



May 24, 2005
DIR-05-028

Ms. Aundra Richards
Department of Energy
Berkeley Site Office
Berkeley Laboratory
1 Cyclotron Road, MS 90R1042
Berkeley, CA 94720

Subject: **Radionuclide Air Emission Report for 2004**

Dear Ms. Richards:

I'm pleased to present, for DOE Site Office certification, Berkeley Lab's Radionuclide Air Emission Report for 2004, as required by Subpart H of 40 CFR Part 61 of the National Emission Standards for Hazardous Air Pollutants (NESHAP). Please note that the calculated dose of 0.01 mrem (0.0001 mSv) from Berkeley Lab airborne emissions in 2004 is well below the dose standard of 10 mrem/year (0.1 mSv/year).

The report is due to EPA by June 30, 2005. After signing the certification statement (located on page 37), please send the report to Mr. Jack Broadbent, EPA Region IX. Please forward a copy of the certification page to Ron Pauer (MS 85B0198). If you have any questions on this report, please contact Ron at (510) 486-7614.

Sincerely,

Phyllis Pei
EH&S Division Director, Lawrence Berkeley National Laboratory

PP:lw

Attachment

c: w/ Attachment
E. Lau
D. McGraw
C. Schwab (DOE)
N. Ware

w/o Attachment
R. Pauer
L. Wahl



Department of Energy
Office of Science
Berkeley Site Office
Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90-1023
Berkeley, California 94720

JUN 17 2005

Mr. Jack Broadbent
Director, Air Division, A-1-1
U. S. Environmental Protection Agency
Region IX
75 Hawthorne Street
San Francisco, CA 94105

SUBJECT: Radionuclide Air Emission Annual Reports for Calendar Year 2004

Dear Mr. Broadbent:

Enclosed are copies of Radionuclide Air Emission Reports (Under Subpart H of 40 CFR 61) for Calendar Year 2004 for the Lawrence Berkeley National Laboratory (LBNL).

Should you have any questions, please contact Carl Schwab (510) 486-4298.

Sincerely,

A handwritten signature in cursive script, appearing to read "Aundra Richards".

Aundra Richards
Site Manager
Berkeley Site Office

Enclosure: Radionuclide Air Emission Report for 2004 for LBNL

cc: Eleanor D. Thornton, EPA Headquarters, Office of Radiation and Indoor Air, w/encl
Gustavo Vazquez, DOE/EH-412 w/ encl (3 copies)
Mike Bandrowski, EPA Region IX, A-1-1 w/o encl
Linnea Wahl, LBNL w/o encl
Hattie Carwell, BSO w/o encl
Carl Schwab, BSO w/ encl
Mal Humphry, ORO w/ encl.



E.O. Lawrence Berkeley National Laboratory
Environment, Health, and Safety Division
Environmental Services Group



United States Department of Energy

U.S. Department of Energy

Radionuclide Air Emission Report for 2004

(in compliance with 40 CFR 61, Subpart H)

Operation Office Information

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

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One Cyclotron Road
Berkeley, CA 94720

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

Site Information

Operator: University of California
Ernest Orlando Lawrence Berkeley National Laboratory

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

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

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FACILITY INFORMATION

- 1.1 SITE DESCRIPTION
- 1.2 COMPLIANCE STATUS OF BERKELEY LAB
- 1.3 SOURCE DESCRIPTION

1.1 SITE DESCRIPTION

1.1.1 Laboratory Operations

The Ernest Orlando Lawrence Berkeley National Laboratory (Berkeley Lab) is a multi-program national laboratory managed by the University of California (UC) for the U.S. Department of Energy (DOE). Berkeley Lab's major role is to conduct basic and applied research in biology, physics, chemistry, materials, and energy. Berkeley Lab, the birthplace of the cyclotron, was founded by the late Nobel laureate, Ernest Orlando Lawrence, in 1931.

Berkeley Lab operates facilities encompassing areas where radionuclides are handled and stored that are subject to the U.S. Environmental Protection Agency (EPA) radioactive air emission regulations in 40 CFR Part 61, Subpart H, of the National Emission Standards for Hazardous Air Pollutants (NESHAP). [Figure 1](#) illustrates the Berkeley Lab general site configuration and locations of buildings.

Radiochemical and radiobiological studies performed at Berkeley Lab typically use millicurie¹ quantities of a variety of radionuclides. All use of radioactive material at Berkeley Lab must be conducted in accordance with an internal authorization or permit. A radiation work authorization is issued for long-term projects that operate under routine radiological conditions; a radiation work permit is issued for nonresearch projects or tasks that require special radiation protection measures. Each authorization or permit is reviewed at least every 18 months, depending on changes to the project. 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). [Table 1](#) identifies buildings at Berkeley Lab where use or production of unsealed radioactive material was authorized in 2004.

¹ One millicurie (mCi) is equal to 3.7×10^7 Becquerel (Bq).

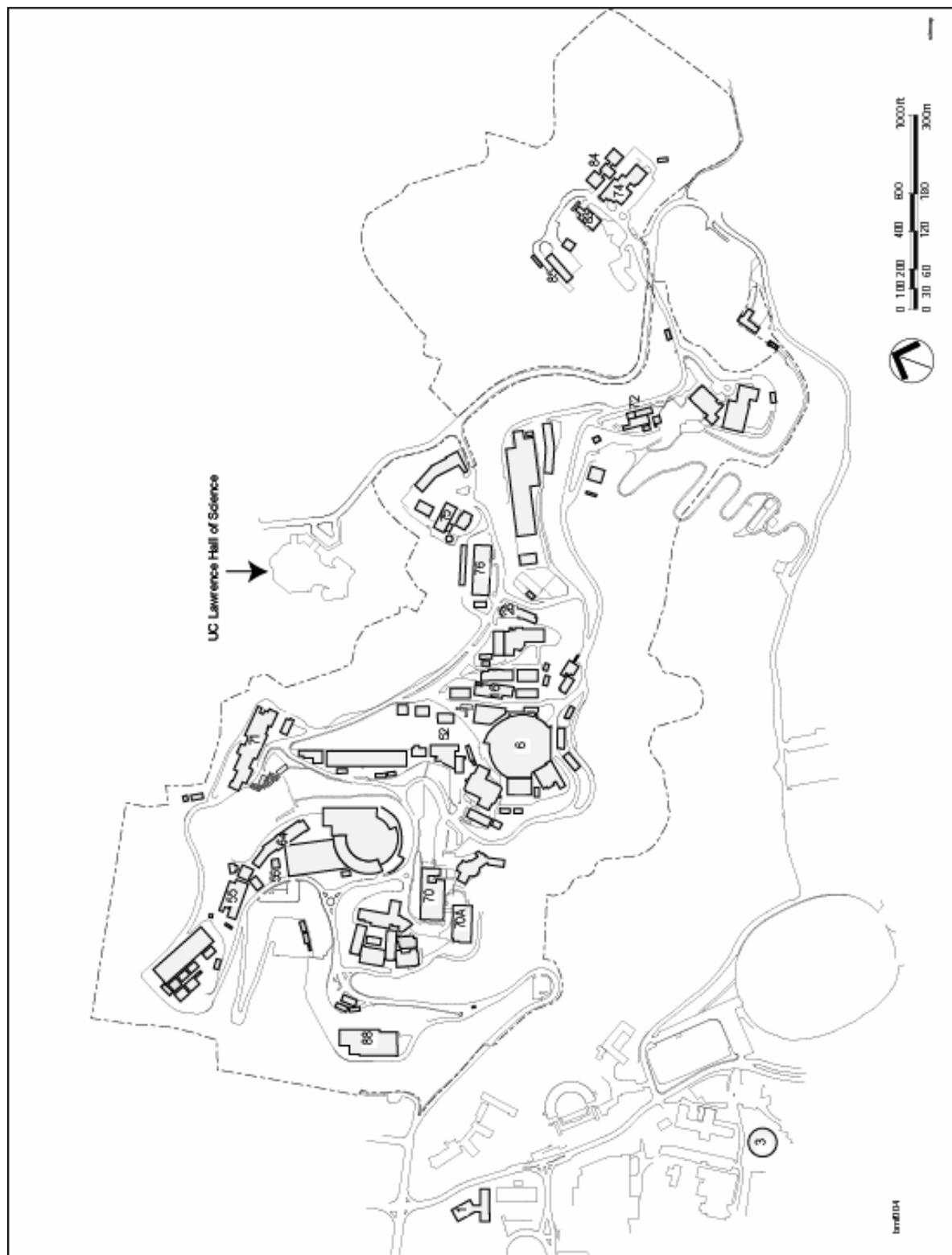


Figure 1 Berkeley Lab Buildings

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

Building number	Building description or function
1	Donner Laboratory
3	Calvin Laboratory
6	Advanced Light Source (ALS)
16	Accelerator and Fusion Research
26	Radioanalytical Laboratory
52	Accelerator and Fusion Research
55	Center for Functional Imaging and Life Sciences Research
56	Biomedical Isotope Facility
64	Life Sciences Research
70	Environmental Energy Technology, Nuclear Science, and Earth Sciences Research
70A	Nuclear, Chemical, and Life Sciences Research
71	Accelerator and Fusion Research
72	Low-Background Facility
74	Life Sciences Research
75	Former Tritium Labeling Facility
76	Radioanalytical Laboratory
83	Life Sciences Research
84	Life Sciences Research
85	Hazardous Waste Handling Facility
88	88-Inch Cyclotron

1.1.2 Berkeley Lab Site

The Berkeley Lab main site is situated on a hillside above the main campus of UC Berkeley. This 200-acre (80-hectare) site is located on the west and southwest-facing slope of the Berkeley hills, at elevations ranging from 500 to 1,100 ft (150 to 330 m) above sea level within the cities of Berkeley and Oakland. It is located about 3 miles (5 km) east of San Francisco Bay and about 15 miles (25 km) east of the city of San Francisco (Figure 2).

Berkeley Lab is located in an urban/wildland interface zone on land owned by the university. Berkeley Lab is surrounded by university land on nearly all sides. In addition, Berkeley Lab maintains a landscape buffer zone between its facilities and the site boundary. Beyond the northern boundary of Berkeley Lab are university facilities and single-family homes, and beyond the western boundary are multiunit dwellings, student residence halls, and commercial buildings. The area to the east and south, which is also part of the university's lands, is maintained in a largely natural state and includes UC recreational facilities and the UC Botanical Garden. The nearest farm is in Wildcat Canyon Regional Preserve, which is about 2 miles (3.2 km) north of Berkeley Lab, where cattle graze.

The western portion of Berkeley Lab is in the city of Berkeley (population 102,743) and the eastern portion is in the city of Oakland (population 399,484). The population within 50 miles (80 km) of Berkeley Lab increased by about 30% during the 1980s and 1990s from 5 to 6.6 million, as determined by the 2000 census.

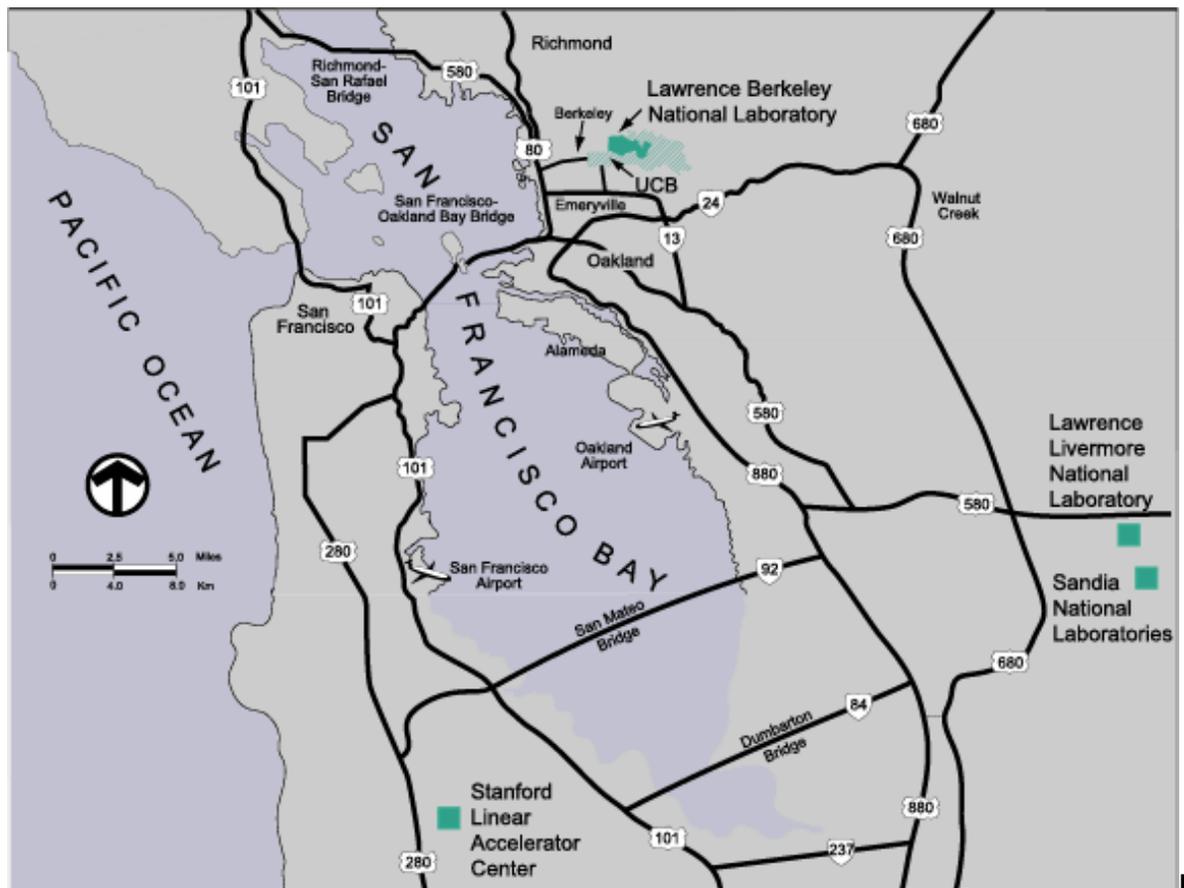


Figure 2 San Francisco Bay Area Map

1.1.3 The Climate at Berkeley Lab

The climate of the Berkeley Lab site is greatly influenced by its proximity to the Pacific Ocean and its exposure to the maritime air that flows in from San Francisco Bay. The climate is also influenced on the east by the hills paralleling the eastern shore of the San Francisco Bay. These physical barriers contribute significantly to the relatively warm, wet winters and cool, dry summers of the site. Seasonal temperature variations are small, with approximate mean temperatures of 63°F (17°C) during the summer and 48°F (9°C) during the winter. The average annual rainfall is about 29 in. (74 cm). About 95% of the rainfall occurs from October through April, and intensities are seldom greater than 0.5 in./h (1.3 cm/h). Thunderstorms, hail, and snow are rare. Winds are usually light, but summer sea breezes can reach up to 20–30 mph (9–13 m/s). Winds from winter storms can reach speeds of 30–40 mph (13–18 m/s). The predominant wind directions are westerly and northwesterly during fair weather and southeasterly in advance of storms.

1.2 COMPLIANCE STATUS OF BERKELEY LAB

Berkeley Lab has been in full compliance with the requirements of 40 CFR, Part 61, Subpart H, since 1995, when EPA sent DOE written confirmation that Berkeley Lab had satisfactorily completed all requirements of a federal facility compliance agreement (FFCA). As part of the FFCA, Berkeley Lab formalized all phases of its NESHAP program and proposed a graded strategy for performing emissions measurements required by Section 61.93(b)(4)(i) of the NESHAP regulations. Categories of emissions measurements are determined by the greatest potential effective dose equivalent from airborne radionuclide emissions that could be received by a member of the public at an offsite point where there is a residence, school, business, or office (the maximally exposed individual [MEI]).

Airborne radionuclides are potentially emitted from any of several locations (release points) at Berkeley Lab, such as stacks atop buildings or radioactive material areas within buildings. Stack release points represent one or more radioactive material areas where the potential dose to the MEI could exceed 0.001 mrem/yr. Emissions from stack release points are measured by sampling or monitoring. Emissions from other release points are controlled by radiation work authorizations or permits and by periodic evaluation; no monitoring is required because the potential dose to the MEI is less than 0.001 mrem/yr. [Table 2](#) summarizes the EPA-approved NESHAP compliance strategy for emissions measurements that Berkeley Lab has followed since the beginning of 1995 and lists the number of release points in each measurement category in 2004.

Table 2 Summary of NESHAP Compliance Strategy for Measuring Emissions in 2004

Annual effective dose equivalent (mrem/yr) ^a	Category	Requirements	Number of release points
≥ 10.0	Non-compliant	Reduction or relocation of source term and reevaluation prior to authorization.	0
1.0 × 10 ⁻¹ to 10.0	I	<ul style="list-style-type: none"> • Continuous sampling or monitoring. • Telemetry for nuclides with half-lives < 100 h • EPA application to construct or modify. 	0
5.0 × 10 ⁻² to 1.0 × 10 ⁻¹	II	Continuous sampling with weekly analysis.	9
1.0 × 10 ⁻² to 5.0 × 10 ⁻²	III	Continuous sampling with monthly analysis.	15
1.0 × 10 ⁻³ to 1.0 × 10 ⁻²	IV	Sampling annually during project activity.	0
< 1.0 × 10 ⁻³	V	Inventory controlled by radiation work authorization/permit and periodic evaluation. No monitoring required.	103

^a 1 mrem = 1.0 × 10⁻² mSv

1.3 SOURCE DESCRIPTION

Berkeley Lab uses a wide variety of radionuclides in its radiochemical and radiobiological research programs. In addition, radioactive gases are a by-product of charged-particle 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.

All radionuclides that are authorized for use or storage at Berkeley Lab are considered when evaluating the potential to emit airborne radionuclides. A list of these authorized radionuclides is maintained in the NESHAP files. As required by 40 CFR Part 61, when evaluating the potential for emissions, no credit is taken for emission controls, such as filters and other devices that prevent radionuclides from being emitted into the air, and the appropriate EPA-specified physical state factor (provided in 40 CFR Part 61, Appendix D) is applied. Based on the potential to emit airborne radionuclides, the number and location of monitored and sampled stacks subject to each compliance category changes throughout the year in response to changes in research projects. During 2004, 24 stacks at eight buildings at Berkeley Lab had the potential to emit radionuclides into the atmosphere at a level that required sampling under the criteria in [Table 2](#) (Category I–IV). The buildings that these stacks exhaust are listed in [Table 3](#), along with the measurement categories.

Table 3 Buildings with Potential to Emit Airborne Radionuclides in 2004

Buildings with release points	NESHAP Compliance strategy category					Total
	Category I	Category II	Category III	Category IV ^a	Category V	
1	0	0	1	0	6	7
3	0	0	0	0	1	1
6	0	0	0	0	10	10
16	0	0	0	0	1	1
26	0	0	0	0	3	3
52	0	0	0	0	1	1
55	0	0	1	0	10	11
56	0	2	0	0	0	2
64	0	0	0	0	1	1
70	0	1	3	0	4	8
70A	0	2	4	0	24	30
71	0	0	0	0	2	2
72	0	0	0	0	4	4
74	0	0	0	0	13	13
75	0	0	4	0	3	7
76	0	0	0	0	1	1
83	0	0	0	0	1	1
84	0	0	0	0	9	9
85	0	2	0	0	0	2
88	0	2	2	0	9	13
Total	0	9	15	0	103	127

^a No sources were measured under Category IV requirements; sources potentially having a dose impact between 1.0×10^{-2} and 1.0×10^{-3} mrem/yr (1.0×10^{-4} and 1.0×10^{-5} mSv/yr) were measured using the more rigorous Category III requirements.

All Berkeley Lab release points that were operational in 2004 were minor sources of radionuclides; that is, the effective dose equivalent to the MEI from each release point was less than 0.1 mrem/yr (1.0×10^{-3} mSv/yr), the threshold limit for Category I measurements. Minor release points (Category II-IV) were continuously sampled with weekly or monthly analysis of the samples. As shown in Table 3, all Category IV release points were measured using the more rigorous Category III requirements.

To determine the annual dose from airborne emissions, the full set of authorized radionuclides was reviewed, and a subset was developed that includes 87 radionuclides that were potentially used (received or measured) in 2004 (Table 4).

Table 4 Radionuclides Potentially Used (Received or Measured) In 2004

Element	Atomic number	Radionuclide	Principal radiation type	Energy (MeV)	Half-Life
Actinium	89	²²⁷ Ac	alpha	4.953	21.8 years
			beta	0.045	
		²²⁸ Ac	beta	1.158	6.2 hours
				1.731	
			gamma	0.338	
Americium	95	²⁴¹ Am	alpha	5.41	432.7 years
			gamma	5.44	
		²⁴³ Am	alpha	5.276	7370 years
				5.234	
			gamma	0.075	
Antimony	51	¹²⁴ Sb	beta	2.301	60.2 days
			gamma	0.603	
		¹²⁵ Sb	beta	0.302	2.8 years
				0.428	
			gamma	0.601	
Argon	18	⁴¹ Ar	beta	1.198	1.8 hours
			gamma	1.294	
Barium	56	¹³³ Ba	gamma	0.356	10.5 years
				0.081	
Berkelium	97	²⁴⁹ Bk	beta	0.124	330 days
Bismuth	83	²⁰⁷ Bi	gamma	0.570	32 years
Bromine	35	⁷⁶ Br	beta	3.400	16.0 hours
			gamma	0.559	
				0.657	
				1.854	
		⁷⁷ Br	gamma	0.239	2.4 days
Cadmium	48	¹¹³ Cd	beta	0.093	7.7×10^{15} years
			gamma	0.521	
Californium	98	²⁴⁹ Cf	alpha	5.813	351 years
			gamma	0.388	

Table 4 Radionuclides Potentially Used (Received or Measured) In 2004 (continued)

Element	Atomic number	Radionuclide	Principal radiation type	Energy (MeV)	Half-Life
Californium		²⁵⁰ Cf	alpha	5.989	13.1 years
				6.030	
Carbon	6	¹¹ C	positron	0.960	20.4 minutes
		¹⁴ C	beta	0.157	5715 years
Cerium	58	¹⁴¹ Ce ^a	beta	0.436	32.5 days
			gamma	0.581	
		¹⁴⁴ Ce	beta	0.145	
			beta	0.318	284.6 days
Cesium	55	¹³⁴ Cs	beta	0.658	2.1 years
			gamma	0.605	
				0.796	
				1.038	
				1.168	
				1.365	
Cesium	55	¹³⁷ Cs ^a	beta	0.514	30.1 years
			gamma	0.662	
Chromium	24	⁵¹ Cr	gamma	0.320	27.7 days
Cobalt	27	⁵⁶ Co	positron	1.459	77.3 days
			gamma	0.847	
				1.238	
		⁵⁷ Co	gamma	0.122	271.8 days
		⁵⁸ Co	positron	0.474	70.9 days
			gamma	0.811	
		⁶⁰ Co	beta	0.318	5.3 years
			gamma	1.333	
				1.173	
Copper	29	⁶⁴ Cu	beta	0.578	12.7 hours
			positron	0.651	
			gamma	1.346	
Curium	96	²⁴³ Cm	alpha	5.785	29.1 years
			gamma	0.278	
				0.228	
		²⁴⁴ Cm	alpha	5.763	18.1 years
				5.805	
		²⁴⁵ Cm	alpha	5.362	8500 years
			gamma	0.133	
				0.175	
		²⁴⁶ Cm	alpha	5.343	4760 years
				5.386	
		²⁴⁸ Cm	alpha	5.035	348,000 years
				5.078	
Europium	63	¹⁵² Eu	beta	0.699	13.5 years
			gamma	0.122	
				0.344	
				1.408	
Fluorine	9	¹⁸ F	positron	0.635	1.8 hours

Table 4 Radionuclides Potentially Used (Received or Measured) In 2004 (continued)

Element	Atomic number	Radionuclide	Principal radiation types	Energy (MeV)	Half-Life
Gold	79	¹⁹⁸ Au	beta	0.961	2.7 days
			gamma	0.412	
Hydrogen	1	³ H (Tritium)	beta	0.0186	12.3 years
Iodine	53	¹²³ I	gamma	0.159	13.2 hours
			gamma	0.035	59.4 days
			beta	0.15	1.6 × 10 ⁷ years
			gamma	0.040	
			beta	0.606	
Iron	26	⁵⁵ Fe	gamma	0.364	
			x-rays	0.108	2.73 years
			beta	0.466	44.5 days
			gamma	1.099	
Krypton	36	⁷⁶ Kr	gamma	1.292	
			gamma	0.045	14.8 hours
			gamma	0.270	
Manganese	25	⁵⁴ Mn	gamma	0.316	
			gamma	0.835	312.1 days
Mercury	80	¹⁹⁴ Hg	x-rays	0.097	520 years
Neptunium	93	²³⁷ Np	alpha	4.78	2.1 × 10 ⁶ years
			gamma	0.030	
			gamma	0.087	
			beta	0.341	2.4 days
			gamma	0.438	
			gamma	0.106	
gamma	0.228				
Nickel	28	⁶³ Ni	beta	0.278	
			beta	0.067	101 years
Niobium	41	⁹⁵ Nb	beta	0.160	35.0 days
			gamma	0.765	
Nitrogen	7	¹³ N	positron	1.190	10.0 minutes
Osmium	76	¹⁸⁵ Os	gamma	0.642	93.6 days
			gamma	0.717	
			gamma	0.875	
			gamma	0.880	
Oxygen	8	¹⁵ O	positron	1.72	122 seconds
Phosphorus	15	³² P	beta	1.71	14.3 days
			beta	0.25	
Plutonium	94	²³⁸ Pu	alpha	5.50	87.7 years
			alpha	5.46	
			alpha	5.156	24,100 years
			alpha	5.144	
			alpha	5.105	
		²⁴⁰ Pu	alpha	5.124	6560 years
			alpha	5.168	
		²⁴¹ Pu	beta	0.021	14.4 years

Table 4 Radionuclides Potentially Used (Received or Measured) In 2004 (continued)

Element	Atomic number	Radionuclide	Principal radiation types	Energy (MeV)	Half-Life		
Plutonium		²⁴² Pu	alpha	4.856	375,000 years		
				4.901			
Polonium	84	²¹⁰ Po	alpha	5.30	138.9 days		
Potassium	17	⁴⁰ K	beta	1.33	1.3 × 10 ⁹ years		
			gamma	1.461			
Protactinium	91	²³¹ Pa	alpha	4.950	32,800 years		
				5.013			
				5.029			
			gamma	0.027			
				0.300			
Radium	88	²²⁶ Ra	beta	0.256	27 days		
			gamma	0.312			
			alpha	4.784			
Radium	88	²²⁶ Ra	gamma	4.602	1599 years		
				0.186			
			alpha	4.784			
Rubidium	37	⁸⁶ Rb	beta	1.77	18.7 days		
			gamma	1.08			
Silver	47	¹⁰⁸ Ag	beta	1.65	2.4 minutes		
			positron	0.88			
			gamma	0.619			
				0.633			
Sodium	11	²² Na	positron	0.546	2.6 years		
			gamma	1.275			
			²⁴ Na	beta		1.391	15.0 hours
				gamma		1.369	
						2.754	
Strontium	38	⁹⁰ Sr	beta	0.546	28.8 years		
Sulfur	16	³⁵ S	beta	0.167	87.2 days		
Tantalum	73	¹⁸² Ta	beta	0.522	114.4 days		
				0.25			
			gamma	0.068			
				1.121			
Technetium	43	⁹⁹ Tc	beta	0.294	213,000 years		
			gamma	0.141			
Thallium	81	²⁰¹ Tl	gamma	0.167	3.0 days		
Thorium	90	²²⁸ Th	alpha	5.340	1.9 years		
				5.423			
			gamma	0.132			
				0.166			
				0.216			
			²²⁹ Th	alpha		4.845	7300 years
						4.901	
	4.814						
gamma	0.194						
	0.086						
			0.211				

Table 4 Radionuclides Potentially Used (Received or Measured) In 2004 (continued)

Element	Atomic number	Radionuclide	Principal radiation types	Energy (MeV)	Half-Life
Thorium		²³⁰ Th	alpha	4.688	75,400 years
			gamma	4.621	
				0.068	
		²³² Th	alpha	4.012	1.4 × 10 ¹⁰ years
				3.947	
Titanium	22	⁴⁴ Ti	x-rays	0.004	59.9 years
Uranium	92	²³² U	alpha	5.320	69.8 years
				5.264	
		²³³ U	alpha	4.824	159,200 years
				4.783	
				4.398	
		²³⁵ U	alpha	4.366	7.0 × 10 ⁸ years
			gamma	0.144	
				0.186	
				4.197	
		²³⁸ U ^a	alpha	4.147	4.5 × 10 ⁹ years
Yttrium	39	⁹⁰ Y	beta	2.281	2.67 days
Zinc	30	⁶⁵ Zn	gamma	1.116	243.8 days
Zirconium	40	⁹⁵ Zr	beta	0.368	64.0 days
				0.400	
			gamma	0.724	
				0.757	
		⁹⁷ Zr	beta	1.92	16.8 hours

^a Includes progeny

As discussed above, release points in categories II through IV were sampled or monitored, in accordance with Berkeley Lab's *Quality Assurance Project Plan for Radionuclide NESHAP*. At continuously sampled sites, a representative sample of the exhaust air passes through the appropriate collection medium (silica gel for ³H, sodium hydroxide solution for ¹⁴C, activated carbon for ¹²⁵I, and fiberglass filter for particulate alpha- and beta-emitting radionuclides). Each medium is replaced either weekly or monthly, depending on the measurement category. The radionuclides collected on the media are analyzed either at a commercial laboratory or an on-site 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).

Release points in Category V were, in general, not sampled or monitored. Instead, Berkeley Lab evaluated the effective dose equivalent from Category V release points by assuming that all radionuclides received during the year were completely used at Category V release points. The amount of each radionuclide emitted was determined 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. In fact, for most sources comprising a mixture of Category II–V release points, emissions are overestimated because they are quantified by

adding the calculated emission of received radionuclides (as described above) to the amount measured by sampling or monitoring the exhaust stack.

The total number of Category V release points is based on the number of areas where radionuclide use or production was authorized, regardless of whether radionuclides were actually used there during the year. This method also provides a conservative, upper-bound estimate of the impact of radioactive airborne emissions.

To estimate effective dose equivalent, CAP88-PC, Version 2, provides a library of 265 radionuclides; however, this library does not include all of the radionuclides potentially used at Berkeley Lab. For radionuclides not included in the library, EPA has approved the interim use of surrogates at Berkeley Lab ([Attachment A](#)). Berkeley Lab selects a surrogate radionuclide that is similar to the actual radionuclide in its metabolic behavior, mode of decay, and decay energy. Note that for surrogates used to represent radionuclides not included in the CAP88-PC library, the dose contribution to the sitewide MEI is very low: in 2004, the dose from all surrogates taken together is about 3×10^{-2} % of the total dose from all radionuclides.

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

Furthermore, all tritium releases are assumed to be in the form of tritiated water because CAP88-PC cannot calculate doses from releases of tritiated hydrogen gas. CAP88-PC treats all tritium gas releases as tritiated water, which overestimates the dose from inhalation by a factor of approximately 10,000 ([ICRP 1996](#)).

In estimating effective dose equivalent from Category II–IV release points, the actual measured sample activities were used to calculate an annual total, in accordance with DOE guidance ([DOE 1991](#)), even when the reported individual sample activity was less than the analytical laboratory's minimum detectable activity. Of the radionuclides listed in [Table 4](#), three radionuclides account for most (99.9%) of the activity emitted: ^{18}F , ^{11}C , and ^3H .

Following DOE guidance ([DOE 1994](#)), many Berkeley Lab release points were grouped using the following criteria:

- The sum of the effective dose equivalent attributable to all release points in the group must be less than 0.1 mrem (1×10^{-3} mSv).
- Release points must be in close proximity (in the same or a nearby building), with similar operations and similar nuclides used in the facilities.

- Critical receptors must be the same.

Using this grouping scheme, Berkeley Lab identified 12 NESHAP point sources (buildings with stacks or vents) and group sources (two or more point sources) (Table 5). In 2004, no area sources (emissions sources that are not clearly delimited and are not point or group sources) were identified.

For each source, Berkeley Lab used the EPA-approved atmospheric dispersion dose calculation computer code CAP88-PC, Version 2, to estimate the effective dose equivalent to the member of the public nearest to the source (the local MEI). The doses to local MEIs were compared to determine the location of the member of the public who could receive the greatest dose from all Berkeley Lab radioactive air emissions (the sitewide MEI). The location of the sitewide MEI is a hypothetical person residing at the UC Lawrence Hall of Science, 460 m east of Building 56 (the source of greatest emissions in 2004). The CAP88-PC computer model assessments were performed separately to simulate seven point sources and five group sources. In addition, where the local MEI is very close to the source (as at Buildings 1 and 3), a second EPA-approved computer code, COMPLY, was used to assess the choice of sitewide MEI.

As identified in [Figure 1](#), Buildings 1 and 3 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. Annual radioactive air emissions from these off-site buildings and the associated effective dose equivalent at each local MEI 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.

Table 5 NESHAP Point and Group Sources In 2004

NESHAP Source	Type of source	Location
Building 1	Point	UC Berkeley Campus
Building 3	Point	UC Berkeley Campus
Building 6, 16, and 52	Group	Main Site
Buildings 26 and 76	Group	Main Site
Buildings 55, 56, and 64	Group	Main Site
Buildings 70 and 70A	Group	Main Site
Building 71	Point	Main Site
Building 72	Point	Main Site
Buildings 74, 83, and 84	Group	Main Site
Building 75	Point	Main Site
Building 85	Point	Main Site
Building 88	Point	Main Site

1.3.1 Building 1 (Donner Laboratory)

Scientists at Donner Laboratory conduct research on biological molecules, such as cholesterol and growth factors, that are related to heart disease and cancer in humans. In addition, researchers study how genes replicate and are repaired after damage by environmental stresses. The building is located at the eastern edge of the UC Berkeley campus. The radionuclides used are ^{14}C , ^3H , ^{125}I , ^{32}P , and ^{35}S as labeled amino acids and DNA precursors. Many UC Berkeley campus employees share this building for various other research activities. Work is mostly done on bench tops and in hoods. Emissions are from building vents and hoods.

In 2004, most release points at Building 1 were classified as Category V, for which the radionuclide inventory was controlled by radiation work authorizations and permits and by periodic assessments. One stack on Building 1 was sampled and analyzed monthly for ^{125}I , ^{14}C , gross alpha, gross beta, and ^3H . To estimate the dose, ^{232}Th and ^{90}Sr were used as surrogates for alpha- and beta-emitting radionuclides, respectively. A summary of the CAP88-PC input parameters and effective dose equivalent for this source is presented in [Table 6](#).

The local MEI is 10–30 m from Building 1 stacks, so the EPA-approved dose calculation computer code COMPLY, Version 1.6, was used in addition to CAP88-PC to assess the dose to the local MEI ([Wahl 2005](#)). Local MEI doses calculated by both models are much less (by one to three orders of magnitude) than the calculated CAP88-PC doses from other Berkeley Lab buildings to a hypothetical resident at the UC Lawrence Hall of Science, so they have no effect on the choice of sitewide MEI. The calculated CAP88-PC local MEI dose is shown in [Table 6](#).

Table 6 Building 1 Source Characteristics and Dose Impacts

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radio-nuclide (surrogate) ^a	Annual emission (Ci/yr) ^b	Local MEI dose (mrem/yr) ^c	Percent of total dose (%)
18	10	ESE	UC Berkeley	C-14	6.7E-05	3.0E-07	1.7
				H-3	4.4E-05	6.8E-09	< 0.1
				I-125	1.4E-06	9.7E-07	5.7
				P-32	1.5E-05	2.2E-07	1.3
				S-35	4.9E-05	2.0E-07	1.2
				Gross alpha (Th-232)	6.7E-08	1.5E-05	88.9
				Gross beta (Sr-90)	2.3E-07	2.4E-07	1.4
Total						1.7E-05	100%

^a For radionuclides not listed in CAP88-PC library, surrogate radionuclides (in parentheses) were used to model dose

^b 1 Ci = 3.7×10^{10} Bq

^c 1 mrem = 1.0×10^{-2} mSv

1.3.2 Building 3 (Calvin Laboratory)

The Calvin Laboratory conducts basic research on the dynamics of living cells. The laboratory has made significant contributions to our understanding of the molecular mechanisms of photosynthesis and of the effects of environmental pollutants on plant and animal cells. As with Building 1, this building is located in the eastern portion of the UC Berkeley campus. The predominant radionuclide used is ^{35}S as a labeled amino acid; ^{14}C , ^3H , ^{32}P , and ^{33}P are also used in small quantities. Building 3 is occupied by Berkeley Lab and UC Berkeley personnel. Work is done on bench tops and in hoods. Emissions are from building vents and hoods.

In 2004, all release points in Building 3 were classified as Category V, and the radionuclide inventory was controlled by radiation work authorizations and permits and by periodic assessments. No sampling or monitoring was required. For dose calculations, ^{32}P was used as a surrogate for ^{33}P , which is not included in the CAP88-PC library, because they have similar metabolic and radiological properties. A summary of the CAP88-PC input parameters and the effective dose equivalent for this source is presented in [Table 7](#).

The local MEI is about 30 m from Building 3 stacks, so the EPA-approved dose calculation computer code COMPLY, Version 1.6, was used in addition to CAP88-PC to assess the dose to the local MEI ([Wahl 2005](#)). Local MEI doses calculated by both models are much less (by two to four orders of magnitude) than the calculated CAP88-PC doses from other Berkeley Lab buildings to a hypothetical resident at the UC Lawrence Hall of Science, so they have no effect on the choice of sitewide MEI. The calculated CAP88-PC local MEI dose is shown in [Table 7](#).

Table 7 Building 3 Source Characteristics and Dose Impacts

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radionuclide (surrogate) ^a	Annual emission (Ci/yr) ^b	Local MEI dose (mrem/yr) ^c	Percent of total dose (%)
15	30	S	UC Berkeley	C-14	1.0E-07	4.0E-09	0.3
				H-3	1.5E-06	2.1E-09	0.2
				P-32	5.0E-07	5.0E-08	4.2
				P-33 (P-32)	6.0E-06	6.0E-07	50.0
				S-35	2.2E-05	5.4E-07	45.2
Total					1.2E-06	100%	

^a For radionuclides not listed in CAP88-PC library, surrogate radionuclides (in parentheses) were used to model dose

^b 1 Ci = 3.7×10^{10} Bq

^c 1 mrem = 1.0×10^{-2} mSv

1.3.3 Buildings 6, 16, and 52 (Advanced Light Source and Accelerator and Fusion Research)

The ALS in Building 6 is one of the world's brightest synchrotron radiation sources, producing light in the extreme ultraviolet and soft x-ray regions of the spectrum. The ALS is a national user facility open to qualified scientists and engineers, in a broad range of disciplines, from national laboratories, private industry, and universities.

The ALS synchrotron accelerates electrons to 1.5 GeV, and the storage ring maintains a normal operating beam current of 400 mA at an energy between 1 and 2 GeV. The ALS produces neutrons during its operation, which activate the components of air in the injector vault. Because the ALS is a low-power accelerator, compared to Berkeley Lab's other accelerators such as the 88-Inch Cyclotron, its generation of air activation products is substantially lower. The maximum annual emissions of ^{13}N and ^{15}O (the most significant air activation products) are calculated based on an optimally thick aluminum target with a 1.5-GeV incident electron beam. These are conservative estimates that have not been exceeded since their original determination (Donahue 1991).

At the ALS, the beam is under ultra-high vacuum within the beam enclosure. The beam enclosure is ventilated by an exhaust system to a roof stack. These stacks are not sampled or monitored because Building 6 release points are classified as Category V, and no special effluent capture or recovery systems are required for the ALS emissions.

In Buildings 16 and 52, research is conducted on equipment and techniques used in prompt gamma analysis to characterize the chemical composition of unknown materials. In 2004, the release points in Buildings 16 and 52 were classified as Category V: no sampling or monitoring was required.

The radionuclide inventory at Buildings 6, 16, and 52 was controlled by radiation work authorizations and permits and by periodic assessments. A summary of the CAP88-PC input parameters and effective dose equivalent for this source is presented in Table 8.

Table 8 Building 6, 16, and 52 Source Characteristics and Dose Impacts

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radio-nuclide	Annual emission (Ci/yr) ^a	Local MEI dose (mrem/yr) ^b	Percent of total dose (%)
9	350	NNE	UC Lawrence Hall of Science	N-13	1.80E-05	1.5E-08	98.9
				O-15	9.40E-08	6.3E-11	0.4
				Ar-41	1.00E-07	1.1E-10	0.7
				Total		1.5E-08	100%

^a 1 Ci = 3.7×10^{10} Bq

^b 1 mrem = 1.0×10^{-2} mSv

1.3.4 Buildings 26 and 76 (Radioanalytical Laboratories)

In these buildings, low-activity radiochemical analyses of bioassay samples, work-place and environmental samples, and hazardous waste are performed by Berkeley Lab. In addition, Building 76 has some detector calibration sources. Trace quantities of radionuclides are used in sample spiking and standards preparation. Emissions are from building vents and hood exhaust stacks.

In 2004, release points within Buildings 26 and 76 were classified as Category V, and the radionuclide inventory was controlled by radiation work authorizations and permits and by periodic assessments. No sampling or monitoring was required.

Because all radioactive samples analyzed during the year were sent to the Hazardous Waste Handling Facility after analysis, the annual emissions were conservatively estimated as the amount sent as waste multiplied by the appropriate EPA-specified physical state emission factor (provided in 40 CFR Part 61, Appendix D). For completeness, all identified radionuclides were considered regardless of their very small measured quantities and insignificant dose impact.

For dose calculations, ^{111}Ag , ^{241}Pu , ^{82}Br , ^{64}Cu , ^{245}Cm , ^{241}Am , ^{60}Co , ^{152}Eu , ^{87}Kr , and ^{54}Mn were used as surrogates for ^{108}Ag , ^{249}Bk , ^{76}Br , ^{77}Br , ^{249}Cf , ^{250}Cf , ^{56}Co , ^{194}Hg , ^{76}Kr , and ^{185}Os , respectively. The latter radionuclides are not included in the CAP88-PC library, and the surrogates were chosen because they have similar metabolic and radiological properties. A summary of the CAP88-PC input parameters and the effective dose equivalent for this source is presented in [Table 9](#).

Table 9 Building 26/76 Source Characteristics and Dose Impacts

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radionuclide (surrogate) ^a	Annual emission (Ci/yr) ^b	Local MEI dose (mrem/yr) ^c	Percent of total dose (%)
8	250	N	UC Lawrence Hall of Science	Ac-228	4.0E-14	1.3E-14	< 0.1
				Ag-108 (Ag-111)	7.0E-17	2.2E-18	< 0.1
				Am-241	9.7E-10	2.0E-06	15.4
				Am-243	6.6E-12	1.4E-08	0.1
				Ba-133	6.0E-10	4.6E-09	< 0.1
				Bk-249 (Pu-241)	2.6E-09	5.3E-08	0.4
				Br-76 (Br-82)	1.8E-14	6.5E-16	< 0.1
				Br-77 (Cu-64)	1.0E-15	2.5E-18	< 0.1
				C-14	3.8E-08	8.1E-10	< 0.1
				Ce-144 ^d	1.5E-12	2.3E-12	< 0.1
				Cf-249 (Cm-245)	1.1E-09	2.5E-06	18.9
				Cf-250 (Am-241)	2.0E-13	4.2E-10	< 0.1

Cm-243	5.5E-13	7.7E-10	< 0.1
Cm-244	4.5E-14	4.9E-11	< 0.1
Cm-245	3.8E-16	8.2E-13	< 0.1
Cm-246	3.0E-15	6.4E-12	< 0.1
Cm-248	1.2E-15	9.4E-12	< 0.1
Co-56 (Co-60)	2.6E-15	6.5E-14	< 0.1
Co-57	1.9E-11	5.1E-12	< 0.1
Co-58	1.4E-15	7.0E-16	< 0.1
Co-60	4.2E-10	1.0E-08	0.1
Cr-51	3.3E-16	2.5E-18	< 0.1
Cs-134	2.2E-11	1.7E-10	< 0.1
Cs-137 ^d	9.7E-10	7.6E-10	< 0.1

Table 9 Building 26/76 Source Characteristics and Dose Impacts (continued)

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radionuclide (surrogate) ^a	Annual emission (Ci/yr) ^b	Local MEI dose (mrem/yr) ^c	Percent of total dose (%)
				Eu-152	1.0E-16	2.7E-15	< 0.1
				Fe-55	5.2E-11	6.3E-13	< 0.1
				H-3	4.2E-08	3.6E-11	< 0.1
				Hg-194 (Eu-152)	2.4E-14	6.2E-13	< 0.1
				I-125	5.2E-09	1.6E-08	0.1
				I-129	1.1E-10	9.4E-09	0.1
				I-131	5.9E-09	6.7E-09	0.1
				K-40	5.0E-15	5.4E-14	< 0.1
				Kr-76 (Kr-87)	4.0E-16	8.4E-19	< 0.1
				Mn-54	2.0E-11	3.4E-11	< 0.1
				Na-22	4.3E-14	5.2E-13	< 0.1
				Ni-63	2.7E-11	3.9E-13	< 0.1
				Np-237	5.7E-12	1.1E-08	0.1
				Np-239	8.5E-16	1.1E-17	< 0.1
				Os-185 (Mn-54)	3.8E-15	6.3E-15	< 0.1
				P-32	1.0E-08	4.8E-10	< 0.1
				Pa-231	2.6E-13	4.8E-10	< 0.1
				Po-210	4.0E-14	1.7E-12	< 0.1
				Pu-238	1.4E-09	1.7E-06	13.5
				Pu-239	4.2E-09	5.5E-06	42.6
				Pu-241	9.0E-09	1.8E-07	1.4
				Pu-242	4.4E-14	5.5E-11	< 0.1
				Ra-226	5.0E-12	2.1E-10	< 0.1
				S-35	1.0E-08	9.5E-11	< 0.1
				Sb-125	4.3E-16	1.1E-15	< 0.1
				Sr-90	3.0E-10	9.4E-10	< 0.1
				Tc-99	2.9E-12	1.2E-12	< 0.1
				Th-229	2.4E-13	6.4E-10	< 0.1
				Th-230	1.2E-11	1.2E-08	0.1
				Th-232	4.5E-11	6.2E-08	0.5
				U-232	2.5E-13	4.6E-10	< 0.1
				U-235	1.1E-10	5.3E-08	0.4
				U-238 ^d	1.4E-09	7.9E-07	6.1
				Y-90	1.8E-11	6.5E-13	< 0.1
				Zn-65	2.9E-11	3.8E-11	< 0.1
				Total		1.3E-05	100%

^a For radionuclides not listed in CAP88-PC library, surrogate radionuclides (in parentheses) were used to model dose

^b 1 Ci = 3.7×10^{10} Bq

^c 1 mrem = 1.0×10^{-2} mSv

^d Includes progeny

1.3.5 Buildings 55, 56, and 64 (Center for Functional Imaging, Biomedical Isotope Facility, and Life Sciences Research)

In Building 56, researchers at the Biomedical Isotope Facility develop radiopharmaceuticals and advanced medical imaging technologies, including positron emission tomography (PET), single photon emission computed tomography (SPECT), and nuclear magnetic resonance imaging (MRI). Researchers apply these technologies to the study of heart disease, aging, neurological and psychiatric diseases, and cancer. Building 56 houses a small cyclotron to support such studies.

The Building 56 cyclotron accelerates protons to 11 MeV, with a normal operating beam current of 50 μA . The cyclotron produces ^{18}F , ^{11}C , ^{13}N , and ^{15}O , which are used for positron emission tomography and other experimental studies. In addition, in collaboration with the 88-Inch Cyclotron, the Building 56 cyclotron produces ^{11}C , ^{14}O , ^{15}O , ^{13}N , ^{17}F , and ^{18}F , which are used for the Berkeley Experiments with Accelerated Radioactive Species (BEARS) Project. All the potentially airborne radionuclides produced at Building 56 are positron emitters.

At the Building 56 cyclotron, the entire beam path is enclosed within shielding, and the enclosure is ventilated by an exhaust system to a roof stack. All emissions from the cyclotron enclosure are through the roof stack, which is monitored by a real-time positron detector. No special effluent capture or recovery systems are required for the cyclotron emissions.

A second stack at Building 56 is also continuously monitored for positron-emitting radionuclides using real-time radiation detectors. This stack exhausts air from lead-shielded glove boxes in Room 56-100, adjacent to the cyclotron enclosure, where positron-emitting radionuclides produced in the cyclotron are handled.

The Building 56 cyclotron's safety systems (monitoring, filtration, isolation, safety interlocks, and ventilation) were designed to ensure that the facility has a negligible impact on the surrounding environment. In 1995, a Berkeley Lab safety analysis determined that the facility is designed and operated to maintain exposures to the public and the environment as low as reasonably achievable.

For dose calculations, all positron-emitting radionuclides measured in effluent from the Building 56 stacks are assumed to be ^{18}F . Fluorine-18 is an appropriate surrogate for radioisotopes of carbon, nitrogen, and oxygen because it overestimates the dose that would be received from the other radionuclides. In 2004, ^{18}F emitted from Building 56 stacks accounted for about 72% of the dose to the sitewide MEI. The location of this hypothetical person is the UC Lawrence Hall of Science, 460 m east of Building 56, even though a closer, local MEI is located 250 m north-northwest of Building 56. This is due to prevailing wind directions (from the west and west-northwest) that tend to carry airborne emissions toward the UC Lawrence Hall of Science.

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.

At Building 55, the primary radiological activities carried out by life sciences researchers are positron emission tomography using ^{18}F (produced at the Building 56 cyclotron). Other projects include metabolic studies using radioiodine and tritium, a gene therapy study, work with ^{32}P to determine the metabolic fate of DNA-based imaging agents, and evaluation of cardiac kinetics using various radioactive tracers (such as $^{99\text{m}}\text{Tc}$ and ^{201}Tl). Work with radioactive iodine is done in a fume hood with a high-efficiency particulate air (HEPA) filter and a tetraethylene diamine (TEDA)-doped carbon filter.

In 2004, ^{201}Tl was among the radionuclides received for use at Building 55, but it is not included in the CAP88-PC library. To model the dose from this radionuclide, the surrogate ^{67}Ga was used. This surrogate is appropriate because it has similar metabolic and radiological properties to the received radionuclide. In 2004, one stack on Building 55 was sampled and analyzed monthly for ^{125}I , gross alpha, and gross beta. To estimate the dose, ^{232}Th and ^{90}Sr were used as surrogates for alpha- and beta-emitting radionuclides, respectively.

In Building 64, life sciences researchers use ^{32}P to label probes for DNA analysis. In 2004, the release point in Building 64 was classified as Category V, and the radionuclide inventory was controlled by radiation work authorizations and permits and by periodic assessments. No sampling or monitoring was required. A summary of the CAP88-PC input parameters and the effective dose equivalent for this source is presented in [Table 10](#).

Table 10 Building 55/56/64 Source Characteristics and Dose Impacts

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radionuclide (surrogate) ^a	Annual emission (Ci/yr) ^b	Local MEI dose (mrem/yr) ^c	Percent of total dose (%)
16	250	NNW	Residence	H-3	5.0E-07	3.1E-10	< 0.1
				I-123	1.6E-04	1.2E-06	< 0.1
				I-125	4.0E-04	1.1E-03	14.0
				I-131	5.5E-05	4.9E-05	0.6
				P-32	2.8E-06	1.1E-07	< 0.1
				Tc-99m	1.6E-04	7.3E-08	< 0.1
				Tl-201 (Ga-67)	4.0E-06	1.7E-08	< 0.1
				F-18	3.3E+00	6.6E-03	85.1
				Alpha (Th-232)	9.1E-09	7.9E-06	0.1
				Beta (Sr-90)	4.6E-08	1.3E-07	< 0.1
Total					7.8E-03	100%	

^a For radionuclides not listed in CAP88-PC library, surrogate radionuclides (in parentheses) were used to model dose

^b 1 Ci = 3.7×10^{10} Bq

^c 1 mrem = 1.0×10^{-2} mSv

1.3.6 Buildings 70 and 70A (Nuclear, Chemical, Life, and Earth Sciences and Environmental Energy Technology)

Nuclear Science Division programs include research in nuclear structure and reactions, relativistic nuclear collisions, nuclear and particle astrophysics, nuclear data evaluation, and nuclear theory. Chemical Sciences Division conducts research in the areas of chemical physics and the dynamics of chemical reactions, the structure and reactivity of transient species, electron spectroscopy, surface chemistry and catalysis, electrochemistry, chemistry of the actinide elements and their relationship to environmental and physiological issues, and atomic physics. Life Sciences Division programs include studies of tumor cells, DNA damage from radiation, and impacts of cosmic radiation exposure to astronauts. Earth Sciences Division and Environmental Energy Technology programs perform fundamental and applied research related to energy and environmental resources.

Programs carried out in these facilities include super-heavy nuclear studies, waste migration research using tracer amounts of radionuclides, nuclear chemistry experiments, analysis of activated geological samples, and radiation biology research. Research activities using radioactive material are carried out by various research groups in the many small laboratories within Buildings 70 and 70A.

In 2004, 28 release points in Buildings 70 and 70A were classified as Category V and an additional 10 release points were sampled continuously and analyzed weekly (Category II) or monthly (Category III and IV). In addition to being continuously sampled, one stack on Building 70A was monitored for alpha-emitting radionuclides with a real-time, continuous air monitor. For this stack, the greatest measured results were from the continuous sampling system, and these results were used to determine emissions from the stack. Sampled radionuclides include ^{125}I , ^{14}C , gross alpha, gross beta, and ^3H .

In addition to sampled emissions, radionuclides received for use at all Category II-V release points during the year are typically assumed to be emitted. In 2004, legacy material stored in the Heavy Elements Research Laboratory (HERL) in Building 70A was inventoried and entered into the receipts database. This material was used primarily in laboratories exhausted by sampled or monitored stacks. For the small amount of legacy material used in Building 70A laboratories that are not exhausted by sampled or monitored stacks (Category V release points), the inventoried quantity was multiplied by the appropriate EPA-specified physical state emission factor and then added to the actual measured emissions. This approach provided a conservative estimate of emissions from Building 70A.

To estimate dose, ^{232}Th and ^{90}Sr were used as surrogates for alpha- and beta-emitting radionuclides, respectively. A summary of the CAP88-PC input parameters and effective dose equivalent for this source is presented in [Table 11](#).

Table 11 Building 70/70A Source Characteristics and Dose Impacts

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radio-nuclide (surrogate) ^a	Annual emission (Ci/yr) ^b	Local dose (mrem/yr) ^c	Percent of total dose (%)			
16	270	WSW	UC Berkeley dormitory	C-14	1.5E-05	8.4E-08	< 0.1			
				Ce-141	5.9E-11	7.7E-13	< 0.1			
				Co-60	3.9E-11	2.1E-10	< 0.1			
				Cs-134	1.6E-11	2.9E-11	< 0.1			
				Eu-152	3.3E-11	1.9E-10	< 0.1			
				Fe-59	1.0E-06	8.7E-08	< 0.1			
				H-3	1.7E-05	3.2E-09	< 0.1			
				I-125	4.3E-08	3.6E-08	< 0.1			
				Na-24	1.6E-08	1.0E-10	< 0.1			
				P-32	1.7E-05	2.1E-07	0.1			
				Pa-233	4.4E-11	8.1E-13	< 0.1			
				Rb-86	8.7E-11	1.6E-12	< 0.1			
				S-35	5.0E-06	1.6E-08	< 0.1			
				Tc-99	5.1E-05	7.3E-06	3.8			
				U-233	1.9E-09	1.8E-07	0.1			
				U-238 ^d	4.3E-10	9.6E-08	< 0.1			
				Alpha (Th-232)	7.0E-07	1.8E-04	94.9			
				Beta (Sr-90)	2.2E-06	1.9E-06	1.0			
				Total					1.9E-04	100%

^a For radionuclides not listed in CAP88-PC library, surrogate radionuclides (in parentheses) were used to model dose

^b 1 Ci = 3.7×10^{10} Bq

^c 1 mrem = 1.0×10^{-2} mSv

^d Includes progeny

1.3.7 Building 71 (Accelerator and Fusion Research)

Building 71 formerly housed the Heavy Ion Linear Accelerator (HILAC), which is no longer in operation. In 2004, the Laser Optics and Accelerator Systems Integrated Studies (l'OASIS) Group used the building for a low-voltage, laser-driven accelerator, which is authorized to produce solid ^{18}F on targets for use at other facilities. The accelerator operates at voltages too low to produce air activation products and in 2004, no ^{18}F was produced. Thus there were no airborne radionuclide emissions from Building 71 in 2004.

1.3.8 Building 72 (Low-Background Facility)

The Low-Background Facility in Building 72 is used to perform gamma spectroscopy to characterize low-level radioactive material in support of low-activity materials certification; studies in cosmic ray and neutron activation; nuclear science experiments; and environment, safety, and health activities. In 2004, ^{198}Au , ^{207}Bi , ^{194}Hg , ^{182}Ta , ^{44}Ti , and ^{97}Zr were among the radionuclides received for use at Building 72, but they are not included in the CAP88-PC library. To model the dose from these

radionuclides, the surrogates ^{192}Ir , ^{181}Hf , ^{152}Eu , ^{181}Hf , ^{144}Ce , and ^{99}Mo , respectively, were used. The surrogates are appropriate because they have similar metabolic and radiological properties to the received radionuclides.

In 2004, release points in Building 72 were classified as Category V, and the radionuclide inventory was controlled by radiation work authorizations and permits and by periodic assessments. A summary of the CAP88-PC input parameters and effective dose equivalent for this source is presented in [Table 12](#).

Table 12 Building 72 Source Characteristics and Dose Impacts

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radio-nuclide (surrogate) ^a	Annual emission (Ci/yr) ^b	Local MEI dose (mrem/yr) ^c	Percent of total dose (%)
3	230	SSW	UC Berkeley	Ac-227	1.7E-12	7.5E-09	0.0%
				Au-198			
				(Ir-192)	5.4E-11	4.7E-11	0.0%
				Ba-133	6.0E-14	7.5E-13	0.0%
				Bi-207			
				(Hf-181)	6.1E-13	2.2E-13	0.0%
				Cd-113	1.3E-13	0.0E+00	0.0%
				Co-58	1.9E-05	1.5E-05	75.4%
				Co-60	2.4E-08	9.8E-07	4.9%
				Cr-51	5.4E-14	6.8E-16	0.0%
				Cu-64	1.0E-08	4.4E-11	0.0%
				Eu-152	1.0E-08	4.2E-07	2.1%
				Fe-59	5.9E-07	3.7E-07	1.9%
				Hg-194			
				(Eu-152)	9.5E-13	3.9E-11	0.0%
				Mn-54	5.4E-11	1.4E-10	0.0%
				Na-24	2.0E-08	1.0E-09	0.0%
				Nb-95	2.7E-14	9.9E-15	0.0%
				P-32	1.9E-10	1.4E-11	0.0%
				Pa-231	1.0E-12	3.4E-09	0.0%
				Sb-124	2.0E-08	2.6E-08	0.1%
				Ta-182			
				(Hf-181)	1.1E-12	3.9E-13	0.0%
				Th-228	1.1E-16	1.9E-13	0.0%
				Th-229	5.3E-10	2.6E-06	13.0%
				Th-232	1.0E-12	2.5E-09	0.0%
				Ti-44			
(Ce-144)	2.7E-12	7.6E-12	0.0%				
Zr-95	8.3E-07	5.0E-07	2.5%				
Zr-97							
(Mo-99)	3.7E-08	1.3E-09	0.0%				
Total					2.0E-05	100%	

^a For radionuclides not listed in CAP88-PC library, surrogate radionuclides (in parentheses) were used to model dose

^b 1 Ci = 3.7×10^{10} Bq

^c 1 mrem = 1.0×10^{-2} mSv

1.3.9 Buildings 74, 83, and 84 (Life Sciences)

Research in these buildings includes a wide variety of cell biology, virology, research medicine, and genomics projects that seek to integrate experimental and theoretical connections between genes, their regulation, and their higher order organization within cells and tissues, the repair processes that maintain their integrity, and the functions of the protein machines they encode and to better understand the effect of genotype-environment interactions on the risk of harmful health effects associated with low-dose exposure to ionizing radiation.

Emissions from Building 74 come from stacks that vent hoods and individual workplaces. Buildings 83 and 84 vent through HEPA-filtered biological cabinets. When research activities involve ^{125}I , they are normally carried out in TEDA-doped activated-carbon-filtered enclosures; however, no radioactive iodine was received in 2004.

In 2004, release points in Buildings 74, 83, and 84 were classified as Category V, and the radionuclide inventory was controlled by radiation work authorizations and permits and by periodic assessments. No sampling or monitoring was required. A summary of the CAP88-PC input parameters and the effective dose equivalent for this source is presented in [Table 13](#).

Table 13 Buildings 74/83/84 Source Characteristics and Dose Impacts

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radio-nuclide	Annual emission (Ci/yr) ^a	Local MEI dose (mrem/yr) ^b	Percent of total dose (%)
7	160	SSE	UC Berkeley	P-32	1.0E-04	2.2E-05	99.8
				S-35	1.0E-06	4.2E-08	0.2
Total						2.2E-05	100%

^a 1 Ci = 3.7×10^{10} Bq

^b 1 mrem = 1.0×10^{-2} mSv

1.3.10 Building 75 (Former National Tritium Labeling Facility)

The National Tritium Labeling Facility (NTLF) was a national resource center funded by the National Institutes of Health and engaged in tritium-labeling research and development. The facility was mainly used for activities in which a wide variety of molecules was labeled with tritium and purified for further use in chemical, biochemical, and radiopharmaceutical studies. In fall 2001, the National Institutes of Health cancelled its funding of the NTLF, and the facility ceased labeling operations in December 2001.

In the past, the NTLF was the only source at Berkeley Lab that historically resulted in more than 1% of the NESHAP effective dose equivalent standard of 10 mrem/yr. Currently, low-level emissions are due to residual tritium in facility spaces such as ducts and wall coverings. There are two stacks associated with past NTLF activities: one on the northern hillside near Building 75 and one on the

roof of Building 75. In 2004, continuous sampling with subsequent laboratory analysis was performed on both stacks.

Other release points in Building 75 include Room 127, which in 2004 was used only for gamma spectroscopy of sealed material, but where the ducts may have been contaminated with low levels of tritium and alpha- and beta-emitting radionuclides from past handling of hazardous waste. Another room in Building 75 was used in previous years for tritium calorimetry. In 2004, emissions from these locations were sampled and analyzed monthly for tritium.

A summary of the CAP88-PC input parameters and the effective dose equivalent for this source is presented in [Table 14](#).

Table 14 Building 75 Source Characteristics and Dose Impacts

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radionuclide (surrogate) ^a	Annual emission (Ci/yr) ^b	Local MEI dose (mrem/yr) ^c	Percent of total dose (%)
8.5	110	NW	UC	H-3	3.75E-02		
6.7			Lawrence Hall of Science	H-3	6.72E-02	2.6E-04	57.8
7.0				H-3	2.01E-04		
				Alpha (Th-232)	3.32E-08	1.9E-04	41.8
				Beta (Sr-90)	1.14E-07	1.8E-06	0.4
Total						4.5E-04	100%

^a For radionuclides not listed in CAP88-PC library, surrogate radionuclides (in parentheses) were used to model dose

^b 1 Ci = 3.7×10^{10} Bq

^c 1 mrem = 1.0×10^{-2} mSv

1.3.11 Building 85 (Hazardous Waste Handling Facility)

Radioactive and hazardous waste generated by Berkeley Lab research and support operations is sent to Building 85, where it is processed for shipping to off-site disposal facilities. In 2004, this building had two stacks equipped with continuous air sampling systems to collect alpha- and beta-emitting radionuclides, ¹⁴C, ¹²⁵I, and ³H. To estimate the dose, ²³²Th and ⁹⁰Sr were used as surrogates for alpha- and beta-emitting radionuclides, respectively. A summary of the CAP88-PC input parameters and effective dose equivalent from Building 85 is presented in [Table 15](#).

Table 15 Building 85 Source Characteristics and Dose Impacts

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radionuclide (surrogate) ^a	Annual emission (Ci/yr) ^b	Local MEI dose (mrem/yr) ^c	Percent of total dose (%)
16	210	SSE	UC Berkeley	C-14	3.7E-03	7.9E-05	28.3
				H-3	4.9E-02	3.5E-05	12.6
				I-125	1.2E-06	3.9E-06	1.4
				Gross alpha (Th-232)	1.6E-07	1.6E-04	57.5
				Gross beta (Sr-90)	1.4E-07	4.6E-07	0.2
				Total		2.8E-04	100%

^a For radionuclides not listed in CAP88-PC library, surrogate radionuclides (in parentheses) were used to model dose

^b 1 Ci = 3.7×10^{10} Bq

^c 1 mrem = 1.0×10^{-2} mSv

1.3.12 Building 88 (88-Inch Cyclotron)

The 88-Inch Cyclotron at Building 88 accelerates beams from hydrogen to uranium in support of national programs in nuclear science, biology, medicine, and industrial applications. The energy of the cyclotron's beam depends on the ion being accelerated. For example, protons, which are light ions, can be accelerated to 65 MeV; ²⁰⁹Bi, a heavy ion, can be accelerated to 1.6 GeV. The normal operating current of the beam is 100 μ A.

The ions accelerated in the cyclotron may be radioactive, and the targets that the ion beam strikes may also be radioactive. Use of these radionuclides is approved by radiation work authorizations. In addition, the cyclotron produces neutrons during its operation, which can activate the components of air. The major air activation products produced by the cyclotron are ¹¹C, ¹³N, and ¹⁵O, all positron-emitting radionuclides.

The cyclotron is enclosed within a vault, and the vault is ventilated by an exhaust system to a roof stack. Emissions from the roof stack are monitored by a real-time positron detector. For projects that accelerate radioactive gases, an effluent-capture system in the cyclotron pit collects and stores vacuum pump exhaust in holding bags until the short-lived radionuclides have decayed.

Emissions in 2004 were estimated based on emissions measurements from three stacks that were sampled for alpha- and beta-emitting radionuclides and on measurements of positron-emitting radionuclides from the stack that exhausts the cyclotron vault. To estimate the dose, all positron-emitting radionuclides from this facility were assumed to be ¹¹C, and alpha- and beta-emitting radionuclides were assumed to be ²³²Th and ⁹⁰Sr, respectively. Carbon-11 is an appropriate surrogate for radioisotopes of nitrogen and oxygen because it overestimates the dose that would be received from the other radionuclides. A summary of the CAP88-PC input parameters and the effective dose equivalent for this source is presented in [Table 16](#).

Table 16 Building 88 Source Characteristics and Dose Impacts

Release height (m)	Local MEI distance (m)	Local MEI dir.	Local MEI description	Radio-nuclide (surrogate) ^a	Annual emission (Ci/yr) ^b	Local MEI dose (mrem/yr) ^c	Percent of total dose (%)
13	110	W	Residence	Positron (C-11)	4.0E-01	3.5E-04	88.7
				Gross alpha (Th-232)	9.1E-08	4.5E-05	11.2
				Gross beta (Sr-90)	2.5E-07	3.7E-07	0.1
				Total		4.0E-04	100%

^a For radionuclides not listed in CAP88-PC library, surrogate radionuclides (in parentheses) were used to model dose

^b 1 Ci = 3.7×10^{10} Bq

^c 1 mrem = 1.0×10^{-2} mSv

AIR EMISSIONS DATA

Source and emission control information are summarized in Table 17. Quantities of radionuclides potentially emitted from Berkeley Lab sources in 2004 are presented in Table 18.

Table 17 Sources and Emission Controls In 2004

Source	Number of release points	Type of control	Efficiency (%)	Distance to nearest member of public ^a
Point sources				
Building 1	7	None ^b	NA ^c	10 m (classrooms in same building)
Building 3	1	None ^b	NA	30 m (UC Berkeley)
Building 71	2	None	NA	190 m (Residence)
Building 72	4	None	NA	230 m (UC Berkeley)
Building 75	7	None	NA	110 m (UC Lawrence Hall of Science)
Building 85	2	HEPA	>99	210 m (UC Berkeley)
Building 88	13	HEPA TEDA-DAC ^d	>99 >75	110 m (Residence)
Group sources				
Buildings 6/16/52	12	None ^e	NA	350 m (UC Lawrence Hall of Science)
Buildings 26/76	4	HEPA	>99	250 m (UC Lawrence Hall of Science)
Buildings 55/56/64	14	HEPA TEDA-DAC ^f	>99 >75	250 m (Residence)
Buildings 70/70A	38	HEPA None ^g	>99 NA	270 m (UC Berkeley Dormitory)
Buildings 74/83/84	23	HEPA TEDA-DAC None	>99 >75 NA	160 m (UC Berkeley)

^a 1 m = 3.281 ft

^b Emissions are from Berkeley Lab fume hoods, which do not require filtration for the small radionuclide amounts used

^c Not applicable

^d TEDA-doped activated carbon traps

^e Radionuclides emitted from accelerators are short-lived air activation products, for which emission control is impractical

^f At Building 55 only

^g Stacks included in this group vent a number of laboratories whose research employs microcurie and millicurie quantities (between 3.7×10^4 and 3.7×10^7 Bq) of a number of actinides

Table 18 Airborne Radioactivity Potentially Emitted In 2004

Radionuclide (surrogate) ^a	Activity potentially emitted		Total (%)
	(Ci/yr)	(Bq/yr)	
F-18	3.27E+00	1.21E+11	85.5
C-11	3.97E-01	1.47E+10	10.4
H-3	1.54E-01	5.68E+09	4.0
C-14	3.81E-03	1.41E+08	0.1
I-125	4.05E-04	1.50E+07	< 0.1
Tc-99m	1.62E-04	5.99E+06	< 0.1
I-123	1.62E-04	5.99E+06	< 0.1

Table 18 Airborne Radioactivity Potentially Emitted In 2004 (continued)

Radionuclide (surrogate) ^a	Activity potentially emitted		Total (%)
	(Ci/yr)	(Bq/yr)	
P-32	1.38E-04	5.10E+06	< 0.1
S-35	7.66E-05	2.84E+06	< 0.1
I-131	5.50E-05	2.04E+06	< 0.1
Tc-99	5.10E-05	1.89E+06	< 0.1
Co-58	1.86E-05	6.89E+05	< 0.1
N-13	1.80E-05	6.66E+05	< 0.1
P-33 (P-32)	6.00E-06	2.22E+05	< 0.1
Tl-201 (Ga-67)	4.00E-06	1.48E+05	< 0.1
Beta (Sr-90)	2.94E-06	1.09E+05	< 0.1
Fe-59	1.59E-06	5.90E+04	< 0.1
Alpha (Th-232)	1.05E-06	3.89E+04	< 0.1
Zr-95	8.28E-07	3.06E+04	< 0.1
Ar-41	1.00E-07	3.70E+03	< 0.1
O-15	9.40E-08	3.48E+03	< 0.1
Zr-97 (Mo-99)	3.67E-08	1.36E+03	< 0.1
Na-24	3.64E-08	1.35E+03	< 0.1
Co-60	2.47E-08	9.12E+02	< 0.1
Sb-124	2.00E-08	7.40E+02	< 0.1
Eu-152	1.00E-08	3.71E+02	< 0.1
Cu-64	1.00E-08	3.70E+02	< 0.1
Pu-241	9.00E-09	3.33E+02	< 0.1
Pu-239	4.21E-09	1.56E+02	< 0.1
Bk-249 (Pu-241)	2.62E-09	9.70E+01	< 0.1
U-233	1.90E-09	7.03E+01	< 0.1
U-238	1.58E-09	5.84E+01	< 0.1
Pu-238	1.43E-09	5.31E+01	< 0.1
Cf-249 (Cm-245)	1.14E-09	4.21E+01	< 0.1
Cs-137 ^b	9.73E-10	3.60E+01	< 0.1
Am-241	9.67E-10	3.58E+01	< 0.1
Ba-133	6.00E-10	2.22E+01	< 0.1
Th-229	5.28E-10	1.95E+01	< 0.1
Sr-90	2.98E-10	1.10E+01	< 0.1
U-238 ^b	2.69E-10	9.94E+00	< 0.1
I-129	1.11E-10	4.11E+00	< 0.1
U-235	1.10E-10	4.08E+00	< 0.1
Rb-86	8.74E-11	3.23E+00	< 0.1
Mn-54	7.44E-11	2.75E+00	< 0.1
Ce-141	5.91E-11	2.19E+00	< 0.1
Au-198 (Ir-192)	5.40E-11	2.00E+00	< 0.1
Fe-55	5.15E-11	1.91E+00	< 0.1
Th-232	4.61E-11	1.71E+00	< 0.1
Pa-233	4.35E-11	1.61E+00	< 0.1

Table 18 Airborne Radioactivity Potentially Emitted In 2004 (continued)

Radionuclide (surrogate) ^a	Activity potentially emitted		Total (%)
	(Ci/yr)	(Bq/yr)	
Cs-134	3.72E-11	1.38E+00	< 0.1
Zn-65	2.87E-11	1.06E+00	< 0.1
Ni-63	2.67E-11	9.88E-01	< 0.1
Co-57	1.85E-11	6.85E-01	< 0.1
Y-90	1.80E-11	6.66E-01	< 0.1
Th-230	1.24E-11	4.59E-01	< 0.1
Am-243	6.60E-12	2.44E-01	< 0.1
Np-237	5.69E-12	2.11E-01	< 0.1
Ra-226	5.02E-12	1.86E-01	< 0.1
Ti-44 (Ce-144)	2.72E-12	1.01E-01	< 0.1
Ac-227	1.68E-12	6.22E-02	< 0.1
Ce-144 ^b	1.50E-12	5.55E-02	< 0.1
Pa-231	1.25E-12	4.64E-02	< 0.1
Ta-182 (Hf-181)	1.07E-12	3.94E-02	< 0.1
Hg-194 (Eu-152)	9.69E-13	3.59E-02	< 0.1
Bi-207 (Hf-181)	6.08E-13	2.25E-02	< 0.1
Cm-243	5.55E-13	2.05E-02	< 0.1
U-232	2.51E-13	9.29E-03	< 0.1
Cf-250 (Am-241)	2.00E-13	7.41E-03	< 0.1
Cd-113	1.29E-13	4.77E-03	< 0.1
Cr-51	5.43E-14	2.01E-03	< 0.1
Cm-244	4.47E-14	1.65E-03	< 0.1
Pu-242	4.40E-14	1.63E-03	< 0.1
Na-22	4.30E-14	1.59E-03	< 0.1
Po-210	4.00E-14	1.48E-03	< 0.1
Ac-228	4.00E-14	1.48E-03	< 0.1
Nb-95	2.70E-14	9.99E-04	< 0.1
Br-76 (Br-82)	1.80E-14	6.66E-04	< 0.1
K-40	5.00E-15	1.85E-04	< 0.1
Cm-246	3.00E-15	1.11E-04	< 0.1
Co-56 (Co-60)	2.60E-15	9.62E-05	< 0.1
Os-185 (Mn-54)	2.47E-15	9.14E-05	< 0.1
Cm-248	1.20E-15	4.44E-05	< 0.1
Br-77 (Cu-64)	1.00E-15	3.70E-05	< 0.1
Np-239	8.52E-16	3.15E-05	< 0.1
Sb-125	4.32E-16	1.60E-05	< 0.1
Kr-76 (Kr-87)	4.00E-16	1.48E-05	< 0.1
Cm-245	3.80E-16	1.41E-05	< 0.1
Th-228	1.06E-16	3.90E-06	< 0.1
Ag-108 (Ag-111)	7.00E-17	2.59E-06	< 0.1
Total	3.83E+00	1.42E+11	100%

^a For radionuclides not listed in CAP88-PC library, surrogate radionuclides (in parentheses) were used to model dose^b Includes progeny

DOSE ASSESSMENTS

- 3.1 DESCRIPTION OF DOSE MODEL
- 3.2 SUMMARY OF INPUT PARAMETERS
- 3.3 COMPLIANCE ASSESSMENT
- 3.4 CERTIFICATION

3.1 DESCRIPTION OF DOSE MODEL

To comply with NESHAP regulations and meet DOE guidance, the EPA atmospheric dispersion and radiation dose calculation computer code, CAP88-PC, Version 2.0, was used to calculate the effective dose equivalent to an individual within each population segment at various distances and from various release points. A total of 13 CAP88-PC individual runs were executed to model the 12 point and group sources described in Section 1. (Multiple runs were required for some sources because CAP88-PC can model only 36 radionuclides in a single run.) For 2004, the group source comprising Buildings 55, 56, and 64 was identified as the most significant source of airborne radionuclides emitted from Berkeley Lab. This source was responsible for 85% of the total dose to the sitewide MEI, which was determined to be at the UC Lawrence Hall of Science. The effective dose equivalent to the sitewide MEI is the sum of doses from all 13 CAP88-PC runs (Table 19).

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 2004 (Table 18) were assumed to be released from a hypothetical, centrally located stack that is 16 m high, is 0.3 m in diameter, and has an exit velocity of 4.1 m/s (Wahl 2003). Because CAP88-PC 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. A summary of the collective dose assessment attributed to each potentially emitted radionuclide is given in Table 20.

Input to the CAP88-PC calculations of individual and population dose 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 40 CFR 61, Subpart H.

In addition, 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. The two outputs were identical, indicating that the code performed as intended.

Table 19 Summary of Dose Assessment from All Berkeley Lab Sources

Building number	Building name/function	Release height (m)	Relative to nearest off-site member of public ^a				Relative to UC Lawrence Hall of Science ^b			
			Distance (m)	Direction	Description	Dose (mrem/yr) ^c	Distance (m)	Direction	Dose (mrem/yr)	Percent of total dose (%)
1	Donner Lab at UC Berkeley	18	10	ESE	UC Berkeley	1.7×10^{-5}	990	ENE	2.5×10^{-5}	0.3
3	Calvin Lab at UC Berkeley	15	30	S	UC Berkeley	1.2×10^{-6}	1060	NE	1.2×10^{-6}	< 0.1
6/16/52	ALS/ Accelerator & Fusion Research	9	350	NNE	UC Lawrence Hall of Science	1.5×10^{-8}	350	NNE	1.5×10^{-8}	< 0.1
26/76	Radioanalytical Lab	8	250	N	UC Lawrence Hall of Science	1.3×10^{-5}	250	N	1.3×10^{-5}	0.1
55/56/64	Center for Functional Imaging/Biomedical Isotope Facility/Life Sciences	16	250	NNW	Residence	7.8×10^{-3}	460	E	7.8×10^{-3}	85.2
70/70A	Nuclear/Chemical/Life/Earth/Environmental Sciences	16	270	WSW	UC Berkeley Dormitory	1.9×10^{-4}	530	ENE	2.9×10^{-4}	3.2
71	Accelerator & Fusion Research	13	190	NNW	Residence	0	310	ESE	0	0
72	Low-Background Facility	3	230	SSW	UC Berkeley	2.0×10^{-5}	500	NW	2.3×10^{-5}	0.3
74/83/84	Life Sciences	7	160	SSE	UC Berkeley	2.2×10^{-5}	690	WNW	1.9×10^{-5}	0.2
75	Former NTLF	8.5 ^d 6.7 ^e 7.0 ^f	110	NW	UC Lawrence Hall of Science	4.5×10^{-4}	110	NW	4.5×10^{-4}	4.9
85	Hazardous Waste Handling Facility	16	210	SSE	UC Berkeley	2.8×10^{-4}	570	WNW	3.1×10^{-4}	3.4
88	88-Inch Cyclotron	13	110	W	Residence	4.0×10^{-4}	690	ENE	2.3×10^{-4}	2.5
Total									9.2×10^{-3}	100%

^a Local MEI^b Sitewide MEI^c 1 mrem = 1.0×10^{-2} mSv^d Former NTLF stack on hillside^e Former NTLF rooftop stack^f Other Building 75 stacks

Table 20 Summary of Collective Dose to the Population within 80 km of Berkeley Lab

Radionuclide ^a (surrogate)	Collective dose (person-rem/yr) ^b	Percent of total (%)
F-18	7.62E-02	63.7
Alpha (Th-232)	1.96E-02	16.4
C-14	7.17E-03	6.0
H-3	5.86E-03	4.9
I-125	5.40E-03	4.5
C-11	2.89E-03	2.4
Tc-99	1.23E-03	1.0
Beta (Sr-90)	2.80E-04	0.2
I-131	2.23E-04	0.2
P-32	2.14E-04	0.2
Co-58	1.71E-04	0.1
Pu-239	7.64E-05	0.1
S-35	4.57E-05	< 0.1
Cf-249 (Cm-245)	3.36E-05	< 0.1
Am-241	2.76E-05	< 0.1
Pu-238	2.41E-05	< 0.1
Th-229	1.93E-05	< 0.1
U-233	1.34E-05	< 0.1
Fe-59	1.16E-05	< 0.1
Co-60	1.09E-05	< 0.1
U-238	9.79E-06	< 0.1
P-33 (P-32)	9.30E-06	< 0.1
U-238 ^c	8.26E-06	< 0.1
Zr-95	5.38E-06	< 0.1
I-123	5.20E-06	< 0.1
Eu-152	4.47E-06	< 0.1
Pu-241	2.51E-06	< 0.1
Tc-99m	1.22E-06	< 0.1
Th-232	8.62E-07	< 0.1
U-235	7.32E-07	< 0.1
Bk-249 (Pu-241)	7.31E-07	< 0.1
Cs-137 ^c	4.08E-07	< 0.1
Tl-201 (Ga-67)	3.68E-07	< 0.1
Sb-124	2.80E-07	< 0.1
Am-243	1.88E-07	< 0.1

Table 20 Summary of Collective Dose to the Population within 80 km of Berkeley Lab (continued)

Radionuclide ^a (surrogate)	Collective dose (person-rem/yr) ^b	Percent of total (%)
Th-230	1.61E-07	< 0.1
Np-237	1.47E-07	< 0.1
Ba-133	8.06E-08	< 0.1
N-13	6.89E-08	< 0.1
Ac-227	5.63E-08	< 0.1
I-129	4.00E-08	< 0.1
Pa-231	3.20E-08	< 0.1
Sr-90	2.84E-08	< 0.1
Na-24	1.48E-08	< 0.1
Cm-243	1.06E-08	< 0.1
Zr-97 (Mo-99)	1.01E-08	< 0.1
Cs-134	6.43E-09	< 0.1
U-232	6.31E-09	< 0.1
Cf-250 (Am-241)	5.70E-09	< 0.1
Ra-226	3.39E-09	< 0.1
Ar-41	2.72E-09	< 0.1
Mn-54	2.15E-09	< 0.1
Zn-65	1.30E-09	< 0.1
Pu-242	7.58E-10	< 0.1
Cm-244	6.73E-10	< 0.1
Au-198 (Ir-192)	4.92E-10	< 0.1
Hg-194 (Eu-152)	4.33E-10	< 0.1
Cu-64	3.09E-10	< 0.1
Rb-86	1.63E-10	< 0.1
Cm-248	1.29E-10	< 0.1
Co-57	9.40E-11	< 0.1
Cm-246	8.74E-11	< 0.1
Pa-233	6.26E-11	< 0.1
Ti-44 (Ce-144)	6.22E-11	< 0.1
Ce-141	5.96E-11	< 0.1
O-15	5.90E-11	< 0.1
Ce-144 ^c	3.57E-11	< 0.1
Po-210	2.75E-11	< 0.1
Fe-55	2.11E-11	< 0.1
Cm-245	1.12E-11	< 0.1

Table 20 Summary of Collective Dose to the Population within 80 km of Berkeley Lab (continued)

Radionuclide ^a (surrogate)	Collective dose (person-rem/yr) ^b	Percent of total (%)
Na-22	9.82E-12	< 0.1
Ni-63	9.32E-12	< 0.1
Y-90	8.58E-12	< 0.1
Ta-182 (Hf-181)	4.04E-12	< 0.1
Bi-207 (Hf-181)	2.29E-12	< 0.1
Th-228	1.39E-12	< 0.1
K-40	1.16E-12	< 0.1
Co-56 (Co-60)	1.15E-12	< 0.1
Nb-95	1.67E-13	< 0.1
Ac-228	1.39E-13	< 0.1
Os-185 (Mn-54)	7.12E-14	< 0.1
Sb-125	2.00E-14	< 0.1
Br-76 (Br-82)	9.78E-15	< 0.1
Cr-51	7.26E-15	< 0.1
Np-239	1.60E-16	< 0.1
Br-77 (Cu-64)	3.09E-17	< 0.1
Kr-76 (Kr-87)	6.08E-18	< 0.1
Ag-108 (Ag-111)	4.43E-17	< 0.1
Cd-113	0.00E+00	< 0.1
Total	1.20E-01	100%

^a For radionuclides not listed in CAP88-PC library, surrogate radionuclides (in parentheses) were used to model dose

^b 1 person-rem = 1×10^{-2} person-Sv

^c Includes progeny

3.2 SUMMARY OF INPUT PARAMETERS

Run options for CAP88-PC individual dose assessments include distances to receptors. Twenty such distances were specified, including distance to the nearest local member of the public, the residence nearest the 88-Inch Cyclotron, the residence nearest the Building 56 accelerator, and the Lawrence Hall of Science (the MEI). To estimate population dose, the population file prepared in 2002 based on the LandScan Global Population Database for 2001 was used ([Gallegos 2002](#)).

Meteorological data were compiled from on-site data for 2004. Berkeley Lab began collecting this data in early 1994 at a 66-ft (20-m) tower located in the central portion of the Laboratory. Site-specific values for annual precipitation (38.1 in. [96.9 cm]) and average temperature (54.7°F [12.6°C]) were used. The 2004 wind data are provided in [Attachment B](#).

Source data include stack height, diameter, and exit velocity. Momentum plume rise was chosen for all sources. Release heights are shown in Table 19. For all point and group sources (except Building 75), other stack input parameters were 4 in. (0.1 m) diameter and 0 ft/s (0 m/s) exit velocity. At the former NTLF in Building 75, input parameters for the stack on the hillside were 3 ft (0.91 m) diameter and 25.1 ft/s (7.66 m/s) exit velocity and for the stack on the roof were 1.7 ft (0.53 m) diameter and 18.7 ft/s (5.69 m/s) exit velocity. For remaining sources in Building 75, the default parameters of 4 in. (0.1 m) diameter and 0 ft/s (0 m/s) exit velocity were used.

Agricultural data were obtained from the California Department of Food and Agriculture, as documented in a memo to the NESHAP files ([Wahl 2004](#)). The values include 1.9 beef cows per km², 4.0 milk cows per km², and 4.6% land cultivated for vegetable crops. The urban scenario was chosen, which is appropriate for the Berkeley Lab site.

Nuclide data for the 2004 radioactive air emissions were both measured and conservatively derived based on the quantities received or used during the year, and data are shown in [Table 18](#) in [Section 2](#). Surrogates were chosen as described in [Section 1.3](#). To estimate population dose, three CAP88-PC runs were performed using stack parameters of a hypothetical, centrally located stack (discussed in [Section 3.1](#)), with the source term replaced by all the radionuclides listed in [Table 18](#). The results of the three runs were summed.

3.3 COMPLIANCE ASSESSMENT

This compliance assessment used the computer code CAP88-PC, Version 2.0, to calculate the effective dose equivalent to a sitewide MEI. This exposure represents the sum of impacts from all 12 sources modeled to that location (the MEI at the UC Lawrence Hall of Science). A summary of the dose assessment for each source is presented in Table 19.

Effective dose equivalent: 0.01 mrem/year (1.0×10^{-4} mSv/year)

Location of sitewide MEI: UC Lawrence Hall of Science at 460 m east of Buildings 55/56/64

3.4 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: Phyllis Pei Date: 6/10/05
Phyllis Pei

Division Director, Environment, Health, and Safety Division, Lawrence Berkeley National Lab

Signature: Aundra Richards Date: 6/16/05
Aundra Richards

Director, DOE Berkeley Site Office

ADDITIONAL INFORMATION

4.1 ADDITIONS OR MODIFICATIONS

4.2 UNPLANNED RELEASES

4.3 DIFFUSE EMISSIONS

4.1 ADDITIONS OR MODIFICATIONS

There were no facility additions or modifications in 2004. There were, however, changes in emissions measurement and reporting in 2004, based primarily on changes in work authorized. Changes from last year's report include deletion of stack sampling locations.

4.1.1 Deleted Sampling Locations

In 2004, two sampling locations were deleted.

- At Building 1, the quantities of radionuclides authorized for use in Room 373 was decreased, so sampling of the Room 373 fume hood stack was no longer required and was discontinued in December 2004.
- At Building 75, the room where tritium calorimetry had been conducted, Room 112B, was decontaminated, so sampling of the room air was discontinued in July 2004.

4.2 UNPLANNED RELEASES

There were no unplanned releases in 2004.

4.3 DIFFUSE EMISSIONS

In 2004, no area sources were identified that potentially presented a source of fugitive emissions to the public.

SUPPLEMENTAL INFORMATION

- 5.1 DOSE ESTIMATE
- 5.2 RADON EMISSIONS
- 5.3 EMISSION POINTS

5.1 DOSE ESTIMATE

Provide an estimate of collective effective dose equivalent (person-rem/yr) for 2004 releases.

The estimated collective effective dose equivalent to persons living within 80 km of Berkeley Lab is 0.12 person-rem (0.0012 person-Sv) attributable to 2004 Berkeley Lab airborne emissions ([see Table 20](#)).

5.2 RADON EMISSIONS

Provide information on the status of compliance with Subparts Q and T of 40 CFR Part 61, if applicable. Although exempt from Subpart H, provide information on ^{220}Rn emission from sources containing ^{232}U and ^{232}Th where emissions potentially can exceed 0.1 mrem/yr (10^{-6} Sv/yr) to the public or 10% of the nonradon dose to the public. Provide information on nondisposal/nonstorage sources of ^{222}Rn emissions where emissions potentially can exceed 0.1 mrem/yr (10^{-6} Sv/yr) to the public or 10% of the nonradon dose to the public.

Subparts Q and T of 40 CFR 61 are not applicable to Berkeley Lab, as the Laboratory does not process, manage, or possess uranium mill tailings, ^{226}Ra , ^{232}U , or ^{232}Th , in quantities that could produce an impact of 0.1 mrem/yr (1×10^{-6} Sv/yr) to a member of the public.

5.3 EMISSION POINTS

For the purpose of assessing facility compliance with the NESHAP effluent monitoring requirements of Subpart H under Section 61.93(b), give the number of emission points subject to the continuous monitoring requirements, the number of these emission points that do not comply with the Section 61.93(b) requirements, and if possible, the cost for upgrades. Describe site periodic confirmatory measurement plans. Indicate the status of the QA program described by Appendix B, Method 114.

In 2004, 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. Berkeley Lab's sampling, monitoring, and analytical methods fully conform to Section 61.93(b) requirements. Berkeley Lab has a) identified all release points and evaluated emissions, b) categorized release points by effective dose equivalent, and

c) suggested suitable measurement methodology for each point. Periodic confirmatory measurements were conducted in accordance with the EPA-approved NESHAP compliance strategy established as part of Berkeley Lab's fulfillment of its NESHAP FFCA ([Table 2](#)).

The program meets or exceeds provisions contained in Appendix B, Method 114. The current Berkeley Lab *Environmental Monitoring Plan* and Environmental Services Group procedures contain quality assurance elements consistent with Method 114. Berkeley Lab's *Quality Assurance Project Plan for Radionuclide NESHAP* was originally developed and approved in August 1994 and was most recently revised in May 2004.

REFERENCES

ICRP 1996: International Commission on Radiological Protection, *Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 4, Inhalation Dose Coefficients*, ICRP 71 (1996).

DOE 1991: U.S. Department of Energy, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, DOE/EH-0173T (January 1991).

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).

Donahue 1991: Donahue, R., *Air Activation in the ALS Storage Ring*, Lawrence Berkeley National Laboratory Health Physics Note #191 (April 8, 1991).

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).

Wahl 2005: Wahl, L., "Comparison of Buildings 1 and 3 Dose Modeled using COMPLY and CAP88-PC," memo ES-05-014 to file documenting comparison of 2004 dose using COMPLY and CAP88-PC dose calculation models (March 7, 2005).

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

ATTACHMENTS

7.1 ATTACHMENT A: EPA APPROVAL OF SURROGATES

7.2 ATTACHMENT B: 2004 METEOROLOGICAL DATA

7.1 ATTACHMENT A: EPA APPROVAL OF SURROGATES



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

APR -7 2005

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 February 4, 2005 was sent by you to Jack Broadbent, Director of the Air Division in EPA Region IX.

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, which is the most current version approved for regulatory purposes. 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 2004 Annual National Emissions Standards for Hazardous Air Pollutants (NESIAP) Report, which is due at EPA in June 2005.

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 Attachment 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 dose attributable to these surrogates is 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. When approved, version 3 will obviate the need for surrogates. A slide show on CAP-88 version 3 is now available on the EPA website, www.epa.gov/radiation/assessment/CAP88. The model will be available for use in fall 2005.

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 2004 Annual NESHAP Report. Should you or your staff have any questions, please contact Behram Shroff at 202-343-9707.

Sincerely,



Bonnie C. Gitlin, Acting Director
Radiation Protection Division
Office of Radiation and Indoor Air

Attachment1: Table of Surrogates

cc: Elliott Zenick, OGC
Dick Lessler, R9

Table 1. Surrogates for Radionuclides Used at Berkeley Lab (Including New Radionuclides Used in 2004 [highlighted])

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 (mrem/μCi)	Limiting Organ
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	1.5E+10 y	alpha	W	5.00E-13	4.11E+07	bone
¹⁰⁹ Ag	2.1 m	beta, gamma	NA	NA	1.24E-04 ^h	submerision	¹¹¹ Ag	7.5 d	beta, gamma	W	4.00E-07	1.72E+04 ^h	submerision
¹⁹⁹ Au	183.0 d	EC, gamma	Y	2.00E-07	1.30E-01	whole body	²⁰³ Pb	70.9 d	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 Pb	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
²⁴⁰ 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	pos, gamma	W	1.00E-05	2.56E-01	whole body
⁴⁵ Ca	162.7 d	beta	W	4.00E-07	6.52E-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	⁹⁰ 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
²⁴⁰ Cf	350.6 y	alpha, gamma	Y	4.00E-12	4.31E-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
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

Radio-nuclide	Half-Life ^a	Decay Mode ^b	Lung Class ^c	DAC ^d	DCF ^e	Limiting Organ	Surrogate	Half-Life	Decay Mode	Lung Class	DAC	DCF ^f	Limiting Organ
¹⁶⁵ Er	10.4 h	EC	W	8.00E-05	2.99E-02	whole body	¹⁶⁵ 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	5.32E-01	whole body	^{152m} Eu	9.3 h	beta, gamma	W	3.00E-06	8.19E-01	whole body
²⁵³ Es	20.5 d	alpha	W	6.00E-10	3.96E-03	whole body	²³⁵ 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	0.96E-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	9.52E-00	whole body	¹⁸¹ Hf	42.4 d	beta, gamma	W	2.00E-07	1.29E+01	whole body
^{17F}	64.5 s	pos, EC	NA	NA	NA	NA	^{18F}	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
²³⁷ Fm	100.5 d	alpha, gamma	W	7.00E-11	2.95E-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	1.91E-02	whole body	¹⁵² Eu	13.5 y	EC, beta, gamma	W	1.00E-08	2.21E+02	whole body
¹⁷³ Hf	1.9 y	EC, gamma	D	4.00E-06	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	2.37E+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	1.56E+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	¹⁹ F	1.8 h	pos, EC	NA	NA	NA	NA
¹⁹ Ne	17.2 s	pos, gamma	NA	NA	NA	NA	¹⁹ F	1.8 h	pos, EC	NA	NA	NA	NA
¹⁵ O	122.2 s	pos, EC	NA	NA	NA	NA	¹¹ 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	⁵¹ 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	5.00E-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	DCF ^f (mrem/µCi)	Limiting Organ
¹⁰¹ Rh	3.3 y	EC, gamma	Y	6.00E-08	3.96E+01	whole body	⁹⁹ 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	⁶¹ Co	5.3 y	beta, gamma	Y	1.00E-08	2.19E+02	whole body
⁴⁸ 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	⁷⁵ 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-08	1.32E-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	26.0 m	beta, gamma	D	3.00E-07	7.81E+00	whole body
¹⁷⁰ Tm	128.6 d	beta, gamma	W	9.00E-08	2.83E-01	whole body	¹⁶¹ Hf	42.4 d	beta, gamma	W	2.00E-07	1.29E+01	whole body
²³⁸ 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	⁸⁸ Y	64.0 h	beta, gamma	Y	3.00E-07	8.44E+00	whole body
¹⁶⁵ 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	EC, pos, gamma,	Y	3.00E-07	1.09E+01	whole body
⁸⁸ Zr	83.4 d	EC, gamma	D	9.00E-06	2.12E-01	whole body	^{110m} Ag	249.9 d	beta, gamma	D	5.00E-08	3.96E+01	whole body
⁸⁸ Zr	3.3 d	pos, gamma, EC	Y	1.00E-06	2.37E+00	whole body	⁸⁸ Zr	64.0 d	beta, gamma	Y	1.00E-07	2.33E+01	whole body
⁹¹ Zr	16.8 h	beta, gamma	Y	5.00E-07	4.33E+00	whole body	⁹⁸ 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^e (radionuclide of interest) to DCF (surrogate)
^g Not available or applicable
^h Submerston DCF in mrem/μCi/cm³

7.2 ATTACHMENT B: 2004 METEOROLOGICAL DATA

N A	.00160	.00171	.00000	.00000	.00000	.00000	1805	2004
NNE A	.00091	.00103	.00000	.00000	.00000	.00000	1805	2004
NE A	.00148	.00171	.00000	.00000	.00000	.00000	1805	2004
ENE A	.00217	.00444	.00000	.00000	.00000	.00000	1805	2004
E A	.00182	.00319	.00000	.00000	.00000	.00000	1805	2004
ESE A	.00148	.00262	.00000	.00000	.00000	.00000	1805	2004
SE A	.00194	.00068	.00000	.00000	.00000	.00000	1805	2004
SSE A	.00137	.00080	.00000	.00000	.00000	.00000	1805	2004
S A	.00217	.00114	.00000	.00000	.00000	.00000	1805	2004
SSW A	.00376	.00125	.00000	.00000	.00000	.00000	1805	2004
SW A	.00422	.00205	.00000	.00000	.00000	.00000	1805	2004
WSW A	.00513	.00148	.00000	.00000	.00000	.00000	1805	2004
W A	.00501	.00046	.00000	.00000	.00000	.00000	1805	2004
WNW A	.00308	.00080	.00000	.00000	.00000	.00000	1805	2004
NW A	.00194	.00091	.00000	.00000	.00000	.00000	1805	2004
NNW A	.00182	.00171	.00000	.00000	.00000	.00000	1805	2004
N B	.00023	.00023	.00000	.00000	.00000	.00000	1805	2004
NNE B	.00011	.00000	.00000	.00000	.00000	.00000	1805	2004
NE B	.00046	.00023	.00000	.00000	.00000	.00000	1805	2004
ENE B	.00011	.00057	.00080	.00000	.00000	.00000	1805	2004
E B	.00023	.00080	.00091	.00000	.00000	.00000	1805	2004
ESE B	.00046	.00080	.00011	.00000	.00000	.00000	1805	2004
SE B	.00057	.00034	.00011	.00000	.00000	.00000	1805	2004
SSE B	.00456	.00855	.00057	.00000	.00000	.00000	1805	2004
S B	.00615	.01014	.00046	.00000	.00000	.00000	1805	2004
SSW B	.00422	.00786	.00091	.00000	.00000	.00000	1805	2004
SW B	.00889	.01071	.00023	.00000	.00000	.00000	1805	2004
WSW B	.00866	.01721	.00046	.00000	.00000	.00000	1805	2004
W B	.01037	.00957	.00217	.00000	.00000	.00000	1805	2004
WNW B	.00353	.00217	.00011	.00000	.00000	.00000	1805	2004
NW B	.00137	.00148	.00068	.00000	.00000	.00000	1805	2004
NNW B	.00034	.00114	.00057	.00000	.00000	.00000	1805	2004
N C	.00023	.00000	.00034	.00000	.00000	.00000	1805	2004
NNE C	.00011	.00011	.00000	.00000	.00000	.00000	1805	2004
NE C	.00011	.00000	.00011	.00000	.00000	.00000	1805	2004
ENE C	.00023	.00023	.00046	.00068	.00000	.00000	1805	2004
E C	.00011	.00000	.00262	.00068	.00000	.00000	1805	2004
ESE C	.00114	.00137	.00046	.00011	.00000	.00000	1805	2004
SE C	.00239	.00433	.00228	.00114	.00000	.00000	1805	2004
SSE C	.00536	.00615	.00114	.00057	.00000	.00000	1805	2004
S C	.00524	.00638	.00046	.00011	.00000	.00000	1805	2004
SSW C	.00342	.00057	.00034	.00011	.00000	.00000	1805	2004
SW C	.00296	.00057	.00000	.00000	.00000	.00000	1805	2004
WSW C	.00581	.01003	.00023	.00000	.00000	.00000	1805	2004
W C	.01538	.02826	.01470	.00000	.00000	.00000	1805	2004
WNW C	.01766	.02393	.00353	.00011	.00000	.00000	1805	2004
NW C	.00205	.00228	.00148	.00011	.00000	.00000	1805	2004
NNW C	.00046	.00091	.00011	.00000	.00000	.00000	1805	2004
N D	.00125	.00479	.00524	.00023	.00000	.00000	1805	2004
NNE D	.00023	.00114	.00057	.00000	.00000	.00000	1805	2004
NE D	.00034	.00011	.00023	.00000	.00000	.00000	1805	2004
ENE D	.00091	.00091	.00365	.00148	.00000	.00000	1805	2004
E D	.00262	.00148	.00274	.00205	.00011	.00000	1805	2004
ESE D	.01026	.01698	.00866	.00057	.00000	.00000	1805	2004
SE D	.00866	.01789	.01299	.00593	.00205	.00023	1805	2004

SSE D	.00194	.00034	.00410	.00228	.00000	.00000	1805	2004
S D	.00080	.00000	.00103	.00000	.00000	.00000	1805	2004
SSW D	.00057	.00000	.00023	.00000	.00000	.00000	1805	2004
SW D	.00023	.00000	.00011	.00000	.00000	.00000	1805	2004
WSW D	.00023	.00000	.00023	.00000	.00000	.00000	1805	2004
W D	.00205	.00410	.00182	.00011	.00000	.00000	1805	2004
WNW D	.00957	.02644	.01379	.00251	.00000	.00000	1805	2004
NW D	.01014	.00741	.00228	.00011	.00000	.00000	1805	2004
NNW D	.00308	.00980	.00296	.00000	.00000	.00000	1805	2004
N E	.00103	.00376	.00000	.00000	.00000	.00000	1805	2004
NNE E	.00057	.00080	.00023	.00000	.00000	.00000	1805	2004
NE E	.00057	.00011	.00034	.00000	.00000	.00000	1805	2004
ENE E	.00114	.00057	.00011	.00000	.00000	.00000	1805	2004
E	.00251	.00217	.00068	.00000	.00000	.00000	1805	2004
ESE E	.01014	.00638	.00148	.00000	.00000	.00000	1805	2004
SE E	.01048	.01071	.00011	.00000	.00000	.00000	1805	2004
SSE E	.00581	.00103	.00034	.00000	.00000	.00000	1805	2004
S E	.00068	.00000	.00000	.00000	.00000	.00000	1805	2004
SSW E	.00080	.00000	.00011	.00000	.00000	.00000	1805	2004
SW E	.00000	.00000	.00000	.00000	.00000	.00000	1805	2004
WSW E	.00046	.00011	.00000	.00000	.00000	.00000	1805	2004
W E	.00114	.00877	.00000	.00000	.00000	.00000	1805	2004
WNW E	.00581	.00558	.00000	.00000	.00000	.00000	1805	2004
NW E	.00809	.00365	.00011	.00000	.00000	.00000	1805	2004
NNW E	.00524	.00786	.00171	.00000	.00000	.00000	1805	2004
N F	.01014	.00376	.00011	.00000	.00000	.00000	1805	2004
NNE F	.00672	.00262	.00000	.00000	.00000	.00000	1805	2004
NE F	.00604	.00205	.00011	.00000	.00000	.00000	1805	2004
ENE F	.00855	.00353	.00011	.00000	.00000	.00000	1805	2004
E F	.00946	.00627	.00011	.00000	.00000	.00000	1805	2004
ESE F	.01402	.00251	.00011	.00000	.00000	.00000	1805	2004
SE F	.01949	.00422	.00000	.00000	.00000	.00000	1805	2004
SSE F	.02416	.01276	.00057	.00000	.00000	.00000	1805	2004
S F	.01607	.00775	.00011	.00000	.00000	.00000	1805	2004
SSW F	.01299	.00467	.00000	.00000	.00000	.00000	1805	2004
SW F	.01140	.00399	.00000	.00000	.00000	.00000	1805	2004
WSW F	.01162	.01208	.00000	.00000	.00000	.00000	1805	2004
W F	.01083	.01288	.00000	.00000	.00000	.00000	1805	2004
WNW F	.01140	.00137	.00000	.00000	.00000	.00000	1805	2004
NW F	.01538	.00296	.00000	.00000	.00000	.00000	1805	2004
NNW F	.01368	.00387	.00000	.00000	.00000	.00000	1805	2004

ACRONYMS AND ABBREVIATIONS

ALS	Advanced Light Source
BEARS	Berkeley Experiments with Accelerated Radioactive Species
CAP88-PC	EPA-approved dose calculation software
COMPLY	EPA-approved dose calculation software
DNA	Deoxyribonucleic acid
DOE	U. S. Department of Energy
EDE	Effective dose equivalent
EPA	U. S. Environmental Protection Agency
FFCA	Federal facility compliance agreement
HEPA	High-efficiency particulate air
HERL	Heavy Elements Research Laboratory
HILAC	Heavy Ion Linear Accelerator
l'OASIS	Laser Optics and Accelerator Systems Integrated Studies
MEI	Maximally exposed individual
MRI	Magnetic resonance imaging
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NTLF	National Tritium Labeling Facility
PET	Positron emission tomography
SPECT	Single photon emission computed tomography
TEDA	Triethylene diamine
TEDA-DAC	Triethylene-diamine-doped activated carbon
UC	University of California