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Biota Dose Evaluation for 2015

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Review and Approval

Biota Dose Evaluation for 2015

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1 INTRODUCTION

Department of Energy (DOE) Order 458.1, *Radiation Protection of the Public and the Environment*[1], requires Berkeley Lab to protect biota from radiological activities conducted at the Lawrence Berkeley National Laboratory (LBNL or Berkeley Lab). If actions taken to protect humans from radiation and radioactive materials are not adequate to protect biota, then additional measures to protect biota must be implemented. The DOE approved method used in this evaluation for determining if biota is adequately protected is provided in the DOE technical standard DOE-STD-1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*[2]. This method is also used to demonstrate that the actions taken by Berkeley Lab to protect the health and safety of the public from radiation and radioactive emissions results in sufficiently low levels of radiation exposure such that biota is adequately protected.

As recommended in the standard, this report provides the details of the biota dose evaluation that is summarized in Berkeley Lab's *Site Environmental Report for 2015*[3]. The details of this evaluation include the following:

- Regulatory biota dose limits;
- Methods used to verify compliance with the limits;
- Area of evaluation, sources of exposure, organism types, media types, and radionuclide data;
- Results of the evaluation and the parameters used.

2 DOSE LIMITS

The evaluation applied the biota dose limits adopted by the DOE technical standard DOE-STD-1153-2002 and required by DOE Order 458.1:

- Aquatic animals and terrestrial plants: 1 rad/day (10 mGy/day)
- Riparian and terrestrial animals: 0.1 rad/day (1 mGy/day)

3 METHOD

The biota dose evaluation followed the method outlined in the DOE standard DOE-STD-1153-2002. In the data assembly phase, the area to be evaluated was determined, receptors were identified, and exposure pathways were considered. In the general screening phase, the RESRAD-BIOTA software (version 1.5) recommended by DOE was used to compare creek water, soil, and sediment sample results to the standard's biota concentration guides (BCGs)[4]. If results of the general screening phase verify that radionuclide concentrations are less than BCGs and the dose to receptors is below biota dose limits, then no further analysis is required.

4 EVALUATION DATA

4.1 Evaluation Area

The area under evaluation is the main Berkeley Lab site, as seen in Figure 1, which comprises 200 acres (0.3125 mi^2) of land.

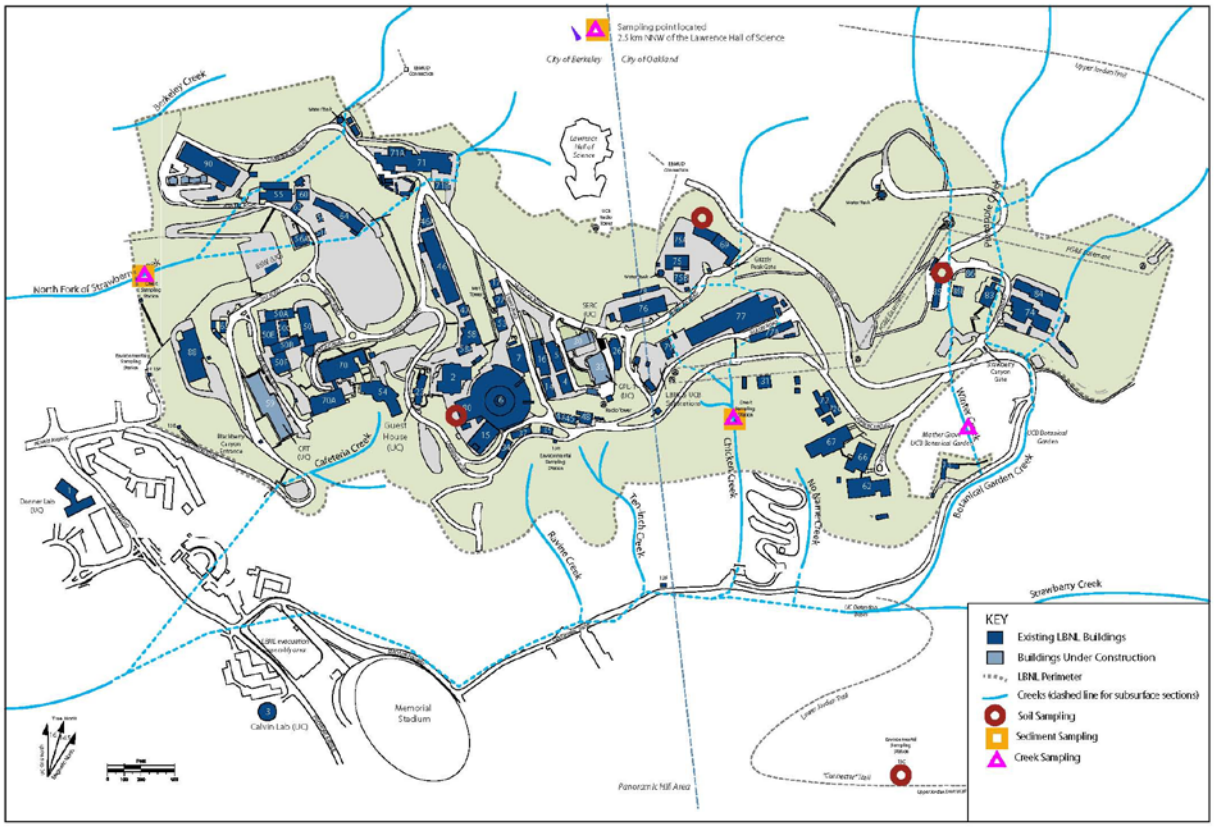

Figure 1. Berkeley Lab Main Site Map Showing Sampling Locations by Type

4.2 Exposure Sources

Exposure pathways that could contribute to an external dose to biota include radionuclides in water, soil, and sediment. Pathways that could contribute to an internal dose in animals include ingestion of water, vegetation, and soil particles; also, inhalation of air and soil particles. In vegetation, uptake of water from air and soil could contribute to an internal dose.

4.3 Organism Types

Receptors (organisms that could be exposed to radionuclides) include vegetation (grasses and forbs, brush, and trees) and the many species of birds, mammals, reptiles, and amphibians for which vegetation provides cover, food, and breeding sites.

4.4 Media Types

Analyzed media include creek water, soil, and sediment. The samples were collected following the Environmental Services Group procedures: Procedure 266, *Soil, Sediment, and Vegetation Sampling*[5] and Procedure 263, *Surface Water Sampling*[6].

4.5 Radionuclides Evaluated

At creeks on or near the Berkeley Lab site, six water (Attachment A) and two sediment (Attachment B) samples were collected and analyzed for radionuclides. At other locations on or near the Berkeley Lab site in 2015, three soil samples were collected and analyzed for radionuclides (Attachment C). Many of these samples were split or analyzed in duplicate for quality assurance purposes.

The analytical laboratories measured several radionuclides in these samples at levels that are similar to fallout and natural background values. (Note that water samples are not always filtered before analysis, so they are likely to contain suspended soil and sediment having background levels of fallout and natural radionuclides.) Of these, the following radionuclides were measured at levels greater than the minimum detectable level (MDL) in one or more media and are included in the DOE standard:

- hydrogen-3 (^{3}H or tritium)
- cesium-137 (^{137}Cs)
- radium-226 (^{226}Ra)
- actinium-228 (^{228}Ac), progeny of thorium-232 (^{232}Th)[1]
- uranium-238 (^{238}U)

In addition, samples were analyzed for potassium-40 (^{40}K), cobalt-56 (^{56}Co), silver-110m (^{110m}Ag), antimony-124 (^{124}Sb), europium-152 (^{152}Eu), thallium-208 (^{208}Tl), bismuth-212 (^{212}Bi), bismuth-214 (^{214}Bi), lead-212 (^{212}Pb), lead-214 (^{214}Pb), thorium-234 (^{234}Th), and uranium-235 (^{235}U). These radionuclides were not considered in the biota dose evaluation because most are naturally occurring radionuclides that are present in the environment at background levels and because:

- ^{152}Eu was not detected in any media;
- ^{234}Th and ^{235}U were not detected in all media;
- ^{56}Co, ^{110m}Ag, ^{124}Sb, ^{208}Tl, ^{212}Bi, ^{214}Bi, ^{212}Pb, and ^{214}Pb are not included in the DOE standard;
- ^{40}K present in samples is not related to Lab operations.

Water, sediment, and soil samples were collected at off-site locations in order to quantify expected background fallout and natural radionuclide concentrations (Attachment D). These background levels are compared to areas that have been potentially affected by Berkeley Lab operations. For water and sediment, the background location is Wildcat Creek. This location is distant from Berkeley Lab and is not connected to the creeks that run through the Lab site. For soil, the background location is at the environmental monitoring station on Panoramic Peak (ENV-13C), which is the next ridge southeast of the Berkeley Lab boundary. Background data is presented for information only; it is not required for the biota dose evaluation.

5 INPUT PARAMETERS AND RESULTS

Using the DOE-endorsed software, RESRAD-BIOTA, ^{3}H, ^{137}Cs, ^{226}Ra, ^{228}Ac (^{232}Th), and ^{238}U measured in creek water, sediment, and soil were compared to BCGs for aquatic and terrestrial biota. As required by the DOE standard, a

[1] In the environment ^{232}Th and its progeny ^{228}Ac are in secular equilibrium; that is, they are found in equal amounts and ^{228}Ac activity is assumed to be equal to ^{232}Th activity.

screening approach was used to initially compare the maximum concentrations of radionuclides in water, sediment, and soil to BCGs[4].

It should be noted that the bulk of the measured radioactivity in soil, sediment, and water samples is due to fallout and natural background radionuclides, with the exception of tritium. Since low levels of tritium persist in groundwater, soil, and vegetation, some locations are considered impacted by releases from the former National Tritium Labeling Facility site (facility released and closed in 2001).

5.1 Aquatic Biota Dose

For the aquatic biota dose evaluation, data from sediment and water samples that are collocated are preferred by DOE-STD-1153-2002[2]. The maximum concentrations of ^{3}H and ^{226}Ra measured in water and sediment were located at Chicken Creek. The maximum concentrations of ^{238}U and ^{228}Ac (^{232}Th) measured in sediment were located at the North Fork of Strawberry Creek and Chicken Creek, respectively. Where a radionuclide was analyzed but not detected in a collocated water sample, the radionuclide concentration in water was calculated from the distribution coefficient (K_d, as determined by RESRAD-BIOTA). The use of distribution coefficients to calculate water concentration results in a significantly more conservative evaluation to biota[2].

The input values and the results are shown in the report generated by the RESRAD-BIOTA program for aquatic biota (Attachment E). The measured radionuclides are less than their corresponding BCGs. In addition, the sum of the concentration-to-BCG ratios for radionuclides in water (water ratios) and the concentration-to-BCG ratios for radionuclides in sediment (sediment ratios) is less than 1. Since Berkeley Lab passes the aquatic screening, further investigation is not required.

5.2 Terrestrial Biota Dose

For the terrestrial biota dose evaluation, data from collocated soil and water samples is not required by DOE-STD-1153-2002[2]. In soil, ^{137}Cs, ^{226}Ra, and ^{228}Ac (^{232}Th) were detected above MDL. In creek water, ^{3}H, ^{226}Ra, and ^{238}U were detected above MDL. The maximum measured concentration of these radionuclides was used. Where a radionuclide was analyzed but not detected in a medium, the water or soil concentration was set equal to the maximum MDL.

The input values and the results are shown in the report generated by the RESRAD-BIOTA program for terrestrial biota (Attachment F). The measured radionuclides are less than their corresponding BCGs. In addition, the sum of the concentration-to-BCG ratios for radionuclides in water (water ratios) and the concentration-to-BCG ratios for radionuclides in soil (soil ratios) is less than 1. Since Berkeley Lab passes the terrestrial screening, further investigation is not required.

6 CONCLUSIONS

At Berkeley Lab, on-site radionuclide concentrations do not exceed BCGs which demonstrates that the dose from Berkeley Lab effluent to plants and animals is well below the biota dose limits as defined in DOE-STD-1153-2002. It is concluded that, in compliance with DOE Order 458.1, the absorbed dose rate from potential exposure to radionuclides in the Berkeley Lab environment to aquatic animals and terrestrial plants does not exceed 1 rad/day and to riparian and terrestrial animals does not exceed 0.1 rad/day.

7 REFERENCES

1. U.S. Department of Energy, *Radiation Protection of the Public and the Environment*, DOE Order 458.1 (June 6, 2011, as amended).
2. U.S. Department of Energy, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*, DOE Standard DOE-STD-1153-2002 (July 2002).
3. Lawrence Berkeley National Laboratory, *Site Environmental Report for 2015*, Report LBNL-27170E-2016 (in preparation).
4. RESRAD-BIOTA for Windows, Version 1.5, developed at the Environmental Assessment Division of Argonne National Laboratory for the U.S. Department of Energy, with support from the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission, www.ead.anl.gov/resrad (November 18, 2009).
5. Lawrence Berkeley National Laboratory, "Soil, Sediment, and Vegetation Sampling," EHS Procedure 266 Revision 9, Environmental Services Group (May 30, 2013).
6. Lawrence Berkeley National Laboratory, "Surface Water Sampling," EHS Procedure 263 Revision 12, Environmental Services Group (September 16, 2013).

Attachment A. 2015 Radionuclide Measurements in Creek Water

LBNL Main Site Affected Areas

Location Name	Analyte Name	Coll. Date/Time	Result	RL	Activity	MDL	Result Units	Sample QC Type
Chicken Creek	Gross alpha	3/30/2015	ND	2	1.5	1.6	pCi/L	Sample
Chicken Creek	Gross alpha	3/30/2015	ND	2	-0.428	3.28	pCi/L	Dup
Chicken Creek	Gross alpha	9/3/2015	ND	2	0.8	2	pCi/L	Sample
N. Fork Strawberry Creek	Gross alpha	3/30/2015	ND	2	1.06	1.79	pCi/L	Sample
N. Fork Strawberry Creek	Gross alpha	9/3/2015	ND	2	0.59	1.08	pCi/L	Sample
Winter Creek	Gross alpha	3/31/2015	ND	2	1.46	1.29	pCi/L	Sample
Winter Creek	Gross alpha	9/3/2015	ND	2	1.04	1.33	pCi/L	Sample
Chicken Creek	Gross beta	3/30/2015	ND	3	1.9	2.4	pCi/L	Sample
Chicken Creek	Gross beta	3/30/2015	ND	3	1.54	2	pCi/L	Dup
Chicken Creek	Gross beta	9/3/2015	3.9	3	3.9	2.6	pCi/L	Sample
N. Fork Strawberry Creek	Gross beta	3/30/2015	ND	3	1.3	2.6	pCi/L	Sample
N. Fork Strawberry Creek	Gross beta	9/3/2015	ND	3	0.81	1.51	pCi/L	Sample
Winter Creek	Gross beta	3/31/2015	ND	3	1.1	1.8	pCi/L	Sample
Winter Creek	Gross beta	9/3/2015	ND	3	2.5	1.7	pCi/L	Sample
Chicken Creek	Tritium	3/30/2015	260	200	260	240	pCi/L	Sample
Chicken Creek	Tritium	3/30/2015	ND	200	172	120	pCi/L	Dup
Chicken Creek	Tritium	9/3/2015	ND	200	90	240	pCi/L	Sample
N. Fork Strawberry Creek	Tritium	3/30/2015	ND	200	130	240	pCi/L	Sample
N. Fork Strawberry Creek	Tritium	9/3/2015	ND	200	90	240	pCi/L	Sample
Winter Creek	Tritium	3/31/2015	ND	200	-60	240	pCi/L	Sample
Winter Creek	Tritium	9/3/2015	ND	200	-50	240	pCi/L	Sample
Chicken Creek	Actinium 228	3/30/2015	ND	25	-9.13	9.51	pCi/L	Dup
Chicken Creek	Actinium 228 (Filtered)	3/30/2015	ND	25	14.9	15.2	pCi/L	Sample
Chicken Creek	Actinium 228 (Filtered)	9/3/2015	ND	25	16	18	pCi/L	Sample
N. Fork Strawberry Creek	Actinium 228 (Filtered)	3/30/2015	ND	25	22	15	pCi/L	Sample
N. Fork Strawberry Creek	Actinium 228 (Filtered)	9/3/2015	ND	25	11.6	15.2	pCi/L	Sample
Winter Creek	Actinium 228 (Filtered)	3/31/2015	ND	25	3	38	pCi/L	Sample
Winter Creek	Actinium 228 (Filtered)	9/3/2015	ND	25	3	36	pCi/L	Sample
Chicken Creek	Cesium 137	3/30/2015	ND	8	0.0499	3.75	pCi/L	Dup
Chicken Creek	Cesium 137 (Filtered)	3/30/2015	ND	8	-2.4	4.6	pCi/L	Sample
Chicken Creek	Cesium 137 (Filtered)	9/3/2015	ND	8	-2.6	4.8	pCi/L	Sample
N. Fork Strawberry Creek	Cesium 137 (Filtered)	3/30/2015	ND	8	-2.2	4.3	pCi/L	Sample
N. Fork Strawberry Creek	Cesium 137 (Filtered)	9/3/2015	ND	8	-1.8	4.4	pCi/L	Sample
Winter Creek	Cesium 137 (Filtered)	3/31/2015	ND	8	-0.4	4.3	pCi/L	Sample
Winter Creek	Cesium 137 (Filtered)	9/3/2015	ND	8	0.6	5.6	pCi/L	Sample

[a] Minimum detectable level
ND (Not Detected)

LBNL Main Site Affected Areas

Location Name	Analyte Name	Coll. Date/Time	Result	RL	Activity	MDL	Result Units	Sample QC Type
Chicken Creek	Europium 152	3/30/2015	ND	35	4.11	9.47	pCi/L	Dup
Chicken Creek	Europium 152 (Filtered)	3/30/2015	ND	35	1	22	pCi/L	Sample
Chicken Creek	Europium 152 (Filtered)	9/3/2015	ND	35	-4	24	pCi/L	Sample
N. Fork Strawberry Creek	Europium 152 (Filtered)	3/30/2015	ND	35	6	24	pCi/L	Sample
N. Fork Strawberry Creek	Europium 152 (Filtered)	9/3/2015	ND	35	-1	22	pCi/L	Sample
Winter Creek	Europium 152 (Filtered)	3/31/2015	ND	35	4	21	pCi/L	Sample
Winter Creek	Europium 152 (Filtered)	9/3/2015	ND	35	-7	36	pCi/L	Sample
Chicken Creek	Lead 214	3/30/2015	ND	15	-2.76	7.1	pCi/L	Dup
Chicken Creek	Lead 214 (Filtered)	3/30/2015	ND	20	4.3	14.4	pCi/L	Sample
Chicken Creek	Lead 214 (Filtered)	9/3/2015	ND	20	5.8	9.4	pCi/L	Sample
N. Fork Strawberry Creek	Lead 214 (Filtered)	3/30/2015	ND	20	-0.5	16.2	pCi/L	Sample
N. Fork Strawberry Creek	Lead 214 (Filtered)	9/3/2015	ND	20	-5	22	pCi/L	Sample
Winter Creek	Lead 214 (Filtered)	3/31/2015	ND	20	10.6	7.1	pCi/L	Sample
Winter Creek	Lead 214 (Filtered)	9/3/2015	ND	20	-8	22	pCi/L	Sample
Chicken Creek	Potassium 40	3/30/2015	ND	80	17.9	48.1	pCi/L	Dup
Chicken Creek	Potassium 40 (Filtered)	3/30/2015	ND	140	-6	126	pCi/L	Sample
Chicken Creek	Potassium 40 (Filtered)	9/3/2015	ND	140	-69	165	pCi/L	Sample
N. Fork Strawberry Creek	Potassium 40 (Filtered)	3/30/2015	ND	140	-20	122	pCi/L	Sample
N. Fork Strawberry Creek	Potassium 40 (Filtered)	9/3/2015	ND	140	-47	122	pCi/L	Sample
Winter Creek	Potassium 40 (Filtered)	3/31/2015	ND	140	31	106	pCi/L	Sample
Winter Creek	Potassium 40 (Filtered)	9/3/2015	ND	140	-76	162	pCi/L	Sample
Chicken Creek	Radium 226	3/30/2015	ND	120	14.1	67.6	pCi/L	Dup
Chicken Creek	Radium 226 (Filtered)	3/30/2015	ND	170	20	170	pCi/L	Sample
Chicken Creek	Radium 226 (Filtered)	9/3/2015	ND	170	74	73	pCi/L	Sample
N. Fork Strawberry Creek	Radium 226 (Filtered)	3/30/2015	ND	170	21	105	pCi/L	Sample
N. Fork Strawberry Creek	Radium 226 (Filtered)	9/3/2015	ND	170	-10	170	pCi/L	Sample
Winter Creek	Radium 226 (Filtered)	3/31/2015	ND	170	9	126	pCi/L	Sample
Winter Creek	Radium 226 (Filtered)	9/3/2015	ND	170	-50	210	pCi/L	Sample
Chicken Creek	Uranium 238	3/30/2015	ND	325	29.4	174	pCi/L	Dup
Chicken Creek	Uranium 238 (Filtered)	3/30/2015	29	15	29	54	pCi/L	Sample
Chicken Creek	Uranium 238 (Filtered)	9/3/2015	46	15	46	64	pCi/L	Sample
N. Fork Strawberry Creek	Uranium 238 (Filtered)	3/30/2015	63	15	63	126	pCi/L	Sample
N. Fork Strawberry Creek	Uranium 238 (Filtered)	9/3/2015	50	15	50	180	pCi/L	Sample
Winter Creek	Uranium 238 (Filtered)	3/31/2015	ND	15	8	109	pCi/L	Sample
Winter Creek	Uranium 238 (Filtered)	9/3/2015	ND	15	-48	145	pCi/L	Sample
Chicken Creek	Radium 226	3/30/2015	ND	0.25	0.19	0.14	pCi/L	Sample
Chicken Creek	Radium 226	3/30/2015	0.34	0.25	0.34	0.31	pCi/L	Dup
Chicken Creek	Radium 226 (Filtered)	9/3/2015	ND	0.25	0.13	0.23	pCi/L	Sample
N. Fork Strawberry Creek	Radium 226	3/30/2015	ND	0.25	0.07	0.15	pCi/L	Sample
N. Fork Strawberry Creek	Radium 226 (Filtered)	9/3/2015	ND	0.25	0.07	0.22	pCi/L	Sample
Winter Creek	Radium 226	3/31/2015	ND	0.25	0.09	0.15	pCi/L	Sample
Winter Creek	Radium 226 (Filtered)	9/3/2015	ND	0.25	0.08	0.18	pCi/L	Sample
N. Fork Strawberry Creek	Antimony 124 (Filtered)	3/30/2015	6.8	4.3	6.8	4.3	pCi/L	Sample
Winter Creek	Antimony 124 (Filtered)	9/3/2015	9.8	6.8	9.8	6.8	pCi/L	Sample
Winter Creek	Thallium 208 (Filtered)	3/31/2015	4.9	4.1	4.9	4.1	pCi/L	Sample

[a] Minimum detectable level

ND (Not Detected)

Attachment B. 2015 Radionuclide Measurements in Sediment
LBNL Main Site Affected
Areas

Location Name	Analysis Method	Analyte Name	Coll. Date/Time	Result	RL	Activity	MDL	Result Units	Sample QC Type
Chicken Creek	E900	Gross alpha	10/27/2015	5.17	2	5.17	2.98	pCi/g	Sample
Chicken Creek	E900	Gross alpha	10/27/2015	3.3	2	3.3	1	pCi/g	Split
N. Fork Strawberry Creek	E900	Gross alpha	10/27/2015	7.48	2	7.48	2.41	pCi/g	Sample
Chicken Creek	E900	Gross beta	10/27/2015	16.2	2	16.2	1.86	pCi/g	Sample
Chicken Creek	E900	Gross beta	10/27/2015	2.37	2	2.37	1.22	pCi/g	Split
N. Fork Strawberry Creek	E900	Gross beta	10/27/2015	17.5	2	17.5	2.16	pCi/g	Sample
Chicken Creek	E906EPSM	Tritium	10/27/2015	ND	0.2	0.101	0.174	pCi/g	Sample
Chicken Creek	E906EPSM	Tritium	10/27/2015	ND	0.2	0	0.2	pCi/g	Split
N. Fork Strawberry Creek	E906EPSM	Tritium	10/27/2015	ND	0.2	-0.0102	0.113	pCi/g	Sample
Chicken Creek	GSDRYEP	Actinium 228	10/27/2015	0.711	0.2	0.711	0.126	pCi/g	Sample
Chicken Creek	GSDRYEP	Actinium 228	10/27/2015	0.7	0.1	0.7	0.16	pCi/g	Split
N. Fork Strawberry Creek	GSDRYEP	Actinium 228	10/27/2015	0.629	0.2	0.629	0.109	pCi/g	Sample
Chicken Creek	GSDRYEP	Cesium 137	10/27/2015	ND	0.05	0.0238	0.038	pCi/g	Sample
Chicken Creek	GSDRYEP	Cesium 137	10/27/2015	0.017	0.01	0.017	0.026	pCi/g	Split
N. Fork Strawberry Creek	GSDRYEP	Cesium 137	10/27/2015	0.05	0.05	0.05	0.029	pCi/g	Sample
Chicken Creek	GSDRYEP	Europium 152	10/27/2015	ND	0.3	0.00426	0.084	pCi/g	Sample
Chicken Creek	GSDRYEP	Europium 152	10/27/2015	ND	0.3	0.1	0.108	pCi/g	Split
N. Fork Strawberry Creek	GSDRYEP	Europium 152	10/27/2015	ND	0.3	0.0433	0.081	pCi/g	Sample
Chicken Creek	GSDRYEP	Lead 214	10/27/2015	0.723	0.1	0.723	0.138	pCi/g	Sample
Chicken Creek	GSDRYEP	Lead 214	10/27/2015	0.574	0.1	0.574	0.119	pCi/g	Split
N. Fork Strawberry Creek	GSDRYEP	Lead 214	10/27/2015	0.718	0.1	0.718	0.064	pCi/g	Sample
Chicken Creek	GSDRYEP	Potassium 40	10/27/2015	12.9	0.5	12.9	0.33	pCi/g	Sample
Chicken Creek	GSDRYEP	Potassium 40	10/27/2015	12	0.5	12	0.9	pCi/g	Split
N. Fork Strawberry Creek	GSDRYEP	Potassium 40	10/27/2015	13.5	0.5	13.5	0.276	pCi/g	Sample
Chicken Creek	GSDRYEP	Radium 226	10/27/2015	0.534	0.1	0.534	0.064	pCi/g	Sample
Chicken Creek	GSDRYEP	Radium 226	10/27/2015	0.78	0.1	0.78	0.17	pCi/g	Split
N. Fork Strawberry Creek	GSDRYEP	Radium 226	10/27/2015	0.618	0.1	0.618	0.054	pCi/g	Sample

[a] Minimum detectable level

ND (Not Detected)

LBNL Main Site Affected Areas

Location Name	Analysis Method	Analyte Name	Coll. Date/Time	Result	RL	Activity	MDL	Result Units	Sample QC Type
Chicken Creek	GSDRYEP	Uranium 238	10/27/2015	ND	2	0.868	1.19	pCi/g	Sample
Chicken Creek	GSDRYEP	Uranium 238	10/27/2015	1.73	0.3	1.73	0.92	pCi/g	Split
N. Fork Strawberry Creek	GSDRYEP	Uranium 238	10/27/2015	2.24	2	2.24	1.44	pCi/g	Sample
Chicken Creek	GSDRYEP	Bismuth 212	10/27/2015	0.93	0.43	0.93	0.43	pCi/g	Split
Chicken Creek	GSDRYEP	Bismuth 214	10/27/2015	0.43	0.37	0.43	0.37	pCi/g	Split
Chicken Creek	GSDRYEP	Cobalt 56	10/27/2015	0.074	0.07	0.074	0.071	pCi/g	Split
Chicken Creek	GSDRYEP	Lead 212	10/27/2015	0.76	0.07	0.76	0.07	pCi/g	Split
Chicken Creek	GSDRYEP	Thallium 208	10/27/2015	0.215	0.05	0.215	0.052	pCi/g	Split
Chicken Creek	GSDRYEP	Thorium 234	10/27/2015	1.73	0.92	1.73	0.92	pCi/g	Split

[a] Minimum detectable level

ND (Not Detected)

Attachment C. 2015 Radionuclide Measurements in Soil

LBNL Main Site Affected Areas

Location Name	Analysis Method	Analyte Name	Coll. Date/Time	Result	RL	Activity	MDL	Result Units	Sample QC Type
Building 69	E900	Gross alpha	10/27/2015	9.85	2	9.85	3.1	pCi/g	Sample
Building 80	E900	Gross alpha	10/27/2015	7.7	2	7.7	2.51	pCi/g	Sample
Building 85	E900	Gross alpha	10/27/2015	4.25	2	4.25	2.59	pCi/g	Sample
Building 85	E900	Gross alpha	10/27/2015	2.7	2	2.7	1.1	pCi/g	Split
Building 69	E900	Gross beta	10/27/2015	12.7	2	12.7	2.76	pCi/g	Sample
Building 80	E900	Gross beta	10/27/2015	21.5	2	21.5	1.57	pCi/g	Sample
Building 85	E900	Gross beta	10/27/2015	11.4	2	11.4	2.58	pCi/g	Sample
Building 85	E900	Gross beta	10/27/2015	3.06	2	3.06	1.28	pCi/g	Split
Building 69	E906EPSM	Tritium	10/27/2015	ND	0.2	-0.0067	0.034	pCi/g	Sample
Building 80	E906EPSM	Tritium	10/27/2015	ND	0.2	-0.0018	0.03	pCi/g	Sample
Building 85	E906EPSM	Tritium	10/27/2015	ND	0.2	-0.0031	0.014	pCi/g	Sample
Building 85	E906EPSM	Tritium	10/27/2015	ND	0.2	0.003	0.055	pCi/g	Split
Building 69	GSDRYEP	Actinium 228	10/27/2015	0.309	0.2	0.309	0.134	pCi/g	Sample
Building 80	GSDRYEP	Actinium 228	10/27/2015	0.79	0.2	0.79	0.119	pCi/g	Sample
Building 85	GSDRYEP	Actinium 228	10/27/2015	0.632	0.2	0.632	0.106	pCi/g	Sample
Building 85	GSDRYEP	Actinium 228	10/27/2015	0.451	0.1	0.451	0.191	pCi/g	Split
Building 69	GSDRYEP	Cesium 137	10/27/2015	ND	0.05	0.0437	0.035	pCi/g	Sample
Building 80	GSDRYEP	Cesium 137	10/27/2015	0.107	0.05	0.107	0.035	pCi/g	Sample
Building 85	GSDRYEP	Cesium 137	10/27/2015	ND	0.05	0.0253	0.028	pCi/g	Sample
Building 85	GSDRYEP	Cesium 137	10/27/2015	ND	0.01	-0.012	0.038	pCi/g	Split
Building 69	GSDRYEP	Europium 152	10/27/2015	ND	0.3	-0.0031	0.089	pCi/g	Sample
Building 80	GSDRYEP	Europium 152	10/27/2015	ND	0.3	0.0506	0.094	pCi/g	Sample
Building 85	GSDRYEP	Europium 152	10/27/2015	ND	0.3	0.0027	0.065	pCi/g	Sample
Building 85	GSDRYEP	Europium 152	10/27/2015	ND	0.3	0.06	0.2	pCi/g	Split
Building 69	GSDRYEP	Lead 214	10/27/2015	0.431	0.1	0.431	0.065	pCi/g	Sample
Building 80	GSDRYEP	Lead 214	10/27/2015	0.789	0.1	0.789	0.063	pCi/g	Sample
Building 85	GSDRYEP	Lead 214	10/27/2015	0.507	0.1	0.507	0.047	pCi/g	Sample
Building 85	GSDRYEP	Lead 214	10/27/2015	0.444	0.1	0.444	0.122	pCi/g	Split
Building 69	GSDRYEP	Potassium 40	10/27/2015	6.89	0.5	6.89	0.343	pCi/g	Sample
Building 80	GSDRYEP	Potassium 40	10/27/2015	14.6	0.5	14.6	0.272	pCi/g	Sample
Building 85	GSDRYEP	Potassium 40	10/27/2015	10.1	0.5	10.1	0.302	pCi/g	Sample
Building 85	GSDRYEP	Potassium 40	10/27/2015	8.6	0.5	8.6	0.8	pCi/g	Split
Building 69	GSDRYEP	Radium 226	10/27/2015	0.328	0.1	0.328	0.067	pCi/g	Sample
Building 80	GSDRYEP	Radium 226	10/27/2015	0.573	0.1	0.573	0.062	pCi/g	Sample
Building 85	GSDRYEP	Radium 226	10/27/2015	0.482	0.1	0.482	0.054	pCi/g	Sample
Building 85	GSDRYEP	Radium 226	10/27/2015	0.65	0.1	0.65	0.18	pCi/g	Split
Building 69	GSDRYEP	Uranium 238	10/27/2015	ND	2	1.31	1.34	pCi/g	Sample
Building 80	GSDRYEP	Uranium 238	10/27/2015	ND	2	0	0.994	pCi/g	Sample
Building 85	GSDRYEP	Uranium 238	10/27/2015	ND	2	0.626	0.268	pCi/g	Sample
Building 85	GSDRYEP	Uranium 238	10/27/2015	0.8	0.3	0.8	1.09	pCi/g	Split
Building 85	GSDRYEP	Thallium 208	10/27/2015	0.186	0.06	0.186	0.055	pCi/g	Split
Building 85	GSDRYEP	Lead 212	10/27/2015	0.56	0.09	0.56	0.093	pCi/g	Split

[a] Minimum detectable level

ND (Not Detected)

Attachment D. 2015 Radionuclide Measurements in Background

Background Creek Sampling

Location Name	Analyte Name	Coll. Date/Time	Result	RL	Activity	MDL	Result Units	Sample QC Type
Wildcat Creek	Gross alpha	3/31/2015	ND	2	-0.12	1.31	pCi/L	Sample
Wildcat Creek	Gross alpha	9/3/2015	ND	2	0.47	1.31	pCi/L	Sample
Wildcat Creek	Gross beta	3/31/2015	ND	3	1	2	pCi/L	Sample
Wildcat Creek	Gross beta	9/3/2015	ND	3	1.9	1.7	pCi/L	Sample
Wildcat Creek	Tritium	3/31/2015	ND	200	10	240	pCi/L	Sample
Wildcat Creek	Tritium	9/3/2015	ND	200	10	240	pCi/L	Sample
Wildcat Creek	Actinium 228 (Filtered)	3/31/2015	ND	25	2	28	pCi/L	Sample
Wildcat Creek	Actinium 228 (Filtered)	9/3/2015	ND	25	16	16	pCi/L	Sample
Wildcat Creek	Bismuth 214 (Filtered)	9/3/2015	11.6	9.7	11.6	9.7	pCi/L	Sample
Wildcat Creek	Cesium 137 (Filtered)	3/31/2015	ND	8	0.2	3.6	pCi/L	Sample
Wildcat Creek	Cesium 137 (Filtered)	9/3/2015	ND	8	-0.7	4.6	pCi/L	Sample
Wildcat Creek	Europium 152 (Filtered)	3/31/2015	ND	35	-4	20	pCi/L	Sample
Wildcat Creek	Europium 152 (Filtered)	9/3/2015	ND	35	-10	27	pCi/L	Sample
Wildcat Creek	Lead 214 (Filtered)	3/31/2015	ND	20	1.2	14.4	pCi/L	Sample
Wildcat Creek	Lead 214 (Filtered)	9/3/2015	ND	20	-3	19	pCi/L	Sample
Wildcat Creek	Potassium 40 (Filtered)	3/31/2015	ND	140	-10	103	pCi/L	Sample
Wildcat Creek	Potassium 40 (Filtered)	9/3/2015	ND	140	-16	131	pCi/L	Sample
Wildcat Creek	Radium 226 (Filtered)	3/31/2015	ND	170	-7	112	pCi/L	Sample
Wildcat Creek	Radium 226 (Filtered)	9/3/2015	ND	170	10	170	pCi/L	Sample
Wildcat Creek	Uranium 235 (Filtered)	3/31/2015	14.8	13	14.8	13	pCi/L	Sample
Wildcat Creek	Uranium 238 (Filtered)	3/31/2015	ND	15	5	71	pCi/L	Sample
Wildcat Creek	Uranium 238 (Filtered)	9/3/2015	ND	15	-37	142	pCi/L	Sample
Wildcat Creek	Radium 226	3/31/2015	ND	0.25	0.11	0.17	pCi/L	Sample
Wildcat Creek	Radium 226 (Filtered)	9/3/2015	ND	0.25	0.05	0.24	pCi/L	Sample

[a] Minimum detectable level

ND (Not Detected)

Background Sediment Sampling

Location Name	Analysis Method	Analyte Name	Coll. Date/Time	Result	RL	Activity	MDL	Result Units	Sample QC Type
Wildcat Creek	E900	Gross alpha	10/27/2015	7.63	2	7.63	1.8	pCi/g	Sample
Wildcat Creek	E900	Gross beta	10/27/2015	13.9	2	13.9	1.5	pCi/g	Sample
Wildcat Creek	E906EPSM	Tritium	10/27/2015	ND	0.2	0.0103	0.052	pCi/g	Sample
Wildcat Creek	GSDRYEP	Actinium 228	10/27/2015	0.761	0.2	0.761	0.175	pCi/g	Sample
Wildcat Creek	GSDRYEP	Cesium 137	10/27/2015	ND	0.05	0.00495	0.046	pCi/g	Sample
Wildcat Creek	GSDRYEP	Europium 152	10/27/2015	ND	0.3	0.0549	0.109	pCi/g	Sample
Wildcat Creek	GSDRYEP	Lead 214	10/27/2015	0.56	0.1	0.56	0.17	pCi/g	Sample
Wildcat Creek	GSDRYEP	Potassium 40	10/27/2015	10.6	0.5	10.6	0.39	pCi/g	Sample
Wildcat Creek	GSDRYEP	Radium 226	10/27/2015	0.476	0.1	0.476	0.089	pCi/g	Sample
Wildcat Creek	GSDRYEP	Uranium 238	10/27/2015	ND	2	0.706	1.4	pCi/g	Sample

[a] Minimum detectable level

ND (Not Detected)

Background Soil Sampling

Location Name	Analysis Method	Analyte Name	Coll. Date/Time	Result	RL	Activity	MDL	Result Units	Sample QC Type
ENV-B13C	E900	Gross alpha	10/27/2015	10.3	2	10.3	1.91	pCi/g	Sample
ENV-B13C	E900	Gross beta	10/27/2015	23.4	2	23.4	1.52	pCi/g	Sample
ENV-B13C	E906EPSM	Tritium	10/27/2015	ND	0.2	0.00294	0.014	pCi/g	Sample
ENV-B13C	GSDRYEP	Actinium 228	10/27/2015	0.859	0.2	0.859	0.105	pCi/g	Sample
ENV-B13C	GSDRYEP	Cesium 137	10/27/2015	0.198	0.05	0.198	0.033	pCi/g	Sample
ENV-B13C	GSDRYEP	Europium 152	10/27/2015	ND	0.3	0.0214	0.09	pCi/g	Sample
ENV-B13C	GSDRYEP	Lead 214	10/27/2015	0.648	0.1	0.648	0.065	pCi/g	Sample
ENV-B13C	GSDRYEP	Potassium 40	10/27/2015	16.1	0.5	16.1	0.296	pCi/g	Sample
ENV-B13C	GSDRYEP	Radium 226	10/27/2015	0.553	0.1	0.553	0.059	pCi/g	Sample
ENV-B13C	GSDRYEP	Uranium 238	10/27/2015	ND	2	-0.945	1.79	pCi/g	Sample

[a] Minimum detectable level

ND (Not Detected)

Attachment E. RESRAD-BIOTA Report for Onsite Aquatic Biota

Aquatic BCG Report for Level 1

Title: 2015 LBL Biota Aquatic

Sum of Total Ratio: 4.78E-01

Sum of Water Ratio: 4.69E-01

Sum of Sediment Ratio: 9.18E-03

	Aquatic Animal							
	Water				Sediment			
Nuclide	Concentration (pCi/L)	BCG (pCi/L)	Ratio	Limiting Organism	Concentration (pCi/g)	BCG (pCi/g)	Ratio	Limiting Organism
Cs-137	4.4	1.05E+03	4.20E-03	No	0.05	4.93E+04	1.01E-06	No
H-3	260	4.99E+09	5.21E-08	No	0.00026	7.04E+06	3.69E-11	No
Ra-226	0.34	1.02E+01	3.34E-02	No	0.78	1.45E+04	5.38E-05	No
Th-232	0.01185	3.04E+02	3.90E-05	Yes	0.711	3.29E+06	2.16E-07	No
U-238	63	2.23E+02	2.82E-01	Yes	2.24	4.28E+04	5.23E-05	No
Summed	-	-	3.20E-01	-	-	-	1.07E-04	-

	Riparian Animal							
	Water				Sediment			
Nuclide	Concentration (pCi/L)	BCG (pCi/L)	Ratio	Limiting Organism	Concentration (pCi/g)	BCG (pCi/g)	Ratio	Limiting Organism
Cs-137	4.4	4.26E+01	1.03E-01	Yes	0.05	3.12E+03	1.60E-05	Yes
H-3	260	2.65E+08	9.82E-07	Yes	0.00026	3.74E+05	6.94E-10	Yes
Ra-226	0.34	4.08E+00	8.34E-02	Yes	0.78	1.01E+02	7.71E-03	Yes
Th-232	0.01185	1.68E+03	7.07E-06	No	0.711	1.30E+03	5.47E-04	Yes
U-238	63	7.56E+02	8.33E-02	No	2.24	2.49E+03	9.00E-04	Yes
Summed	-	-	2.70E-01	-	-	-	9.18E-03	-

Attachment F. RESRAD-BIOTA Report for Terrestrial Biota

Terrestrial BCG Report for Level 1

Title: 2015 LBL Biota Terrestrial

Sum of Total Ratio: 2.16E-02

Sum of Water Ratio: 9.15E-04

Sum of Soil Ratio: 2.07E-02

	Terrestrial Animal							
	Water				Soil			
Nuclide	Concentration (pCi/L)	BCG (pCi/L)	Ratio	Limiting Organism	Concentration (pCi/g)	BCG (pCi/g)	Ratio	Limiting Organism
Cs-137	4.7	5.99E+05	7.85E-06	Yes	0.134	2.08E+01	6.46E-03	Yes
H-3	260	2.31E+08	1.13E-06	Yes	0.055	1.74E+05	3.16E-07	Yes
Ra-226	0.34	8.11E+03	4.19E-05	Yes	0.65	5.06E+01	1.29E-02	Yes
Th-232	38	5.36E+04	7.09E-04	Yes	0.79	1.51E+03	5.24E-04	Yes
U-238	63	4.06E+05	1.55E-04	Yes	1.34	1.58E+03	8.49E-04	Yes
Summed	-	-	9.15E-04	-	-	-	2.07E-02	-

	Terrestrial Plant							
	Water				Soil			
Nuclide	Concentration (pCi/L)	BCG (pCi/L)	Ratio	Limiting Organism	Concentration (pCi/g)	BCG (pCi/g)	Ratio	Limiting Organism
Cs-137	4.7	4.93E+07	9.54E-08	No	0.134	2.21E+03	6.07E-05	No
H-3	260	7.04E+09	3.69E-08	No	0.055	1.68E+06	3.27E-08	No
Ra-226	0.34	1.45E+07	2.35E-08	No	0.65	2.88E+02	2.26E-03	No
Th-232	38	3.29E+09	1.16E-08	No	0.79	2.35E+04	3.37E-05	No
U-238	63	4.28E+07	1.47E-06	No	1.34	1.57E+04	8.52E-05	No
Summed	-	-	1.64E-06	-	-	-	2.44E-03	-