



Department of Energy – Office of Science
Pacific Northwest National Laboratory

Marine Sciences Laboratory Radionuclide Air Emissions Report for Calendar Year 2018

SF Snyder
JM Barnett

May 2019

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

The U.S. Department of Energy Office of Science 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. Facility operations include radiological operations with the potential to emit low levels of radioactive materials.

This report is prepared to document compliance with the Code of Federal Regulations, 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 determined 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 2018 was 4.5E-04 mrem (4.5E-6 mSv). No non-routine emissions occurred in 2018. 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-22342-7

**DOE-SC
Pacific Northwest National Laboratory
Marine Sciences Laboratory
Radionuclide Air Emissions Report
Calendar Year 2018**

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)]



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

5/20/19
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
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
PTE	potential-to-emit
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 2017) on the coast of Washington State's Olympic Peninsula (Figure 1.1). The Pacific Northwest Site Office of the U.S. Department of Energy (DOE) Office of Science 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) 2018. The WDOH Radioactive Air Emissions License (RAEL)-014, Renewal 1, was issued in January 2018. This renewal changed the release to a single, fugitive site-wide emission unit. Compared to the prior year, radiological laboratory activities have not changed under the new license.



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 buildings 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. Meteorology at the Sequim Site in 2018 is summarized in Table 1.1. Wind speeds were below average in 2018.

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.

Radiological emissions predominantly occur from laboratories in two buildings: MSL-1 and MSL-5 (Figure 1.2, Figure 1.3, and Figure 1.4). Radiological laboratories activities at MSL include:

- conducting biological, chemical, and physical studies in which marine or aquatic environmental conditions need to be maintained;
- maintenance of a “cleanroom” for ultra-low-level trace measurements in environmental media;
- storage of radioactive and mixed waste; and
- laboratory space that could be set up for radiological work.



Figure 1.2. Battelle Land-Sequim and Marine Sciences Laboratory

Table 1.1. 2018 Meteorological Summary for Sequim, Washington

Parameter	2018 value
Average Temperature	50.4°F (10.2°C)
Average Wind Speed	2.9 mph (1.3 m/s)
Predominant Wind Direction (from)	W
Total Precipitation	14.86 in. (37.7 cm)
Data courtesy of WSU AgWeatherNet (accessed 3/13/19: http://weather.wsu.edu/?p=93250 / Sequim Station).	



Figure 1.3. MSL-1 Building



Figure 1.4. MSL-5 Building

2.0 Radionuclide Air Emissions

This section describes the registered MSL emission unit and presents emissions estimates for operations during CY 2018.

2.1 Major, Minor, and Fugitive Emissions Points

A single nonpoint source minor emission unit, J-MSL, is registered with the state of Washington under the RAEL-014, Renewal-1. 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. J-MSL is also classified as a PIC-4 (licensed PTE of ≤ 0.001 mrem/yr) emission unit (Barnett 2018).

J-MSL is a sitewide emission unit. Essentially, any structure or abatement controls from which an emission traverses is disregarded when compliance determinations are estimated.

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 2018 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. Beta emissions include a significant I-125 component ($1.00\text{E-}6$ Ci) with all other beta-emitter activity emissions of $2.07\text{E-}9$ Ci.

Table 2.1. 2018 MSL Emissions Estimates

Nuclide / Type		2018 – J-MSL ^(a,b) (Ci)
H-3	Beta	6.95E-11
C-14	Beta	2.48E-13
K-40	Beta	7.65E-12
Fe-55	Beta	3.46E-14
Co-57	Beta	1.31E-09
Co-60	Beta	1.23E-13
Sr-90	Beta	1.56E-12
Tc-99	Beta	3.00E-10
Ru-106	Beta	7.83E-13
Sb-125	Beta	1.06E-12
I-125	Beta	1.00E-06
I-129	Beta	2.43E-15
Cs-134	Beta	6.28E-12
Cs-137	Beta	1.86E-10
Ba-133	Beta	1.84E-10
Eu-152	Beta	6.19E-14
Eu-154	Beta	1.50E-13
Eu-155	Beta	1.77E-14
Pb-210	Beta	1.28E-13
Po-208	Alpha	6.96E-10
Po-209	Alpha	1.40E-11
Ra-226	Alpha	4.33E-13
Ra-228	Beta	4.96E-14
Th-228	Alpha	2.60E-13
Th-230	Alpha	1.53E-13
Th-232	Alpha	1.00E-09
U-233	Alpha	6.70E-15
U-234	Alpha	7.76E-09
U-235	Alpha	3.59E-10
U-238	Alpha	8.59E-09
Pu-238	Alpha	8.18E-14
Pu-239	Alpha	3.75E-13
Pu-240	Alpha	3.75E-13
Pu-241	Beta	4.66E-14
Am-241	Alpha	4.34E-13
Total Alpha Ci		1.84E-08
Total Beta Ci		1.00E-06
TOTAL (Ci)		1.02E-06

(a) “Beta” (gray-shaded) includes beta- and gamma-emitters.

(b) Emissions based on 40 CFR 61, Appendix D methods.

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. The license has changed from the prior year, resulting in a change to dose assessment methods. A review of radiological assessment needs under the license renewal is nearing completion, as an update to the Data Quality Objects report (Barnett et al. 2012).

3.1 Dose Model and Potential Receptors

The COMPLY Code version 1.7 (Level 4) (EPA 1989) 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, Subpart H). Some input parameters were changed in consideration of the license renewal (Table 3.1), including release parameters, wind speed, and distance to receptor.

The release height and building dimensions were both reduced from 8 m and 8 m × 30 m, respectively, to 5 m and 5 m × 5 m. Also, the distance from source-to-receptor was updated to reflect the use of a “Central MSL” emission location assumption (48° 4’ 42.45”, 123° 2’ 48.51”; Google Earth, image date July 30, 2017) (see Figure 1.2, yellow marker). This Central MSL location was selected because it is considered central to all operations areas at MSL. Distances from the Central MSL upland assumed release location to lowland boundary locations consider the straight-line rather than horizontal (map) distance; this accounts for the additional plume transport distance resulting from vertical difference of the upland (~30 m above the shore) and shore boundaries.

Table 3.1. COMPLY Input Parameters

Parameter	J-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)	5 m
Building height (m)	5 m
Stack or vent diameter (m)	NA
Volumetric flow rate (m ³ /s)	NA
Distance from source-to-receptor (m)	234 m ^(a)
Building width (m)	5 m
Wind speed (m/s)	1.3 m/s
Distances to sources of food production (m)	234 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 potential MEI distance.

(b) NA(nwr) = not applicable because **no wind rose** data is used.

Potential MEI locations for each of the 16 compass directions are provided in Table 3.2. The nearest location where a member of the public would actually reside or abide (e.g., dwelling, business, school, office) relative to the Central MSL emission location was determined to be 234 m W and is designated as the MEI location (40 CFR Part 61, Subpart H, and WAC 2019) because no wind rose is entered in the COMPLY modeling.

Potential maximum annual air locations are boundary locations in each of the 16 compass directions provided in Table 3.2. The maximum annual air location (WAC 2007) dose was calculated for the nearest boundary location, 129 m ENE of the Central MSL. No members of the public routinely inhabit this shore, boundary location; food modeling in COMPLY for this location assumed food to be grown at a distance resulting from averaging all terrestrial boundary distances, 355 m from Central MSL, as an overestimating assumption.

Table 3.2. Potential MSL MEI Locations and Distances to Boundary

Direction from Central MSL	Smallest Distance to a Potential MEI Location	Smallest Distance to the Battelle Land-Sequim Boundary
N	1,834 m, res	319 m
NNE	30,670 m, busi	211 m
NE	10,000 m, busi	147 m
ENE	1,877 m, res	129 m
E	1,979 m, res	131 m
ESE	2,678 m, res	154 m
SE	3,693 m, res	176 m
SSE	1,532 m, busi	474 m
S	720 m, res	715 m
SSW	723 m, res	753 m
SW	340 m, res	270 m
WSW	276 m, res	203 m
W	234 m, res	187 m
WNW	440 m, res	202 m
NW	1,261 m, busi	290 m
NNW	840 m, res	220 m

Central MSL point and Battelle Land-Sequim (see Figure 1.2).
Blue cell highlight = a shoreline location where no member of the public could occupy 24/7.
res = residential structure.
busi = business (NNE and NE are parks on small island parks; SSE is a marina park; NW is a sewage treatment plant).

3.2 Compliance Assessment

The dose standard in 40 CFR 61, Subpart H, applies to radionuclide air emissions, other than radon, from DOE facilities. The emissions from Table 2.1 resulted in the MEI doses reported in Table 3.3.

Doses were estimated using a unit-release dose factor (UDF_r) times the release rate (A_r) for radionuclide “r” [i.e., UDF_r (mrem/yr per 1 $Ci_{\text{released}}/\text{yr}$) $\times A_r$ ($Ci_{\text{releasead}}$) = D_r (mrem/yr)]. COMPLY v1.7.1-determined UDFs used in the 2018 dose assessment are indicated in Appendix B.

As a conservative (overestimating) assumption, all alpha activity releases except for Th-232 were assumed to be Am-241. The Th-232 dose was estimated separately because the generic alpha-emitter

(Am-241) assumption does not produce a conservative dose result. All beta activity releases except for I-125 were assumed to be Cs-137. The I-125 dose was estimated separately because the generic beta-emitter (Cs-137) assumption overestimates this nuclide dose excessively and would result in a total dose over the RAEL-014 emission unit limit. For other nuclides where the generic nuclide does not produce a conservative result (i.e., I-129, Pb-210, and Ra-228), external calculations were done to make sure a nuclide-specific dose calculation is not a significant portion of the final reported dose (I-129 = 4E-12 mrem/yr; Pb-210 = 1.9E-10 mrem/yr; and Ra-228 = 3.9E-11 mrem/yr).

For CY 2018, the dose assigned to the MSL MEI overestimates any actual offsite dose. The MEI dose was calculated for the nearest potential receptor, 234 m (768 ft) W of Central MSL.

Table 3.3. MSL 2018 MEI Dose

Data/Emission Type		J-MSL
Releases		
	Th-232 (Ci)	1.00E-09
	I-125 (Ci)	1.00E-06
	Remaining Alpha (Ci)	1.74E-08
	Remaining Beta (Ci)	<u>2.07E-09</u>
	Total	1.02E-06 Ci
Annual MEI Dose		
	Th-232 (mrem)	5.87E-05
	I-125 (mrem)	1.13E-04
	Remaining Alpha (mrem) ^(a)	2.73E-04
	Remaining Beta (mrem) ^(b)	<u>1.30E-06</u>
	Total	4.46E-04 mrem
Dose Contribution		
	Alpha	74%
	Beta	26%

(a) Unit dose factor for Am-241 applied to estimated dose.
(b) Unit dose factor for Cs-137 applied to estimate dose.

The EDE to the 2018 MSL MEI from routine J-MSL emissions was 4.5E-04 mrem (4.5E-06 mSv) for 40 CFR Part 61, Subpart H, and WAC 246-247 compliance reporting. Table 3.3 shows the relative contributions of each nuclide and facility to the MEI dose. The 2017 MEI estimate was 1.6E-4 mrem/yr (1.6E-06 mSv/yr) EDE (also see Snyder and Barnett 2018).

Comparing the MSL 2018 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 2018 MEI dose	0.00045	mrem/yr
• Per second natural background radiation	0.0000098	mrem/sec

The EDE to the boundary location where air concentrations of radioactive materials are modeled to be greatest is the nearest distance to the site boundary (see Table 3.2). This location, 129 m (423 ft) ENE of the Central MSL location, is on the shore. Food (vegetables, milk, meat) was assumed to be grown 355 m from the release location. The estimated dose to this individual assumed to be at this shore location 24/7 is 1.0E-03 mrem (1.0E-05 mSv), which is well below the 10 mrem/yr dose standard for WAC 2007 reporting.

4.0 Supplemental Information

This section provides supplemental information related to MSL radionuclide air emissions in 2018. 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 2018 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 ($4.5\text{E-}4$ mrem) was multiplied by a population-weighted air concentration in the direction of maximum collective impact for a collective dose of $5.0\text{E-}4$ person-rem. If the release were dispersed only to the maximum Canadian sector (NNW), the maximum estimated Canadian collective dose would be $2.0\text{E-}4$ 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 2018.
- There were no unplanned emissions in 2018.

5.0 References

40 CFR 61, as amended. *National Emission Standards for Hazardous Air Pollutants* (NESHAP), Appendix B, “Test Methods.”

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

40 CFR 61, as amended. *National Emission Standards for Hazardous Air Pollutants* (NESHAP), Appendix E, “Compliance Procedures Methods for Determining Compliance with Subpart I.”

40 CFR 61, as amended. *National Emission Standards for Hazardous Air Pollutants* (NESHAP), Subpart H, “National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities.”

40 CFR 61, as amended. *National Emission Standards for Hazardous Air Pollutants* (NESHAP), Subpart Q, “National Emission Standards for Radon Emissions from Department of Energy Facilities.”

40 CFR 61, as amended. *National Emission Standards for Hazardous Air Pollutants* (NESHAP), Subpart T, “National Emission Standards for Radon Emissions from the Disposal of Uranium Mill Tailings.”

Barnett JM. 2018. *Pacific Northwest National Laboratory Potential Impact Categories for Radiological Air Emission Monitoring*. PNNL-19904, Rev. 5, Pacific Northwest National Laboratory, Richland, WA

Barnett JM, KM Meier, SF Snyder, EJ Antonio, BG Fritz, and TM Poston. 2012. *Data Quality Objectives Supporting Radiological Air Emissions Monitoring for the Marine Sciences Laboratory, Sequim Site*. PNNL-22111, Pacific Northwest National Laboratory, Richland, WA.

DOC—U.S. Department of Commerce. 2011. 2010 Census Summary File 1-Washington, 2010 Census of Population and Housing [wa_2010_sf1_asr_city.xlsx], U.S. Census Bureau, Department of Commerce, Washington, D.C. Last accessed 3/18/2014 at <http://www.ofm.wa.gov/pop/census2010/data.asp>.

DOE—U.S. Department of Energy. 1995. “Memorandum of Understanding Between the U.S. Environmental Protection Agency and the U.S. Department of Energy Concerning the Clean Air Act Emission Standards for Radionuclides 40 CFR Part 61 Including Subparts H, I, Q & T” (letter to E. Ramona, U.S. Environmental Protection Agency) from Raymond Berube, U.S. Department of Energy, Washington, D.C., May 16.

DOE—U.S. Department of Energy. 2010. *Calculating Potential-to-Emit Radiological Releases and Doses*. DOE/RL-2006-29, Rev 1, Richland Operations Office, Richland, WA.

DOE—U.S. Department of Energy. 2011. *Radiation Protection of the Public and the Environment*. DOE Order 458.1, admin chg 3, Office of Environment, Health, Safety & Security, Washington, D.C.

EPA—U.S. Environmental Protection Agency. 1989. *User’s Guide for the COMPLY Code*. EPA 520/1-89-003, Revision 2, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C. Applicable to COMPLY v1.7; Last accessed (3/22/18): <https://www.epa.gov/radiation/users-guide-comply-code-revision-2>.

NCRP—National Council on Radiation Protection and Measurements. 2009. *Ionizing Radiation Exposure of the Population of the United States*. NCRP, Bethesda, MD.

PNSO—Pacific Northwest Site Office. 2017. *PNNL Terminology Reference Document*. PNSO-REFR-05, U.S. Department of Energy, PNSO, Richland, WA.

Snyder SF and JM Barnett. 2018. *Marine Sciences Laboratory Radionuclide Air Emissions Report for Calendar Year 2017*. PNNL-22342-6, Pacific Northwest National Laboratory, Richland, WA.

Snyder SF and DJ Rokkan. 2016. *Calculating Potential-to-Emit Radiological Releases and Doses*. DOE/RL-2006-29, Revision 2, U.S. Department of Energy, Richland Operations Office, Richland, WA.

WAC—Washington Administrative Code. 2007. *Ambient Air Quality Standards and Emission Limits for Radionuclides*. WAC-173-480, Statutory Law Committee, Olympia, WA.

WAC—Washington Administrative Code. 2019. *Radiation Protection – Air Emissions*. WAC-246-247, Statutory Law Committee, Olympia, WA.

Zuljevic N, TE Seiple, SF Snyder. 2016. *Battelle Land–Sequim Regional Population*. PNNL-25305, Pacific Northwest National Laboratory, Richland, WA.

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Appendix A

List of Radioactive Materials Handled or Potentially Handled, or Authorized for Use at MSL in 2018

Appendix A: List of Radioactive Materials Handled or Potentially Handled, or Authorized for Use at MSL in 2018

Table A.1. List of Radioactive Materials Handled or Potentially Handled, or Authorized for Use at MSL in 2018

Ac-225	Au-195	C-11	Co-58m	F-18	Ho-166	K-42	Nb-91	Pa-234m
Ac-226	Au-195m	C-14	Co-60	Fe-55	Ho-166m	Kr-81	Nb-91m	Pb-203
Ac-227	Au-196	C-15	Co-60m	Fe-59	I-122	Kr-81m	Nb-92	Pb-204m
Ac-228	Au-196m	Ca-41	Cr-49	Fr-221	I-123	Kr-83m	Nb-92m	Pb-205
Ag-105	Au-198	Ca-45	Cr-51	Fr-222	I-124	Kr-85	Nb-93m	Pb-209
Ag-106m	Au-198m	Ca-47	Cr-55	Fr-223	I-125	Kr-85m	Nb-94	Pb-210
Ag-108	Au-199	Cd-107	Cs-131	Ga-67	I-126	Kr-87	Nb-94m	Pb-211
Ag-108m	Ba-131	Cd-109	Cs-132	Ga-68	I-128	Kr-88	Nb-95	Pb-212
Ag-109m	Ba-131m	Cd-111m	Cs-134	Ga-70	I-129	Kr-89	Nb-95m	Pb-214
Ag-110	Ba-133	Cd-113	Cs-134m	Ga-72	I-130	Kr-90	Nb-96	Pd-103
Ag-110m	Ba-133m	Cd-113m	Cs-135	Gd-148	I-130m	La-137	Nb-97	Pd-107
Ag-111	Ba-135m	Cd-115	Cs-135m	Gd-149	I-131	La-138	Nb-97m	Pd-109
Ag-111m	Ba-137m	Cd-115m	Cs-136	Gd-150	I-132	La-140	Nb-98	Pd-109m
Ag-112	Ba-139	Cd-117	Cs-137	Gd-151	I-132m	La-141	Nd-144	Pd-111
Al-26	Ba-140	Cd-117m	Cs-138	Gd-152	I-133	La-142	Nd-147	Pd-112
Al-28	Ba-141	Ce-139	Cs-138m	Gd-153	I-133m	La-144	Ni-56	Pm-143
Am-240	Ba-142	Ce-141	Cs-139	Gd-159	I-134	Lu-177	Ni-57	Pm-144
Am-241	Ba-143	Ce-142	Cs-140	Ge-68	I-134m	Lu-177m	Ni-59	Pm-145
Am-242	Be-10	Ce-143	Cs-141	Ge-69	I-135	Mg-27	Ni-63	Pm-146
Am-242m	Be-7	Ce-144	Cu-64	Ge-71	In-106	Mg-28	Ni-65	Pm-147
Am-243	Bi-207	Cf-249	Cu-66	Ge-71m	In-111	Mn-52	Np-235	Pm-148
Am-244	Bi-208	Cf-250	Cu-67	Ge-75	In-111m	Mn-52m	Np-236	Pm-148m
Am-244m	Bi-210	Cf-251	Dy-159	Ge-77	In-112	Mn-53	Np-236m	Pm-149
Am-245	Bi-210m	Cf-252	Dy-165	Ge-77m	In-112m	Mn-54	Np-237	Pm-150
Am-246	Bi-211	Cl-36	Dy-169	H-3	In-113m	Mn-56	Np-238	Pm-151
Ar-37	Bi-212	Cm-241	Er-169	Hf-175	In-114	Mo-93	Np-239	Po-208
Ar-39	Bi-213	Cm-242	Er-171	Hf-177m	In-114m	Mo-93m	Np-240	Po-209
Ar-41	Bi-214	Cm-243	Es-254	Hf-178m	In-115	Mo-99	Np-240m	Po-210
Ar-42	Bk-247	Cm-244	Eu-150	Hf-179m	In-115m	Mo-103	O-15	Po-211
As-73	Bk-248m	Cm-245	Eu-150m	Hf-180m	In-116	Mo-104	O-19	Po-212
As-74	Bk-249	Cm-246	Eu-152	Hf-181	In-116m	Mo-105	Os-185	Po-212m
As-76	Bk-250	Cm-247	Eu-152m	Hf-182	In-117	N-13	Os-191	Po-213
As-77	Br-82	Cm-248	Eu-152n	Hg-203	In-117m	Na-22	P-32	Po-214
At-217	Br-82m	Cm-249	Eu-154	Hg-205	Ir-189	Na-24	P-33	Po-215
At-218	Br-83	Cm-250	Eu-154m	Hg-206	Ir-190	Na-24m	Pa-231	Po-216
Au-193	Br-84	Co-56	Eu-155	Ho-163	Ir-192	Nb-100	Pa-232	Po-218
Au-193m	Br-84m	Co-57	Eu-156	Ho-164	Ir-194	Nb-101	Pa-233	Pr-142

Table A.1 (cont'd)

Pr-143	Ra-226	Rh-104m	Sc-44m	Sn-125	Tc-98	Th-233	U-240	Y-91m
Pr-144	Ra-227	Rh-105	Sc-46	Sn-125m	Tc-99	Th-234	V-48	Y-92
Pr-144m	Ra-228	Rh-105m	Sc-47	Sn-126	Tc-99m	Ti-44	V-49	Y-93
Pt-191	Rb-81	Rh-106	Sc-48	Sr-82	Tc-101	Ti-45	W-181	Yb-164
Pt-193	Rb-81m	Rn-218	Se-75	Sr-83	Tc-103	Ti-51	W-185	Yb-165
Pt-193m	Rb-82	Rn-219	Se-77m	Sr-85	Tc-106	Tl-200	W-185m	Yb-166
Pt-195m	Rb-82m	Rn-220	Se-79	Sr-85m	Te-121	Tl-201	W-187	Yb-167
Pt-197	Rb-83	Rn-222	Se-79m	Sr-87m	Te-121m	Tl-202	W-188	Yb-169
Pt-197m	Rb-84	Rn-224	Si-31	Sr-89	Te-123	Tl-204	Xe-122	Yb-175
Pt-198m	Rb-84m	Ru-103	Si-32	Sr-90	Te-123m	Tl-206	Xe-123	Yb-177
Pt-199	Rb-86	Ru-105	Sm-145	Sr-91	Te-125m	Tl-206m	Xe-125	Zn-65
Pt-199m	Rb-86m	Ru-106	Sm-146	Sr-92	Te-127	Tl-207	Xe-127	Zn-69
Pu-234	Rb-87	Ru-97	Sm-147	Ta-179	Te-127m	Tl-208	Xe-127m	Zn-69m
Pu-235	Rb-88	S-35	Sm-148	Ta-180	Te-129	Tl-209	Xe-129m	Zr-88
Pu-236	Rb-89	Sb-122	Sm-151	Ta-182	Te-129m	Tl-210	Xe-131m	Zr-89
Pu-237	Rb-90	Sb-122m	Sm-153	Ta-182m	Te-131	Tm-168	Xe-133	Zr-89m
Pu-238	Rb-90m	Sb-124	Sm-155	Ta-183	Te-131m	Tm-170	Xe-133m	Zr-93
Pu-239	Re-186	Sb-124m	Sm-156	Tb-157	Te-132	Tm-171	Xe-135	Zr-95
Pu-240	Re-186m	Sb-124n	Sm-157	Tb-158	Te-133	U-232	Xe-135m	Zr-97
Pu-241	Re-187	Sb-125	Sn-113	Tb-160	Te-133m	U-233	Xe-137	Zr-98
Pu-242	Re-188	Sb-126	Sn-113m	Tb-161	Te-134	U-234	Xe-138	Zr-99
Pu-243	Rh-101	Sb-126m	Sn-117m	Tc-95	Th-227	U-235	Xe-139	Zr-100
Pu-244	Rh-101m	Sb-127	Sn-119m	Tc-95m	Th-228	U-235m	Y-88	-
Pu-246	Rh-102	Sb-128	Sn-121	Tc-96	Th-229	U-236	Y-89m	-
Ra-223	Rh-102m	Sb-128m	Sn-121m	Tc-96m	Th-230	U-237	Y-90	-
Ra-224	Rh-103m	Sb-129	Sn-123	Tc-97	Th-231	U-238	Y-90m	-
Ra-225	Rh-104	Sc-44	Sn-123m	Tc-97m	Th-232	U-239	Y-91	-

Appendix B

COMPLY Unit Dose Factors

Appendix B: COMPLY Unit Dose Factors

COMPLY v1.7.1 (EPA 1989) was used to determine unit-release dose factors, which represent impacts to a hypothetical receptor 234 m from the *Central MSL* point of assumed releases. No wind rose was supplied, meaning the default assumption of wind blowing toward the receptor 25% of the time was used. COMPLY Level 4 with no wind rose was used; other assumptions are listed in Table 3.1 of the main report, including an annual average wind speed (2018) of 1.3 m/s.

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). The COMPLY default inhalation solubility class, in the following table, are used as simplifying, overestimating assumptions for dose determination (see solubility class preferences in Table 3.1 of Snyder and Rokkan 2016).

Table B.1. MSL Unit Dose Factors

Nuclide	Footnote	COMPLY Solubility Class	Unit Dose Factor (mrem/yr EDE per Ci/yr released)
Am-241		W	15700
Cs-137		D	627
I-125		D	113
I-129		D	1680
Pb-210	a	D	1470
Ra-228		W	792
Th-232	b	W	58700

Bold font = alpha-emitting nuclides. All others are beta/gamma emitters.

(a) The solubility class listed is the only available option in COMPLY v1.7.1.

(b) Solubility class S is preferred, but the default class W used as an overestimating assumption.

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