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Pacific Northwest National Laboratory

Marine Sciences Laboratory Radionuclide Air Emissions Report for Calendar Year 2016

SF Snyder
JM Barnett

May 2017

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

The U.S. Department of Energy Office of Science (DOE-SC) Pacific Northwest Site Office has oversight and stewardship duties associated with the Pacific Northwest National Laboratory Marine Sciences Laboratory (MSL), located on Battelle Land-Sequim. The facility has two buildings with the potential to emit low levels of radioactive materials. DOE-SC contracted for exclusive use of its radiological operations effective October 1, 2012.

This report is prepared to document compliance with the Code of Federal Regulation, Title 40, Protection of the Environment, Part 61, *National Emission Standards for Hazardous Air Pollutants*, Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities" and Washington Administrative Code Chapter 246-247, *Radiation Protection–Air Emissions*. Compliance is indicated by comparing the estimated effective dose equivalent (EDE) to the maximally exposed individual (MEI) with the 10 millirem per year (mrem/yr) U.S. Environmental Protection Agency (EPA) standard. The MSL has only fugitive emissions sources. Despite the fact that the regulations are intended for application to point source emissions, fugitive emissions are included with regard to complying with the EPA standard.

The EDE to the MSL MEI due to routine operations in 2016 was 5.7E-04 mrem (5.7E-06 mSv). No non-routine emissions occurred in 2016. The MSL is in compliance with the federal and state 10 mrem/yr standard.

For further information concerning this report, you may contact Thomas M. McDermott, U.S. Department of Energy, Pacific Northwest Site Office, by telephone at (509) 372 4675 or by e-mail at tom.mcdermott@science.doe.gov.

CERTIFICATION OF PNNL-22342-5

DOE-SC
Pacific Northwest National Laboratory
Marine Sciences Laboratory
Radionuclide Air Emissions Report
Calendar Year 2016

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. [verbatim from 40 CFR 61, Subpart H, 61.94(b)(9)]

for RES

Roger E. Snyder, Manager
U.S. Department of Energy
Pacific Northwest Site Office

5-24-17

Date

Acronyms and Abbreviations

CFR	Code of Federal Regulations
Ci	curie
CY	calendar year
DOE	U.S. Department of Energy
DOE-SC	U.S. Department of Energy, Office of Science
EDE	effective dose equivalent
EPA	U.S. Environmental Protection Agency
HEPA	high efficiency particulate air (filter)
Major	a radioactive point source having a radiological dose potential of greater than 0.1 mrem/yr EDE, based on emissions that would result if all pollution-control equipment did not exist but facility operations were otherwise normal
MEI	maximally exposed individual
Minor	a radioactive point source having a radiological dose potential of less than or equal to 0.1 mrem/yr EDE, based on emissions that would result if all pollution-control equipment did not exist but facility operations were otherwise normal
mrem	millirem [i.e., 1×10^{-3} rem]
MSL	Pacific Northwest National Laboratory Marine Sciences Laboratory
mSv	millisievert
NESHAP	National Emission Standards for Hazardous Air Pollutants
NOC	Notice of Construction
PNNL	Pacific Northwest National Laboratory
PNSO	Pacific Northwest Site Office
PTE	potential-to-emit
QA	quality assurance
RAEL	Radioactive Air Emissions License
rem	roentgen equivalent man
UDF	unit-release dose factor
WAC	Washington Administrative Code
WDOH	Washington State Department of Health

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1.0 Introduction

The Pacific Northwest National Laboratory (PNNL) Marine Sciences Laboratory (MSL) is located on Battelle Land-Sequim (PNSO 2013) on the coast of Washington State's Olympic Peninsula (Figure 1.1). The Pacific Northwest Site Office of the U.S. Department of Energy Office of Science (DOE-SC) oversees MSL activities through an exclusive use contract with Battelle Memorial Institute. MSL is DOE's only marine research laboratory.

This radiological air emissions report meets the Washington Department of Health (WDOH) requirements for radiological National Emission Standards for Hazardous Air Pollutants (NESHAP) compliance reporting for the activities at MSL for calendar year (CY) 2016.

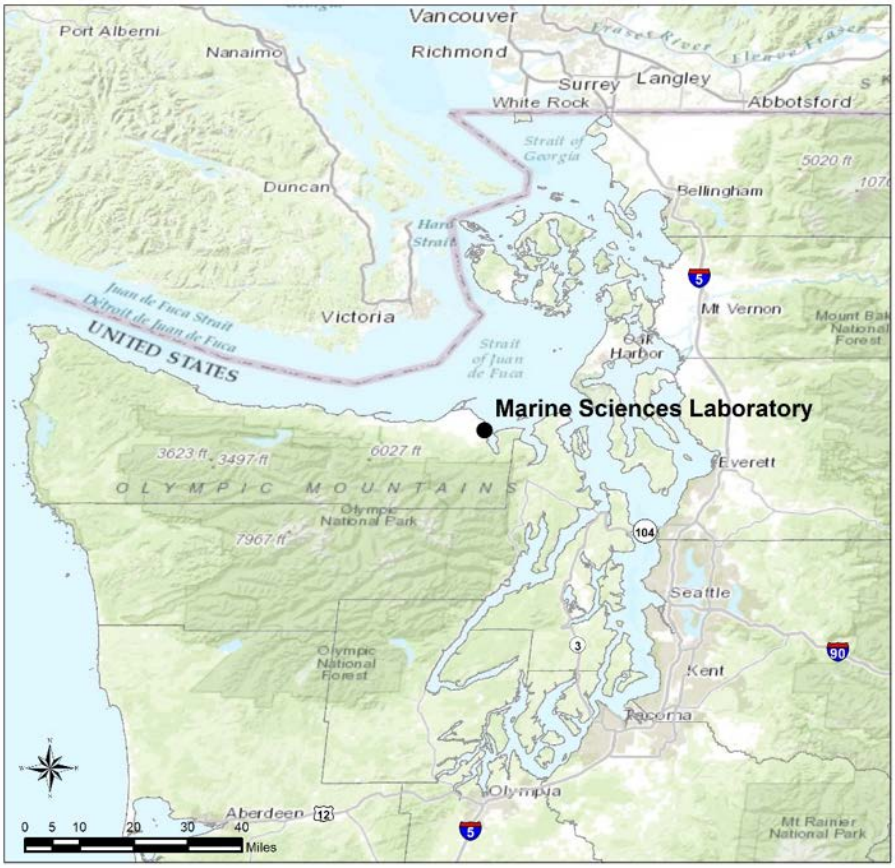

Figure 1.1. MSL in Northwestern Washington State

1.1 Battelle Land-Sequim and MSL Description

Battelle Land-Sequim (Figure 1.2) encompasses 150 acres of uplands and tidelands, of which about 7.5 acres has been developed for research operations. The research operations occur at several laboratories and other facilities in an area referred to as MSL, which includes analytical and general purpose laboratories and wet or support laboratories supplied with heated and cooled freshwater and seawater. MSL has two emission units with the potential to emit low levels of radioactive material. In addition, MSL has a state-of-the-art waste seawater treatment system, a dock facility for a 28-foot research vessel, and a specialized scientific diving boat.

Battelle Land-Sequim lies on the shores of the Strait of Juan de Fuca and is in the rain shadow of the Olympic Mountains in Clallam County, at approximate coordinates 48°04’40” N, 123°02’55” W. Despite its coastal location, it receives less than 15 inches of rainfall on average annually. Average monthly temperatures range from 31°F to 70°F. Nearby cities are Sequim (population 6,600), Port Angeles (population 19,000), and Port Townsend (population 9,100) (DOC 2011). Seattle is approximately 50 miles from MSL. The nearest sea border with Canada is about 17 miles from MSL in the Salish Sea; the nearest Canadian land border is about 25 miles northwest from MSL.

Emission points are located in two buildings: MSL-1 and MSL-5. MSL-1 (Figure 1.3) contains laboratories for biological, chemical, and physical studies in which marine or aquatic environmental conditions need to be maintained. This facility also houses a “cleanroom” for ultra-low-level trace measurements in environmental media, an electronics shop, and diving equipment storage. MSL-5 (Figure 1.4) contains all-purpose chemistry and biochemistry laboratories. One laboratory in MSL-5 is set up for work with radionuclides; however, any laboratory could be set up for such work. A location for storage of hazardous, radioactive, and mixed waste is provided in MSL-5 Building.

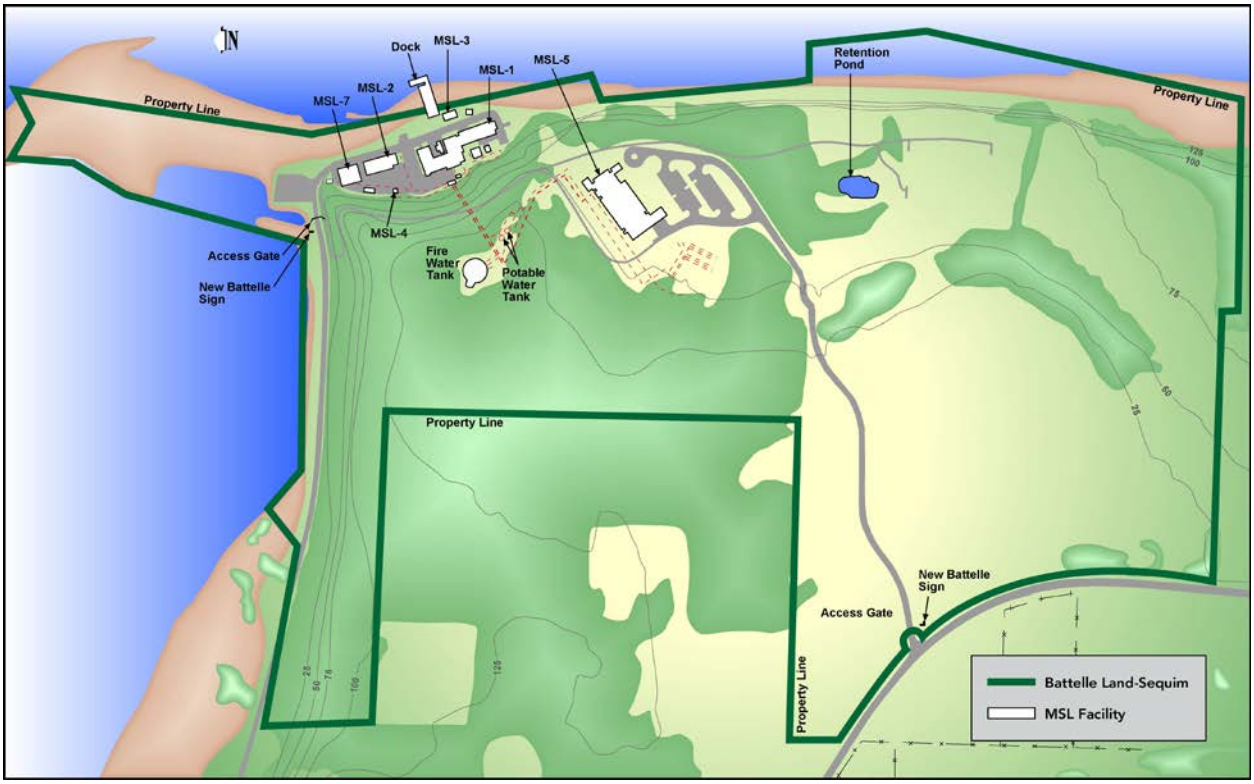

Figure 1.2. Battelle Land-Sequim and Marine Sciences Laboratory

Figure 1.3. MSL-1 Building

Figure 1.4. MSL-5 Building

2.0 Radionuclide Air Emissions

This section describes the two registered MSL emission units and presents emissions estimates for operations during CY 2016.

2.1 Major, Minor, and Fugitive Emissions Points

Two nonpoint source minor emission units associated with MSL-1 and MSL-5 are registered with the state of Washington under the Radioactive Air Emissions License (RAEL)-014. Radioactive air emissions continue to be well below the criteria for classification as a minor emission unit (i.e., potential-to-emit [PTE] contribution is < 0.1 millirem per year [mrem/yr] effective dose equivalent [EDE] to the maximally exposed individual [MEI]). Information regarding the radionuclides of concern, emission rates, and emission unit physical characteristics are described below.

The emission units include EP-MSL-1 and EP-MSL-5 (Figure 1.2). EP-MSL-1 is located on the tidelands, and EP-MSL-5 is located on the upland. The emission unit characteristics are the same for both MSL-1 and MSL-5. These buildings have several locations where radioactive air emissions may originate and exit the building. While they are not fugitive by definition, emissions are fugitive in nature; however, because emissions can come from several points within each building, the emission unit is characterized as a nonpoint source (WAC 2016).

Radiological operations at MSL emit very low levels of radioactive materials. Appendix A contains the full list of radionuclides that may be handled at MSL. The 2016 radioactive material emissions to the air are given in Table 2.1. The 40 CFR 61, Appendix D method of determining unabated emissions was used. No credit was taken for abatement controls (e.g., HEPA filtration) at MSL-1 or MSL-5.

Table 2.1. 2016 MSL Inventory and Emissions Estimates

Nuclide	Emission Type	2016 – EP-MSL-1[(a)] (Ci)	2016 – EP-MSL-5[(a)] (Ci)
K-40	beta/gamma	-	4.78E-12
Fe-55	beta/gamma	-	3.45E-14
Co-57	beta/gamma	-	9.46E-15
Co-60	beta/gamma	-	1.75E-14
Ni-63	beta/gamma	-	3.00E-08
Sr-90	beta/gamma	-	8.32E-13
Tc-99	beta/gamma	-	1.70E-10
Ru-106	beta/gamma	-	4.05E-13
Sb-125	beta/gamma	-	5.32E-13
I-125	beta/gamma	1.00E-06	2.61E-12
I-129	beta/gamma	-	1.15E-17
Cs-134	beta/gamma	-	3.14E-12
Cs-137	beta/gamma	-	3.72E-11
Ba-133	beta/gamma	-	2.00E-11
Eu-152	beta/gamma	-	6.18E-14
Eu-154	beta/gamma	-	1.68E-14
Eu-155	beta/gamma	-	1.77E-14
Pb-210	alpha[(b)]	-	1.28E-13
Po-208	alpha	-	6.97E-10
Po-209	alpha	-	1.40E-11
Ra-226	alpha	-	2.98E-13
Ra-228	alpha[(b)]	-	4.96E-14
Th-228	alpha	-	2.60E-13
Th-230	alpha	-	1.53E-13
Th-232	alpha	-	2.56E-13
U-234	alpha	1.67E-09	1.67E-09
U-235	alpha	7.63E-11	7.65E-11
U-238	alpha	1.66E-09	1.66E-09
Pu-238	alpha	-	8.16E-14
Pu-239	alpha	-	3.75E-13
Pu-240	alpha	-	3.75E-13
Am-241	alpha	-	4.34E-13
TOTAL (Ci) beta/gamma		1.00E-06	3.02E-08
TOTAL (Ci) alpha		3.41E-09	4.12E-09

(a) Emissions based on 40 CFR 61, Appendix D methods.
(b) Although Pb-210 and Ra-228 are beta emitters, their decay products include alpha emitters; therefore, they are considered alpha emitters for dose determination.

3.0 Dose Assessment

This section describes the potential impact of MSL radiological air emissions. Radiological operations at MSL have not changed from the prior year. A review of radiological assessment needs was published in the Data Quality Objects report (Barnett et al. 2012).

3.1 Dose Model and Potential Receptors

The COMPLY Code version 1.6 (Level 4) was used for estimating dose for comparison to the U.S. Environmental Protection Agency (EPA) standard of 10 mrem/yr EDE to any member of the public (40 CFR 61, Subpart H, and WAC 246-247). This code is approved for use for compliance determination (40 CFR 61, Appendix E). Input parameters, originally reported by Barnett et al. (2012), were not changed (Table 3.1).

Potential receptor locations for 16 compass directions are provided in Table 3.2, as reported by Barnett et al. (2012), which concluded that continuation of the 190-m source-to-receptor distance used in prior evaluations would result in an overestimate of any expected receptor impacts, but would continue to be used. The nearest location where a member of the public would actually reside or abide (e.g., dwelling, business, school, office) relative to the MSL-1 or MSL-5 emissions locations was determined to be 270 m W or WNW. Given that winds blow predominantly toward the east (see Table 4.3 of Barnett et al. 2012), away from either of these 270-m receptors, an additional level of conservatism is included.

Table 3.1. COMPLY Input Parameters

Parameter	MSL Value (Level 4)
Nuclide names	<varies by year>
Concentrations (Ci/m^3)	NA
Annual possession amount (Ci)	NA
Release rates (Ci/yr *or* Ci/s)	<varies by year>
Release height (m)	8 m
Building height (m)	8 m
Stack or vent diameter (m)	NA
Volumetric flow rate (m^3/s)	NA
Distance from source-to-receptor (m)	190 m[(a)]
Building width (m)	30 m
Wind speed (m/s)	2 m/s
Distances to sources of food production (m)	190 m[(a)]
Stack temperature (°F)	NA
Ambient air temperature (°F)	NA
Wind rose	NA(nwr)[(b)]
Building length	NA(nwr)[(b)]

NA = not applicable.
(a) Smallest receptor distance to land boundary for either MSL-1 or MSL-5; applied to both emission units.
(b) NA(nwr) = not applicable because **n**o **w**ind **r**ose data is used.

Table 3.2. Potential MSL MEI Locations

Direction from MSL-1 or MSL-5	Smallest distance to BL-S boundary	Smallest Distance to a Receptor Outside BL-S Boundary
N	-	1,790 m res[(a)]
NNE	-	39,700 m res[(a)]
NE	-	9,630 m res[(a)]
ENE	-	2,000 m res[(a)]
E	-	1,900 m res[(a)]
ESE	-	2,620 m res
SE	-	3,930 m res
SSE	-	4,470 m res
S	570 m	640 m res/farm
SSW	630 m	820 m res; 290 m farm
SW	360 m[(a)]	420 m res[(a)]
WSW	230 m	290 m res
W	220 m	270 m res
WNW	230 m	270 m res
NW	280 m	520 m res
NNW	-	1,000 m res/farm

BL-S = Battelle Land-Sequim (see Figure 1.2).
A dash (-) = a shoreline location where no potential receptor could reside or abide.
res = residence site.
(a) Distance from MSL-1 applied; all other distances are from MSL-5.

3.2 Compliance Assessment

The dose standard in 40 CFR 61, Subpart H, applies to radionuclide air emissions, other than radon, from DOE facilities. Dose is estimated as the product of the emission rate (Ci/yr) and unit dose factor (mrem/yr at MEI location per Ci/yr released). Unit dose factors for a number of nuclides are indicated in Appendix B. The Am-241 unit dose factor was applied to all alpha emitters and the Cs-137 unit dose factor was applied to all beta/gamma emitters, as a conservative measure, except for I-129, which used the nuclide-specific dose factor. For CY 2016, the dose assigned to the MSL MEI overestimates any actual offsite dose. The dose was calculated for a location 190 m (0.12 miles) from the emission point which is the location of a hypothetical boundary receptor. This location is also the point of maximum annual air concentration in an unrestricted area where any member of the public may be (WAC 2007). Sea locations were not considered because the dose factors assume vegetable, milk, and meat production at the receptor location.

The EDE to the 2016 MSL MEI from routine and non-routine point source emissions was 5.7E-04 mrem (5.7E-06 mSv). Table 3.3 shows the relative contributions of each nuclide and facility to the MEI dose. The 2015 MEI estimate was 1.1E-4 mrem/yr (1.1E-06 mSv/yr) EDE (Snyder and Barnett 2016).

Table 3.3. MSL 2016 Radionuclide Emissions and MEI Dose

	MSL-1	MSL-5	Total
RELEASES (Ci)			
Beta/gamma	1.00E-06	3.02E-08	1.03E-06
Alpha	3.41E-09	4.12E-09	7.53E-09
MEI EDE (mrem)			
Beta/gamma[(a)]	4.69E-04	1.4E-05	4.8E-04
Alpha[(b)]	3.99E-05	4.8E-05	8.8E-05
Total (mrem)	5.1E-04	6.2E-05	5.7E-04
DOSE CONTRIBUTION (%)			
Beta/gamma	92.2%	23%	85%
Alpha	7.8%	77%	15%

(a) Unit dose factor for Cs-137 applied to estimate dose for all nuclide emissions except I-129.
(b) Unit dose factor for Am-241 applied to estimate dose.

Comparing the MSL 2016 MEI dose to average U.S. background radiation (NCRP 2009):

- Annual natural background radiation 310.0 mrem/yr
- Daily natural background radiation 0.85 mrem/d
- Hourly natural background radiation 0.035 mrem/hr
- Per minute natural background radiation 0.00059 mrem/min
- **MSL 2016 MEI dose** **0.00057** **mrem/yr**
- Per second natural background radiation 0.0000098 mrem/sec

4.0 Supplemental Information

This section provides supplemental information related to MSL radionuclide air emissions in 2016. Supplemental information is provided as part of a Memorandum of Understanding between DOE and EPA (DOE 1995). Collective dose information is reported under DOE O 458.1 requirements (DOE 2011).

4.1 Collective Dose Estimate

An estimated 2.35 million people live within 50 miles (80 km) of MSL, with about 362,000 of those residing in Canada (Zuljevic et al. 2016). The populations and the major U.S. cities at various distances from MSL are given in Table 4.1. Victoria, British Columbia, is the only major Canadian city within 50 miles of MSL and is more than 20 miles from MSL.

Table 4.1. Populations and Significant U.S. Cities within 50 miles of MSL

Population at Indicated Distance[(a)]	Distance (miles)	Cities at Indicated Distances
29,097	0–10	City of Sequim
55,533	10–20	Port Angeles
240,311	20–30	Oak Harbor
701,151	30–40	Anacortes, Bremerton (portion), Edmonds, Everett (portion), Friday Harbor, Marysville (portion), Poulsbo, Shoreline, Stanwood
1,322,999	40–50	Bothell, Bremerton (portion), Everett (portion), Kirkland, Lynnwood, Marysville (portion), Mount Vernon, Seattle (large portion), West Seattle

(a) Zuljevic et al. 2016

The 2016 collective dose was estimated assuming that the total curies released (Table 3.3) were dispersed in a single direction. The maximum collective dose was determined to result from dispersion to the west, which only contains U.S. populations. The MEI dose (5.7E-4 mrem) was multiplied by a population weighted air concentration in the direction of maximum collective impact for a collective dose of 6.4E-4 person-rem. If the release were dispersed only to the maximum Canadian sector (NNW), the maximum estimated Canadian collective dose would be 2.6E-4 person-rem. Dispersal toward the large, but distant, Seattle population sector (SE) would have resulted in a collective dose about 75% less than the collective U.S. dose indicated.

4.2 Compliance Status with Subparts Q and T of 40 CFR 61

- No storage or disposal of radium-bearing materials occurs at MSL; therefore, 40 CFR 61, Subpart Q does not apply to MSL operations.
- No uranium mill tailings or ore disposal activities have been conducted at MSL; therefore, 40 CFR 61, Subpart T does not apply to MSL operations.

4.3 Other Supplemental Information

- Periodic confirmatory measurement information is not required by the Notices of Construction (NOCs).
- The PNNL Radioactive Material Tracking system is used to manage potential emissions below permit thresholds resulting in overall confirmation of inventory limits and emissions estimates to respective NOCs.
- Quality assurance program status of compliance with 40 CFR 61, Appendix B, Method 114 does not apply because no air sampling is conducted at MSL.
- There were no radon emissions in 2016.

5.0 References

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40 CFR 61, as amended. *National Emission Standards for Hazardous Air Pollutants* (NESHAP), Appendix D, "Methods for Estimating Radionuclide Emissions."

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Appendix A

List of Radioactive Materials Handled or Potentially Handled, or Authorized for Use at MSL in 2016

Appendix A: List of Radioactive Materials Handled or Potentially Handled, or Authorized for Use at MSL in 2016

Table A.1. List of Radioactive Materials Handled or Potentially Handled, or Authorized for Use at MSL in 2016

Ac-225	Bk-249	Cs-134m	Ho-166	Mn-56	Pd-109	Rh-102	Ta-180	U-232
Ac-227	Bk-250	Cs-135	Ho-166m	Mo-93	Pm-143	Rh-102m	Ta-182	U-233
Ac-228	Br-82	Cs-136	I-122	Mo-99	Pm-144	Rh-103m	Ta-182m	U-234
Ag-108	Br-82m	Cs-137	I-123	Mo-103	Pm-145	Rh-104	Ta-183	U-235
Ag-108m	Br-83	Cs-138	I-125	Mo-104	Pm-146	Rh-105	Tb-157	U-235m
Ag-109m	Br-84	Cs-139	I-126	Mo-105	Pm-147	Rh-105m	Tb-158	U-236
Ag-110	Br-84m	Cs-140	I-128	N-13	Pm-148	Rh-106	Tb-160	U-237
Ag-110m	Br-85	Cs-141	I-129	Na-22	Pm-148m	Rn-219	Tb-161	U-238
Ag-111	C-11	Cu-64	I-130	Na-24	Pm-149	Rn-220	Tc-95	U-239
Al-26	C-14	Cu-66	I-130m	Na-24m	Pm-151	Rn-222	Tc-95m	U-240
Al-28	C-15	Cu-67	I-131	Nb-91	Po-208	Rn-224	Tc-97	V-48
Am-240	Ca-41	Dy-159	I-132	Nb-91m	Po-209	Ru-97	Tc-97m	V-49
Am-241	Ca-45	Dy-165	I-132m	Nb-92	Po-210	Ru-103	Tc-98	W-181
Am-242	Ca-47	Dy-169	I-133	Nb-93m	Po-211	Ru-105	Tc-99	W-185
Am-242m	Cd-107	Er-169	I-133m	Nb-94	Po-212	Ru-106	Tc-99m	W-187
Am-243	Cd-109	Er-171	I-134	Nb-95	Po-213	S-35	Tc-101	W-188
Am-245	Cd-111m	Es-254	I-134m	Nb-95m	Po-214	Sb-122	Tc-103	Xe-122
Am-246	Cd-113	Eu-150	I-135	Nb-97	Po-215	Sb-124	Tc-106	Xe-123
Ar-37	Cd-113m	Eu-152	In-106	Nb-97m	Po-216	Sb-125	Te-121	Xe-125
Ar-39	Cd-115	Eu-152m	In-111	Nb-98	Po-218	Sb-126	Te-121m	Xe-127
Ar-41	Cd-115m	Eu-154	In-113m	Nb-100	Pr-143	Sb-126m	Te-123	Xe-127m
Ar-42	Cd-117	Eu-155	In-114	Nb-101	Pr-144	Sb-127	Te-123m	Xe-129m
As-74	Cd-117m	Eu-156	In-114m	Nb-103	Pr-144m	Sb-129	Te-125m	Xe-131m
As-76	Ce-139	Eu-157	In-115	Nd-144	Pu-234	Sc-44	Te-127	Xe-133
As-77	Ce-141	F-18	In-115m	Nd-147	Pu-236	Sc-46	Te-127m	Xe-133m
At-217	Ce-142	Fe-55	In-116	Ni-56	Pu-237	Sc-47	Te-129	Xe-135
Au-193	Ce-143	Fe-59	In-116m	Ni-57	Pu-238	Se-75	Te-129m	Xe-135m
Au-194	Ce-144	Fr-221	In-117	Ni-59	Pu-239	Se-79	Te-131	Xe-137
Au-195	Cf-249	Fr-223	In-117m	Ni-63	Pu-240	Se-79m	Te-131m	Xe-138
Au-196	Cf-250	Ga-67	Ir-192	Ni-65	Pu-241	Si-31	Te-132	Xe-139
Au-198	Cf-251	Ga-68	K-40	Np-235	Pu-242	Si-32	Te-133	Y-88
Au-198m	Cf-252	Ga-70	K-42	Np-236	Pu-243	Sm-145	Te-133m	Y-90
Au-199	Cl-36	Ga-72	Kr-81	Np-237	Pu-244	Sm-146	Te-134	Y-90m
Ba-131	Cm-241	Gd-148	Kr-81m	Np-238	Pu-246	Sm-147	Th-227	Y-91
Ba-133	Cm-242	Gd-149	Kr-83m	Np-239	Ra-223	Sm-148	Th-228	Y-91m
Ba-133m	Cm-243	Gd-151	Kr-85	Np-240	Ra-224	Sm-151	Th-229	Y-92
Ba-137m	Cm-244	Gd-152	Kr-85m	Np-240m	Ra-225	Sm-153	Th-230	Y-93
Ba-139	Cm-245	Gd-153	Kr-87	O-15	Ra-226	Sm-157	Th-231	Yb-164
Ba-140	Cm-246	Gd-159	Kr-88	O-19	Ra-228	Sn-113	Th-232	Yb-169
Ba-141	Cm-247	Ge-68	Kr-89	Os-191	Rb-81	Sn-117m	Th-233	Yb-175
Ba-142	Cm-248	Ge-71	Kr-90	P-32	Rb-82	Sn-119m	Th-234	Yb-177
Ba-143	Cm-250	Ge-71m	La-137	P-33	Rb-83	Sn-121	Ti-44	Zn-65
Be-7	Co-56	Ge-75	La-138	Pa-231	Rb-84	Sn-121m	Ti-45	Zn-69
Be-10	Co-57	Ge-77	La-140	Pa-233	Rb-86	Sn-123	Ti-51	Zn-69m
Bi-207	Co-58	Ge-77m	La-141	Pa-234	Rb-87	Sn-125	Tl-201	Zr-88
Bi-208	Co-60	H-3	La-142	Pa-234m	Rb-88	Sn-126	Tl-204	Zr-89
Bi-210	Co-60m	Hf-175	La-144	Pb-209	Rb-89	Sr-85	Tl-206	Zr-93
Bi-210m	Cr-49	Hf-178m	Lu-177	Pb-210	Rb-90	Sr-87m	Tl-207	Zr-95
Bi-211	Cr-51	Hf-179m	Lu-177m	Pb-211	Rb-90m	Sr-89	Tl-208	Zr-97
Bi-212	Cr-55	Hf-181	Mg-27	Pb-212	Re-186	Sr-90	Tl-209	Zr-98
Bi-213	Cs-131	Hf-182	Mg-28	Pb-214	Re-187	Sr-91	Tm-168	Zr-99
Bi-214	Cs-132	Hg-203	Mn-52	Pd-103	Re-188	Sr-92	Tm-170	Zr-100
Bk-247	Cs-134	Ho-163	Mn-54	Pd-107	Rh-101	Ta-179	Tm-171	

Appendix B

COMPLY Unit Dose Factors

Appendix B: COMPLY Unit Dose Factors

As originally reported in Barnett et al. 2012, COMPLY v1.6 was used to determine unit-release dose factors (UDFs), which represent impacts to a hypothetical receptor 190 m from the emission unit with an assumed 2 m/s wind speed and wind blowing toward the receptor 25% of the time. These assumptions are based on calculations of COMPLY v1.6 at Level 4 with no wind rose used. The appropriate solubility class (DOE 2010) was applied, replacing the DOE 2010 solubility classifications (F,M,S) with the analogous solubility classifications available in COMPLY (D,W, Y, respectively). Several nuclides (^{133}Ba, ^{22}Na, ^{210}Pb, ^{3}H, and ^{14}C) are footnoted to indicate that only one option was available (EPA 1989). Additionally, the more conservative (overestimating) classification was applied to uranium. UDFs for radionuclides either in current inventory or previously used at MSL are presented.

Table B.1. MSL Unit Dose Factors

Nuclide	COMPLY Solubility Class	Unit Dose Factor (mrem EDE per Ci/yr released)
^{241}Am[a]	W	11700
^{133}Ba[b]	D	135
^{14}C[c]	"1"	1.5
^{109}Cd	W	5.5
^{57}Co	W	4.8
^{60}Co	W	426
^{137}Cs[a]	D	469
^{154}Eu	W	345
^{155}Eu	W	13.3
^{3}H[b]	V	0.004
^{125}I	D	84.5
^{129}I	D	1250
^{54}Mn	W	27.2
^{22}Na[b]	D	234
^{63}Ni	W	0.3
^{210}Pb[b]	D	1100
^{238}Pu	W	10300
^{239}Pu	W	11200
^{106}Ru	W	13.9
^{90}Sr[d]	Y	211
^{99}Tc	W	32.7
^{234}U	Y	3450
^{235}U	Y	3470
^{238}U	Y	3110
Natural U[e]	Y	3290

Bold font = alpha-emitting nuclides. All others are beta/gamma emitters.
(a) ^{241}Am is the surrogate alpha emitter for those not specifically listed; ^{137}Cs is the surrogate beta emitter for those not specifically listed.
(b) The solubility class listed is the only option available in COMPLY v1.6.
(c) Default class of COMPLY v1.6 used.
(d) Solubility class W is preferred, but not an option. Class Y was used as an overestimating assumption.
(e) Determined from natural uranium mass fractions: 0.000055 ^{234}U; 0.0072 ^{235}U; 0.9928 ^{238}U (DOE 2009).

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