	W	3.00E-11	6.96E+05	bone	^{239}Pu	2.4E4 y	alpha, gamma	W	3.00E-12	7.81E+06	bone
^{149}Eu	93.1 d	EC, gamma	W	1.00E-06	9.62E+00	whole body	^{181}Hf	42.4 d	beta, gamma	W	2.00E-07	1.29E+01	whole body
^{17}F	64.5 s	pos, EC	NA	NA	NA	NA	^{18}F	1.8 h	pos, EC	NA	NA	NA	NA
Fission products	NA	beta	NA	NA	NA	NA	^{137}Cs	30.0 y	beta, gamma	D	6.00E-08	3.19E+01	whole body
^{257}Fm	100.5 d	alpha, gamma	W	7.00E-11	2.85E+05	bone	^{239}Pu	2.4E4 y	alpha, gamma	W	3.00E-12	7.81E+06	bone
^{153}Gd	241.6 d	EC, gamma	D	6.00E-08	2.38E+01	bone	^{210}Pb	22.3 y	beta, gamma	D	1.00E-10	5.37E+03	bone
^{194}Hg	520 y	EC	D	1.00E-08	1.81E+02	whole body	^{152}Eu	13.5 y	EC, beta, gamma	W	1.00E-08	2.21E+02	whole body
^{172}Hf	1.9 y	EC, gamma	D	4.00E-09	3.18E+02	bone	^{210}Pb	22.3 y	beta, gamma	D	1.00E-10	5.37E+03	bone
^{175}Hf	70.0 d	EC, gamma	D	4.00E-07	5.59E+00	bone	^{210}Pb	22.3 y	beta, gamma	D	1.00E-10	5.37E+03	bone
^{111}In	2.8 d	EC, gamma	W	3.00E-06	8.40E-01	whole body	^{152m}Eu	9.3 h	beta, gamma	W	3.00E-06	8.18E-01	whole body
^{76}Kr	14.8 h	gamma	NA	9.00E-06	2.87E+05[h]	submersion	^{87}Kr	1.3 h	beta, gamma	NA	5.00E-06	5.25E+05[h]	submersion
^{77}Kr	1.2 h	EC, gamma	NA	4.00E-06	6.73E+05[h]	submersion	^{87}Kr	1.3 h	beta, gamma	NA	5.00E-06	5.25E+05[h]	submersion
^{79}Kr	1.5 d	EC, pos, gamma	NA	2.00E-05	1.66E+05[h]	submersion	^{85m}Kr	4.5 h	beta, gamma	NA	2.00E-05	1.10E+05[h]	submersion
^{81}Kr	2.3E5 y	EC, gamma	NA	7.00E-04	3.89E+03[h]	submersion	^{85m}Kr	4.5 h	beta, gamma	NA	2.00E-05	1.10E+05[h]	submersion
^{18}Ne	1.7 s	pos, gamma	NA	NA	NA	NA	^{18}F	1.8 h	pos, EC	NA	NA	NA	NA
^{19}Ne	17.2 s	pos, gamma	NA	NA	NA	NA	^{18}F	1.8 h	pos, EC	NA	NA	NA	NA
^{15}O	122.2 s	pos, EC	NA	NA	NA	NA	^{14}O	70.6 s	pos, gamma	NA	NA	NA	NA
^{185}Os	93.6 d	EC, gamma	D	2.00E-07	1.03E+01	whole body	^{54}Mn	312.1 d	EC, gamma	W	3.00E-07	6.70E+00	whole body
^{33}P	25.4 d	beta	W	1.00E-06	2.32E+00	whole body	^{32}P	14.3 d	beta	W	2.00E-07	1.55E+01	whole body
^{184}Re	38.0 d	EC, gamma	W	6.00E-07	5.14E+00	whole body	^{99}Mo	66.0 h	beta, gamma	Y	6.00E-07	3.96E+00	whole body

Radio-nuclide	Half-Life[a]	Decay Mode[b]	Lung Class[c]	DAC[d] (μCi/cm^3)	DCF[e] (mrem/μCi)	Limiting Organ	Surrogate	Half-Life	Decay Mode	Lung Class	DAC (μCi/cm^3)	DCF[f] (mrem/μCi)	Limiting Organ
^{101}Rh	3.3 y	EC, gamma	Y	6.00E-08	3.96E+01	whole body	^{93}Mo	3500 y	EC, gamma	Y	8.00E-08	2.84E+01	whole body
^{102}Rh	207.0 d	EC, beta, gamma	Y	2.00E-08	1.20E+02	whole body	^{60}Co	5.3 y	beta, gamma	Y	1.00E-08	2.19E+02	whole body
^{49}Sc	57.3 m	beta, gamma	Y	2.00E-05	1.02E-01	whole body	^{46}Sc	83.8 d	beta, gamma	Y	1.00E-07	2.96E+01	whole body
^{75}Se	119.8 d	EC, gamma	W	3.00E-07	8.47E+00	whole body	^{76}As	26.3 h	beta, gamma	W	6.00E-07	3.70E+00	whole body
^{182}Ta	115.0 d	beta, gamma	Y	6.00E-08	4.48E+01	whole body	^{181}Hf	42.4 d	beta, gamma	W	2.00E-07	1.29E+01	whole body
^{44}Ti	59.9 y	EC, gamma	Y	2.00E-09	1.02E+03	whole body	^{144}Ce	284.6 d	beta, gamma	Y	6.00E-09	3.73E+02	whole body
^{201}Tl	3.0 d	EC, gamma	D	9.00E-06	2.35E-01	whole body	^{67}Ga	3.3 d	EC, gamma	D	6.00E-06	3.52E-01	whole body
^{204}Tl	3.8 y	beta, EC	D	9.00E-07	2.41E+00	whole body	^{214}Pb	26.8 m	beta, gamma	D	3.00E-07	7.81E+00	whole body
^{170}Tm	128.6 d	beta, gamma	W	9.00E-08	2.63E+01	whole body	^{181}Hf	42.4 d	beta, gamma	W	2.00E-07	1.29E+01	whole body
^{239}U	23.5 m	beta, gamma	Y	6.00E-05	3.74E-02	whole body	^{240}U	14.1 h	beta, gamma	Y	1.00E-06	2.27E+00	whole body
^{88}Y	106.6 d	EC, gamma	Y	1.00E-07	2.81E+01	whole body	^{90}Y	64.0 h	beta, gamma	Y	3.00E-07	8.44E+00	whole body
^{169}Yb	32.0 d	EC, gamma	W	4.00E-07	6.99E+00	whole body	^{113}Sn	115.1 d	EC, gamma	W	5.00E-07	1.07E+01	whole body
^{62}Zn	9.3 h	EC, pos, gamma	Y	1.00E-06	2.06E+00	whole body	^{58}Co	70.9 d	pos, gamma, EC	Y	3.00E-07	1.09E+01	whole body
^{88}Zr	83.4 d	EC, gamma	D	9.00E-08	2.12E+01	whole body	^{110m}Ag	249.9 d	beta, gamma	D	5.00E-08	3.96E+01	whole body
^{89}Zr	3.3 d	pos, gamma, EC	Y	1.00E-06	2.37E+00	whole body	^{95}Zr	64.0 d	beta, gamma	Y	1.00E-07	2.33E+01	whole body
^{97}Zr	16.8 h	beta, gamma	Y	5.00E-07	4.33E+00	whole body	^{99}Mo	66.0 h	beta, gamma	Y	6.00E-07	3.96E+00	whole body

[a] s = seconds; m = minutes; h = hours; d = days; y = years
[b] EC = electron capture; IT = isomeric transition; pos = positron production
[c] Lung clearance classes: D = days; W = weeks; Y = years
[d] Derived air concentration
[e] Dose conversion factor
[f] If surrogate DCF is less than DCF for radionuclide of interest, increase activity emitted by multiplying by ratio of DCF (radionuclide of interest) to DCF (surrogate)
[g] Not available or applicable
[h] Submersion DCF in mrem/h/microCi/cm^3

ATTACHMENT B: METEOROLOGICAL DATA

Wind Direction	Stability Category	Wind Frequency at Given Speed					
		1-3 knotts	4-6 knotts	7-10 knotts	11-16 knotts	17- 21 knotts	> 21 knotts
N	A	.00069	.00011	.00000	.00000	.00000	.00000
NNE	A	.00046	.00000	.00000	.00000	.00000	.00000
NE	A	.00046	.00011	.00000	.00000	.00000	.00000
ENE	A	.00080	.00160	.00000	.00000	.00000	.00000
E	A	.00137	.00228	.00000	.00000	.00000	.00000
ESE	A	.00126	.00217	.00000	.00000	.00000	.00000
SE	A	.00171	.00023	.00000	.00000	.00000	.00000
SSE	A	.00171	.00057	.00000	.00000	.00000	.00000
S	A	.00320	.00114	.00000	.00000	.00000	.00000
SSW	A	.00308	.00206	.00000	.00000	.00000	.00000
SW	A	.00377	.00183	.00000	.00000	.00000	.00000
WSW	A	.00525	.00171	.00000	.00000	.00000	.00000
W	A	.00525	.00103	.00000	.00000	.00000	.00000
WNW	A	.00400	.00023	.00000	.00000	.00000	.00000
NW	A	.00217	.00069	.00000	.00000	.00000	.00000
NNW	A	.00183	.00114	.00000	.00000	.00000	.00000
N	B	.00034	.00046	.00000	.00000	.00000	.00000
NNE	B	.00011	.00011	.00000	.00000	.00000	.00000
NE	B	.00011	.00000	.00011	.00000	.00000	.00000
ENE	B	.00000	.00091	.00114	.00000	.00000	.00000
E	B	.00023	.00137	.00126	.00000	.00000	.00000
ESE	B	.00046	.00069	.00011	.00000	.00000	.00000
SE	B	.00114	.00046	.00000	.00000	.00000	.00000
SSE	B	.00343	.00503	.00114	.00000	.00000	.00000
S	B	.00537	.00491	.00114	.00000	.00000	.00000
SSW	B	.00880	.00605	.00034	.00000	.00000	.00000
SW	B	.00971	.00674	.00046	.00000	.00000	.00000
WSW	B	.00982	.01736	.00091	.00000	.00000	.00000
W	B	.01188	.01062	.00160	.00000	.00000	.00000
WNW	B	.00468	.00114	.00011	.00000	.00000	.00000
NW	B	.00114	.00103	.00034	.00000	.00000	.00000
NNW	B	.00069	.00011	.00000	.00000	.00000	.00000

Wind Direction	Stability Category	Wind Frequency at Given Speed					
		1-3 knotts	4-6 knotts	7-10 knotts	11-16 knotts	17- 21 knotts	> 21 knotts
N	C	.00011	.00000	.00000	.00000	.00000	.00000
NNE	C	.00000	.00000	.00000	.00000	.00000	.00000
NE	C	.00000	.00000	.00011	.00000	.00000	.00000
ENE	C	.00011	.00057	.00160	.00080	.00000	.00000
E	C	.00023	.00057	.00171	.00069	.00000	.00000
ESE	C	.00091	.00228	.00034	.00011	.00000	.00000
SE	C	.00434	.00640	.00137	.00103	.00000	.00000
SSE	C	.00628	.00320	.00251	.00057	.00000	.00000
S	C	.00617	.00320	.00126	.00011	.00000	.00000
SSW	C	.00274	.00091	.00011	.00000	.00000	.00000
SW	C	.00240	.00080	.00000	.00000	.00000	.00000
WSW	C	.00651	.00845	.00057	.00023	.00000	.00000
W	C	.01736	.02627	.01371	.00011	.00000	.00000
WNW	C	.02479	.02445	.00434	.00011	.00000	.00000
NW	C	.00354	.00183	.00114	.00000	.00000	.00000
NNW	C	.00023	.00091	.00023	.00000	.00000	.00000
N	D	.00149	.00400	.00320	.00011	.00000	.00000
NNE	D	.00080	.00091	.00069	.00000	.00000	.00000
NE	D	.00034	.00011	.00000	.00034	.00000	.00000
ENE	D	.00011	.00057	.00514	.00343	.00011	.00000
E	D	.00343	.00137	.00605	.00583	.00034	.00000
ESE	D	.01177	.01805	.00834	.00206	.00000	.00000
SE	D	.01165	.01485	.01382	.00697	.00080	.00000
SSE	D	.00251	.00046	.00251	.00034	.00011	.00000
S	D	.00126	.00000	.00114	.00023	.00000	.00000
SSW	D	.00034	.00000	.00023	.00011	.00000	.00000
SW	D	.00023	.00000	.00000	.00000	.00000	.00000
WSW	D	.00011	.00000	.00011	.00011	.00000	.00000
W	D	.00206	.00343	.00194	.00011	.00000	.00000
WNW	D	.01462	.02228	.01531	.00263	.00000	.00000
NW	D	.01439	.01348	.00149	.00000	.00000	.00000
NNW	D	.00286	.00811	.00788	.00023	.00000	.00000
N	E	.00171	.00183	.00011	.00000	.00000	.00000
NNE	E	.00034	.00080	.00000	.00000	.00000	.00000
NE	E	.00034	.00000	.00000	.00000	.00000	.00000

Wind Direction	Stability Category	Wind Frequency at Given Speed					
		1-3 knotts	4-6 knotts	7-10 knotts	11-16 knotts	17- 21 knotts	> 21 knotts
ENE	E	.00069	.00057	.00023	.00000	.00000	.00000
E	E	.00274	.00240	.00034	.00000	.00000	.00000
ESE	E	.01040	.00571	.00103	.00000	.00000	.00000
SE	E	.00994	.01028	.00000	.00000	.00000	.00000
SSE	E	.00274	.00057	.00034	.00000	.00000	.00000
S	E	.00034	.00000	.00011	.00000	.00000	.00000
SSW	E	.00034	.00000	.00034	.00000	.00000	.00000
SW	E	.00034	.00011	.00011	.00000	.00000	.00000
WSW	E	.00011	.00000	.00000	.00000	.00000	.00000
W	E	.00114	.00537	.00023	.00000	.00000	.00000
WNW	E	.00583	.00514	.00000	.00000	.00000	.00000
NW	E	.01131	.00366	.00000	.00000	.00000	.00000
NNW	E	.00366	.00697	.00228	.00000	.00000	.00000
N	F	.00685	.00263	.00000	.00000	.00000	.00000
NNE	F	.00674	.00137	.00000	.00000	.00000	.00000
NE	F	.00560	.00080	.00000	.00000	.00000	.00000
ENE	F	.00594	.00297	.00011	.00000	.00000	.00000
E	F	.00914	.00434	.00011	.00000	.00000	.00000
ESE	F	.01565	.00320	.00000	.00000	.00000	.00000
SE	F	.02250	.00628	.00000	.00000	.00000	.00000
SSE	F	.02399	.00971	.00046	.00000	.00000	.00000
S	F	.01691	.00560	.00000	.00000	.00000	.00000
SSW	F	.01668	.00617	.00011	.00000	.00000	.00000
SW	F	.01485	.00560	.00000	.00000	.00000	.00000
WSW	F	.01268	.00800	.00000	.00000	.00000	.00000
W	F	.01302	.00925	.00000	.00000	.00000	.00000
WNW	F	.01656	.00114	.00000	.00000	.00000	.00000
NW	F	.01565	.00137	.00000	.00000	.00000	.00000
NNW	F	.01268	.00160	.00000	.00000	.00000	.00000

ATTACHMENT C: POPULATION DATA

Direction	**Population at Distance from Center**												
	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