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EMP, Attachment 3

Dose Assessment Guidance

December 2019

SF Snyder

U.S. DEPARTMENT OF ENERGY

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

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Richland, Washington 99354

Summary

This Dose Assessment Guidance (DAG) describes methods used to comply with the reporting requirements for individual receptor and collective dose for radionuclide air emissions under the U.S. Department of Energy, Office of Science, Pacific Northwest National Laboratory (PNNL) Environmental Monitoring Plan (EMP). The National Emission Standards for Hazardous Air Pollutants (40 CFR 61), Subpart H, is the greatest driver for the requirements. This DAG applies to public dose from radioactive material releases to the air from PNNL Richland Campus and Marine Sciences Laboratory (Sequim, Washington). The application of Richland Campus ambient external dose results is also briefly discussed. The methods used to perform the biota dose assessment reported in the Site Environmental Report are discussed.

This guidance is Attachment 3 to PNNL's EMP (PNNL-20919) and addresses a discrete, vital subject area of the EMP that is subject to revision independent of the main text of the EMP document.

Revision Number	Effective Date	Description of Change
Rev 0	December 2011	Initial document.
Rev 1	December 2019	• Major re-write with the following items highlighted. • PNNL Richland Campus is now more formally defined as an area larger than just the PNNL Site. • Richland Campus Dose Assessments: – Now calculated using CAP88-PC version 4.0 with a 100-year build-up time instead of version 3 with a 50-year build-up time. – Evaluation of Maximum Air location is evaluated in addition to MEI. – PNL-1 and PNL-2 ambient air sampling stations changed from their AC-operated location to their permanent solar-operated locations. All currently operating particulate and ambient external dose stations discussed. – Added discussion of PIC-5 permit dose assignments. • MSL/Sequim Site Dose Assessment and (future) surveillance discussion added. • Biota Dose Assessment added.

Acronyms and Abbreviations

ASER	Annual Site Environmental Report
BCG	Biota Concentration Guide
CAP88-PC v4.0	*Clean Air Act* Assessment Package 1988 – Personal Computer, version 4.0
CFR	*Code of Federal Regulations*
CRD	Contractor Requirements Document
CY	calendar year
DAG	Dose Assessment Guide
DOE	U.S. Department of Energy
EDE	effective dose equivalent
EMP	Environmental Monitoring Plan
EPA	U.S. Environmental Protection Agency
ICRP	International Commission on Radiological Protection
MA	Maximum Air
MEI	maximally exposed individual
MOU	memorandum of understanding
NESHAP	National Emission Standards for Hazardous Air Pollutants
OSL	optically stimulated luminescent
PNNL	Pacific Northwest National Laboratory
RAEL	Radioactive Air Emissions License
RMT	Radioactive Material Tracking System
SAP	Sampling and Analysis Plan
TED	total effective dose
TEDE	total effective dose equivalent
WAC	Washington Administrative Code
WDOH	Washington State Department of Health

Building/Facility Acronyms

LSB	Laboratory Support Building
LSLII	Life Sciences Lab II
MSL	Marine Sciences Laboratory
PSF	Physical Sciences Facility (including Buildings 3410, 3420, 3425, and 3430)
RTL	Research Technology Laboratory
WSU	Washington State University, Tri-Cities campus

Contents

Figures

Tables

1.0 Introduction

This Dose Assessment Guidance (DAG) document is an attachment to the Pacific Northwest National Laboratory (PNNL) Environmental Monitoring Plan (EMP) and describes details of the public dose assessment process for federal compliance:

- 40 CFR 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities," and
- DOE Order 458.1, "Radiation Protection of the Public and the Environment," reporting.

Subpart H contains the dose standard for radionuclide emissions to air. DOE Order 458.1 contains requirements for U.S. Department of Energy (DOE) sites to follow with regard to radionuclide emissions to the environment. The PNNL Richland Campus[1] and the Marine Sciences Laboratory (MSL) / Sequim Site compliance is reported separately due to their disparate locations within the state of Washington (see Figure 1 of the EMP). Dose assessment of radionuclide air emissions from PNNL-managed facilities on the Hanford Site are under the purview of the Hanford Site subcontractor Mission Support Alliance and are not within the scope of this document.

The State of Washington also has regulations that operations at both the Richland Campus and MSL/Sequim Site must comply with. The state regulations are contained in WAC 246-247 and WAC 173-480. The state also administers the two radioactive air emissions licenses (RAEL) issued to the PNNL locations.

Relevant to this DAG, a major part of compliance with U.S. Environmental Protection Agency (EPA) regulations for PNNL Campus and for MSL radionuclide air emissions is determined by meeting the dose standard of 10 mrem in a calendar year (CY) to the maximally-exposed public receptor (40 CFR 61.92).

State regulations additionally include radon and unplanned emissions in their 10 mrem dose criteria to the maximally exposed individual (MEI) member of the public. Also, an evaluation of the Maximum Air (MA) location dose is conducted. The MA location dose, reported to State regulators, is the dose an offsite public receptor would have incurred if they were located at the offsite location of maximum impact from Campus radioactive material emissions to the air. The feature that differentiates the MEI receptor from the MA location is that the MA location can be on undeveloped land or river shore (i.e., no actual receptor is required for the MA dose reporting). The MA location dose result may be the same as or higher than the MEI dose, but will never be lower.

This document reviews the process for dose assessment determinations from radionuclide emissions to air. As indicated in the EMP main text, part of the Environmental Radiation Task includes ambient air particulate sampling and ambient dosimetry. These two topics are discussed as they relate to dose assessment at the two PNNL operations locations.

In the event that liquid effluent pathway doses may need to be calculated for the Site Environmental Report, the GENII version 2.0 model (Napier 2010) may be used. If a different dose assessment option is used, it would be described in the dose documentation.

[1] The PNNL Campus boundary is indicated in Figure 2 of the EMP (Snyder et al. 2019c) including the site of the Laboratory Support Building (LSB) (Building 3350).

1.1 Recent Dose Results

Recent PNNL MEI and MA doses from compliance reporting are presented in Table 1 (e.g., Snyder et al. 2019a and Snyder and Barnett 2019). The MEI and MA receptor locations are determined from atmospheric dispersion modeling of annual radionuclide emissions, using site-specific meteorology. The doses to critical receptors from radionuclide air emissions are well below the 10 mrem standard. These doses are also reported in the Annual Site Environmental Report (ASER) because the PNNL radiological operations on the PNNL Richland Campus and MSL/Sequim Site only result in potential public exposures as a result of radionuclide emissions to air.

Table 1. MEI and MA Dose Summary for Recent Years (mrem/yr)

Year	MEI Dose (mrem/yr EDE)	MA Dose (mrem/yr EDE)	Compliance Model	Report
PNNL Richland Campus				
2014	2.7E-05	Not reported	CAP88-PC	PNNL-20436-5
2015	2.6E-04	3.2E-04	CAP88-PC	PNNL-20436-6
2016	5.8E-04	6.7E-04	CAP88-PC	PNNL-20436-7
2017	2.1E-05	(a)	CAP88-PC	PNNL-20436-8
2018	1.8E-05	2.1E-05	CAP88-PC	PNNL-20436-9
MSL/Sequim Site				
2014	9.0E-05	(a)	COMPLY	PNNL-22342-3
2015	1.1E-04	(a)	COMPLY	PNNL-22342-4
2016	1.6E-04	(a)	COMPLY	PNNL-22342-5
2017	1.6E-04	(a)	COMPLY	PNNL-22342-6
2018	4.5E-04	(a)	COMPLY	PNNL-22342-7

(a) See MEI dose, MEI and MA receptor are at the same location.

1.2 Requirements

The impact of radionuclide air emissions from the PNNL MSL in Sequim, Washington, is indicated by dose estimates at the location of the closest distance-to-boundary from a facility with radiological operations. The fugitive-only emissions at MSL allow a more conservative (i.e., over-estimating), less precise method to be used for evaluating compliance with the dose standard. This boundary location is both the MEI and MA receptor for MSL.

Reporting requirements associated with dose to members of the public from radiological air emissions are in 40 CFR Part 61.94, WAC 246-247-080, and DOE Order 458.1. The MA location dose is associated with WAC 173-480-070. The DOE Order standards for dose from radionuclide air emissions are consistent with EPA dose standards in 40 CFR 61.92 (i.e., 10 mrem/yr to a MEI). The State WAC 246-247 regulations are more restrictive than the Federal EPA standard in that diffuse and radon (radon-220 and radon-222) emissions are explicitly included in the MEI dose determination. Despite the fact that the current contract for the PNNL operations does not include the requirement to meet DOE Order 458.1, Contractor Requirements Document (CRD), paragraph 2.b, public dose limits, the DOE dose limits would be met when EPA limits are met.

The reporting requirements applicable to environmental air surveillance dose assessment are contained in the following:

- 40 CFR 61.94, National Emission Standards for Hazardous Air Pollutants (NESHAP) Subpart H "Compliance and Reporting"
  - Requires DOE sites with airborne radioactive effluent releases to prepare an annual radionuclide air emissions report (e.g., Snyder et al. 2019a), including estimated radionuclide emissions to the atmosphere and, under the Washington Department of Health (WDOH)-accepted approach for PNNL compliance demonstration, their maximum dose impact at an offsite school, residence, business, or office.
- PNNL Richland Campus Radioactive Air Emissions License (RAEL-005) (WDOH 2015)
  - Adopts by reference the reporting requirements in 40 CFR 61, Subpart H, with some additional information. The report submitted to EPA under that regulation also satisfies WDOH reporting requirements if all information required by the State regulation is included.
  - Requires reporting to the WDOH when an annual air monitoring concentration meets or exceeds the 40 CFR 61, Appendix E, Table 2 value (see Sampling and Analysis Plan, EMP, Attachment 1, Table 3.2) or when detection limits exceed 10% of the values.
  - Though not specifically indicated in the license, reporting the offsite location of maximum radioactive air concentrations ("MA location") resulting from stack emissions and calculation of dose to a receptor at that location, whether that location is occupied by a member of the public or not.
- DOE Order 231.1B, "Environment, Safety, and Health Reporting"
  - Requires the ASER to include:
    - Environmental monitoring
    - Types and quantities of radioactive materials emitted or discharged to the environment
    - Dose to a representative person or MEI and collective dose from sources identified under DOE Order 458.1
    - Any radon and progeny releases from DOE sources, where it is a concern; and associated MEI and collective doses
- DOE Order 458.1 Chg 3, "Radiation Protection of the Public and the Environment"[2]
  - Requires reporting when public dose limits of CRD paragraph 2.b are exceeded.
  - Requires reporting actual or potential exposures of the public that could result in either 1) a dose from DOE sources exceeding 100-mrem/yr total effective dose (TED), or exceeding any limit or failing to meet any other requirement specified, or any other legal or applicable limits; or 2) a combined dose equal to or greater than 100 mem/yr TED from DOE and other man-made sources.
  - Requires compliance with 40 CFR 61 subparts, as applicable.
  - Requires biota dose assessment.

[2] This complete Order is not included in full in the current PNNL Site contract (August 14, 2019). However, application of some of its requirements herein is done as a good business practice.

- EPA and DOE MOU, “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, and T”, clarifying requirements
  - Requests information regarding radon-220 emissions, interpreted to mean emissions rates and dose estimates for the site MEI, are reported. This same information for radon-222 is provided.
  - Indicates that 40 CFR 61, Appendix D and Appendix E methods are acceptable for establishing Subpart H compliance.
  - A list of all emission units where operations’ radioactive materials released to ambient air are reported.

2.0 PNNL Richland Campus Dose Assessment Guidance

The PNNL Campus radionuclide releases to ambient air, dispersion and dose model, and the individual and collective dose reporting for 40 CFR 61, Subpart H reporting are described. The ASER reporting may include water and soil radionuclide sources of public receptor exposure; however, currently, the only source of radionuclide emissions to a public receptor is from emissions to ambient air. Therefore, dose assessment for Subpart H reporting is equivalent to public receptor dose assessment methods used for ASER reporting.

2.1 Radionuclide Releases and Dispersion Modeling

Due to the current, very low emissions rates of radioactive materials, doses to individuals are calculated using computer models rather than direct measurements of radionuclide concentrations. (While environmental surveillance does measure external dose and particulate radionuclide air concentrations at Richland Campus ambient sampler station locations, these are confirmatory and include both background and non-PNNL contributions.) Different codes are used at each PNNL site to model atmospheric dispersion and estimate receptor dose. The potential for greater health impacts from Richland Campus emissions necessitates the use of a more detailed atmospheric dispersion modeling. The lower potential impacts from smaller MSL emissions allows the use of a simpler, more conservative (i.e., over-estimating) dispersion model.

2.1.1 Richland Campus Radionuclide Releases

Radionuclide release rates and release locations are required to estimate receptor dose. The radioactive air emissions (Ci/yr) from PNNL Richland Campus operations are provided by PNNL operations staff under the direction of the Environmental Radiation Task lead (see Figure 4 of the EMP). The description of emission units with radionuclide emissions to air are provided in Barnett and Snyder 2018. Annual release rates could be determined by continuous stack sampling, periodic sampling, RADGAS management, or 40 CFR 61, Appendix D methods; in some instances, more than one method may be utilized for an emission unit. The method(s) used is that appropriate to the emission unit, emission form, and/or license requirement.

Release locations are assumed to be either the building location or, in the case of Physical Sciences Facility (PSF) emissions, grouped buildings. Grouped emissions are assumed to be released from the location that results in a dose estimate that is more conservative (i.e., greater) than the dose that would result from individual stack location modeling. Point (stack) and non-point (fugitive or diffuse) emission units within the same building may be modeled separately, if release heights are assigned different values.

2.1.2 Richland Campus Dispersion Modeling

The EPA-approved version of the CAP88-PC software (version 4.0, Rosnick 2014) is used to demonstrate compliance with the NESHAP and State 10 mrem/yr dose standard. Exposure parameters used in CAP88-PC v4.0 compliance calculations for the PNNL Richland Campus MEI are typically default values (Table 2). The site-specific data needed to perform compliance dose calculations for the year of interest at the PNNL Richland Campus include radionuclide release rates, stack (emission location) characteristics, and meteorological data.

Table 2. CAP88-PC Version 4 Parameters Used for the Richland Campus MEI Receptor and Collective Dose Estimation for Annual Compliance Determinations[(a)]

Tab	Parameter Label	Units	CAP-88 Default	MEI	Collective	Comment
Facility	Emission Year	CY	<dropdown box>	<CY of emission>	<CY of emission>	
Population	Run Type	text	<dropdown box>	Individual	Population	
Population	Population Age	text	<dropdown box>	Adult	Adult	
Population	Build-up time	year	100	100	100	WDOH advice for Richland Campus
Population	Midpoints	meter	<user entry>	<based on critical and misc. evaluation locations, as determined by dose assessor>	<based on distances evaluated in the population file>	Generally do not change much from year to year.
Population	Maximum Exposed Individual	Direction, meter	<dropdown boxes>	<as determined by external evaluation of dose assessor based on a PSF particulate emissions and appropriate meteorology>	n/a	
Meteorological	File	n/a	<dropdown box>	<pre-loaded Hanford Site, 300 Area Station 11, 10 m measurement height data file>	<pre-loaded Hanford Site, Station 11, 10 m measurement height data file>	Meteorological data received from Hanford Site staff and reformatted using established PNNL methodology
Meteorological	Annual Precipitation	cm/yr	n/a	Hanford Site, 200 Area, Station 21 HMS total value for the CY	Hanford Site, 200 Area, Station 21 HMS total value for the CY	HMS value is more reliable than 300 Area data.
Meteorological	Annual Ambient Temperature	Degrees Celsius	n/a	Hanford Site, 200 Area, Station 21 HMS average value for the CY	Hanford Site, 200 Area, Station 21 HMS average value for the CY	HMS value is more reliable than 300 Area data.
Meteorological	Lid Height	meter	1000	1000	1000	
Meteorological	Absolute humidity	g/m^3	8.00	8.00	8.00	
Stack	Stack Type, Sources	text	<dropdown boxes>	Stack, 1	Stack, 1	PNNL tradition is to limit each CAP88-PC case (i.e., dataset) to a single release location.

Tab	Parameter Label	Units	CAP-88 Default	MEI	Collective	Comment
Facility	Emission Year	CY	<dropdown box>	<CY of emission>	<CY of emission>	
Stack	Height, Diameter	meter	n/a	<Effective release height, diameter of modeled emission unit>	<Effective release height, diameter of modeled emission unit>	Effective release height. PNNL assumes fugitive and diffuse sources are assumed to have a 10 m effective release height.
Stack	Plume type	text	<dropdown box>	None	None	
Stack	Plume rise for each Pasquill category	meter	0 for all	0 for all	0 for all	
Agricultural	Food source	text	<dropdown box>	Local	Regional	WDOH advice for Richland Campus
Agricultural	Fraction Home produced; from assessment area; imported	0–1	1,0,0 for Local 0,1,0 for Regional	1,0,0	0,1,0	WDOH advice for Richland Campus
Agricultural	Agriculture State	text	<dropdown box, Washington>	Washington	Washington	
Agricultural	Beef cattle density	Number/ha^2	0.0562	0.0562	0.0562	
Agricultural	Milk cattle density	Number/ha^2	0.0150	0.0150	0.0150	
Agricultural	Land fraction cultivated for vegetables	0–1	0.052	0.052	0.052	
Nuclides	<changes annually>	<several>	<several>	Enter a 1 Ci release for each, to use in spreadsheet calculations.	Enter actual emissions for predominant MEI dose contributors.	

(a) If justified appropriately, parameter values may be modified. In some cases, parameter modification may require approval by the state regulator, WDOH.

Table 3. Boundary Locations Relative to Each Physical Sciences Facility Building with a Registered Emission Unit.

Direction	3410 to Boundary	Location Description	3420 to Boundary	Location Description	3430 to Boundary	Location Description
N	1185 m	Hanford Site	1125 m	Hanford Site	1185 m	Hanford Site
NNE	1270 m	Hanford Site	1210 m	Hanford Site	1285 m	Hanford Site
NE	905 m	river (~1490 far river)	995 m	river	1135 m	river
ENE	745 m	river (~1460 far river)	820 m	river	935 m	river
E	715 m	river	780 m	river	890 m	river
ESE	425 m	far side LSB, S of HRRd	505 m	far side LSB, S of HRRd	665 m	Far side LSB, far pond area
SE	630 m	SW corner LSB, 11th&PoB	710 m	11th St	610 m	GW Way & 11th
SSE	640 m	GW Way	850 m	GW Way	1125 m	GW Way
S	1825 m	3rd St	1670 m	4th St	1605 m	4th St
SSW	1030 m	Battelle Blvd	1090 m	Battelle Blvd	990 m	Stevens, just N of Battelle Blvd
SW	835 m	Stevens Dr	730 m	Stevens Dr	590 m	Stevens Dr
WSW	655 m	Stevens Dr	560 m	Stevens Dr & HRRd	450 m	Stevens Dr
W	600 m	Stevens Dr[(a)]	520 m	Stevens Dr[(a)]	415 m	Stevens Dr[(a)]
WNW	650 m	Stevens Dr[(a)]	560 m	Stevens Dr[(a)]	450 m	Stevens Dr[(a)]
NW	840 m	Stevens Dr[(a)]	725 m	Stevens Dr[(a)]	580 m	Stevens Dr[(a)]
NNW	1285 m	Hanford	1215 m	Hanford	1035 m	Stevens Dr

(a) Public land located across Stevens Drive from this location.
GW Way = George Washington Way; HRRd = Horn Rapids Rd; PoB = Port of Benton; LSB = Laboratory Support Building
See Table 5 for distances from PSF buildings to sampling stations.

These data are used as input to the CAP88-PC v4.0 code and are documented in the annual compliance report.

2.1.2.1 CAP88-PC Meteorological Data

As a general description of the CAP88-PC, the code's gaussian plume model disperses the user-input radionuclide emission according to the user-supplied meteorology, provides some intermediate concentration data, and calculates estimates of radiation dose to organs and the whole-body of a receptor. Estimates of radionuclide concentrations in air, land, and food are modeled in the code. Radionuclides taken into the body by inhalation or ingestion may be distributed among different organs and retained for various times. In addition, long-lived radionuclides deposited on the ground can be taken up by agricultural products, may be re-suspended and dispersed by winds, and can be possible contributors to long-term external exposure. Dietary and exposure parameters are used to calculate radionuclide intakes and radiological doses to an adult person.

2.1.2.2 MEI and MA Location Determination

Prior to running compliance determination cases, the MEI location must be determined based on the current meteorology. Assuming no significant new emission sources are now operational in the new year of evaluation, copy the significant emission source file from the prior evaluation year to a new dataset (e.g., loc-new.dat). Note the MEI receptor location in that file and change distances in the Population tab to read the same MEI distance and add several distances incremented 20 meters smaller and larger. Run a 1-Ci-release case of H-3 (gas), Pu-239 (M), and I-129 (F) with the new meteorology (new file with its associated precipitation and temperature).

Based on the evaluation of Snyder et al. 2017, the mid-sector distances from each PSF facility to the PNNL Campus boundary are indicated in Table 3. These distances provide a starting point for MEI and MA determinations. If operations have not changed significantly from the prior year, the prior year's locations provide a more efficient starting point.

Note the Pu-239 X/Q distance (see e.g., CAP88-PC file "loc-new.CHI") that is largest, in the direction of the prior year's MEI and in the immediate adjacent directions. Map that location (e.g., in Google Earth) to make sure that the maximum particulate location is 1) not onsite or at LSB (considered onsite for NESHAP evaluations) and 2) is "developed land" (not shrub-steppe or otherwise vacant land). If it can be disqualified based on these two criteria, find the largest Pu-239 X/Q value that is offsite and occupied/developed property. As you review the *.CHI file, consider if there are other directions with greater Pu-239 X/Q values. Consider if any onsite receptors could be considered members of the public (those who work full-time at an office within an onsite building, but their office access is NOT restricted by PNNL-access control.)

Finally, consider if there are more significant gas or iodine emissions for the current calendar year. If so, review the *.CHI file for maximum locations in a similar manner. The MEI location may be reviewed, again, after final dose determination to reconfirm the location chosen.

The location determinations for the MA receptor are performed after the MEI final dose determinations are complete. This latter determination is possible since the Campus MEI dose estimates are far below the dose standard. The MA location is determined by evaluating all offsite locations in all directions with the emission unit having the most significant dose impact to an offsite receptor.

2.2 Individual Receptor Dose Estimation

The transport of radionuclides from the emission units to the point(s) of exposure is modeled by CAP88-PC v4.0 for environmental transport pathways. Two points of individual member of the public exposure evaluated are the MEI and the MA locations, which could be the same location.

One complication of the smaller size of the PNNL Richland Campus is that the MEI/MA receptor for one facility may not be the MEI/MA location for all facilities. PNNL facilities are proximately located next to different boundaries. Therefore, transport analyses are done for the various release locations. Typically, there is one facility whose MEI/MA dose is larger than the others. This MEI/MA location is determined to be the location of record and then the dose from all other facilities' emissions to this location is determined. The largest MEI and MA receptor results from all site emissions are indicated in the annual compliance report.

Section 2.1.2 discusses receptor parameters, meteorological data, and MEI/MA receptor location determinations. CAP88-PC cases are run with a unit release of each radionuclide emitted for a receptor at the MEI location. This produces a unit-release dose factor for the MEI for each emission unit location modeled. The unit-release dose factors include the dose from the parent and any progeny from that parent. If a parent nuclide is a progeny or has the same progeny nuclide as another emission, they should be run in separate CAP88 datasets. Then spreadsheet calculations are completed to link the actual release with dose factor for the MEI of interest. The prior year's spreadsheet can be updated for the current year's calculations.

The MEI dose is the total dose from each emission unit modeled plus the PIC-5 permits used during the emission year.[3] Major emission units are modeled individually or as a grouped source. Minor emission units are modeled individually or as a grouped source. Radon-220 and radon-222 emissions are modeled separately because they are regulated by WDOH but not included in Subpart H regulations. An MOU between DOE and EPA (DOE 1995) indicates that radon emissions and dose information should be provided in Subpart H reporting.

For information purposes only, a dose determination has been included in PNNL Subpart H reporting to determine the impact to the PNNL MEI from Hanford Site emissions. This information is supplemental but provides useful public information about the potential combined impact of PNNL Richland Campus and Hanford Site radionuclide emissions, both of which result from DOE activities. The two sites are separately managed and operated, so there is no requirement to determine the location of the "Hanford-plus-PNNL emissions' MEI." Additionally, the Hanford Site MEI has been on the PNNL Richland Campus for the last several years, so there is no current informational calculation of the PNNL Richland Campus' radionuclide emissions dose determined for the Hanford Site MEI. If the Hanford Site MEI were offsite of the PNNL Campus in the future, then the dose from PNNL emissions to that Hanford Site MEI location would be calculated and reported as a special calculation.

Dose basis information for the CAP88-PC, version 4.0, and as appropriate for Subpart H compliance determinations is summarized. Dose quantities are reported in units of mrem for individuals to be consistent with the regulatory standard, which is indicated in non-SI units. Units of person-rem are used for the collective dose.

[3] PIC-5 permit doses are not assigned for collective dose calculations, only individual receptor (MEI and MA) dose estimates.

EPA regulations in 40 CFR Part 61, Subpart H, specify that estimates of radiological dose to a member of the public be reported in terms of effective dose equivalent (EDE) or total effective dose equivalent (TEDE), consistent with an older methodology described in International Commission on Radiological Protection (ICRP) Publication 26 (ICRP 1977) and ICRP Publication 30 (ICRP 1979–1988). DOE has adopted use of the TED as recommended in the more recent ICRP Publication 60 (ICRP 1991). Doses calculated as TED and TEDE are similar in most cases. Probably the most significant difference in these two quantities is the organ weighting factors applied. Another difference is the more recent radionuclide transformation (i.e., half-life and ionizing emissions) database applied in TED results. Both TED and TEDE represent the total risk of potential health effects from radiation exposure, including dose from radionuclides taken into the body and dose from sources external to the body.

For internal dose (inhalation and ingestion pathways), CAP88-PC v4.0 uses radiation- and tissue-weighting factors consistent with ICRP Publications 60 (ICRP 1991) and 72 (ICRP 1996) as well as radionuclide transformation information from ICRP Publication 107 (ICRP 2008), and indicates dose in terms of mrem TED. For external exposure dose, CAP88-PC version 4.0 uses external dose factors based on ICRP Publications 26 and 30 (Parts 1-4 and Supplements; ICRP 1977 and 1979-88), as reported in EPA 1993, which incorporated radionuclide transformation information from ICRP Publication 38 (ICRP 1983) and indicate external dose in terms of mrem TEDE. Although the regulations specify that dose be calculated in terms of mrem TEDE, EPA approval of CAP88-PC v4.0 for use by DOE facilities presumes the acceptance of the more recent ICRP (1991, 1996) methods.

Reviews of dose results (individual and collective) are based on criteria developed in Schreckhise et al. 1993 and documented using the review checklist in Appendix D of that document and PNNL Information Release reviews.

2.3 Collective Dose Estimation

Collective dose calculations consider the same pathways as those evaluated for an individual. Regulatory dose standards have not been established for collective dose under the DOE Orders, or WDOH and EPA regulations. However, evaluation of the collective doses (expressed in person-rem) to all residents within a declared radius of the site is required by DOE CRD 458.1 paragraph 2.e(1)(d) and DOE 1995.

PNNL Richland Campus reports a 50-mi (80-km) collective dose, that represents the summed individual doses for the number of individuals involved for all potential exposure pathways. The pathways assigned to the Campus MEI are also applied to the offsite population, as directed by WDOH. The “local” food option is assigned, so that ingestion dose is conservatively assigned. No PIC-5 doses are assigned for collective dose estimation.

The close proximity of the PNNL Richland Campus to the Hanford Site 300 Area allows the 80-km population distribution for the 300 Area to be applied to the Campus collective dose calculations. Geographic distributions of the population residing within an 80-km radius of the four Hanford Site operating areas based on the 2010 Census were evaluated and published in Hamilton and Snyder 2011. These data influence the collective dose by providing estimates of the number of people exposed to radioactive effluents and their proximity to the points of release. Population files may be updated to reflect new construction, especially that in close proximity to the Campus boundary.

The Richland Campus population data for 2010 Census results is shown in Table 4, with a total of 432,757 people within the 80-km (50-mile) radius of the Campus (Hamilton and Snyder 2011,

adjusted). Adjustments were made for recent apartment construction projects SW of the former RTL complex are noted. Use of the data file shown in the figure will provide output that indicates collective dose for sectors with midpoint-distances from the emission point origin of 0.8 km, 2.4 km, 4.0 km, 5.6 km, 7.2 km, 12.05 km, 24.15 km, 40.25 km, 56.35 km, and 72.45 km. These correspond to sectors of 0–1 mi, 1–2 mi, 2–3 mi, 3–4 mi, 4–5 mi, 5–10 mi, 10–20 mi, 20–30 mi, 30–40 mi, and 40–50 mi radii. Annual reviews of development near the site boundary are conducted to, most importantly, review receptors in the nearest sectors or large developments in the nearest two sectors, with subsequent adjustments made to the population file, as appropriate.

Table 4. PNNL Richland Campus 50-mi Population Data

Radii (mi)	Direction Toward																
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0-1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	**2**
1-2	0	0	2	8	29	24	18	22	641[(a)]	1	0	0	0	0	0	0	**745**
2-3	0	1	32	57	27	39	112	466	246	4	1	0	0	0	0	0	**985**
3-4	0	5	35	123	44	39	100	1,317	3,261	215	1,117	48	0	0	0	0	**6,304**
4-5	0	24	37	78	98	74	40	177	8,204	133	136	26	4	0	0	0	**9,031**
5-10	4	236	325	414	310	130	15,107	14,896	28,773	11,526	4,325	890	432	0	0	0	**77,368**
10-20	247	2,020	885	505	186	656	50,970	67,443	10,485	981	2,321	5,117	161	1	1	2	**141,981**
20-30	1,513	1,667	3,573	53	682	361	956	68	301	80	106	13,571	937	40	2	12	**23,922**
30-40	4,787	8,135	1,624	278	185	100	965	65	33,838	4,208	86	14,711	25,767	127	7,646	1,153	**103,675**
40-50	2,661	3,655	169	124	483	23,994	1819	252	2,595	4,131	335	102	22,823	463	1,360	3,778	**68,744**
Total	**9,212**	**15,743**	**6,683**	**1,641**	**2,044**	**25,417**	**70,087**	**84,706**	**88,344**	**21,279**	**8,427**	**34,465**	**50,124**	**631**	**9,009**	**4,945**	**432,757**

(a) For PSF emissions, 1-2 mi S sector changed from 1 to 641 to account for new apartments SW of former RTL Complex; increasing the Hamilton and Snyder (2011) total population from 432,117 to 432,757.

2.4 Use of Ambient Air Particulate Samples for Dose Assessment

Environmental surveillance of radionuclides (particulates, only) in ambient air is performed at the PNNL Richland Campus. Particulate sampling results are not used to demonstrate compliance at the PNNL Richland Campus; the sampling is done to confirm low levels of emissions at the Richland Campus. Four stations sample for site emissions and a background station is located in Benton City, WA (see Figure 1). Table 5 indicates the locations of the site sampling stations relative to radiological facilities. Particulates, only, are currently sampled; site emissions do not indicate a need for radioactive noble gas, tritium, or iodine sampling.

Additional details regarding both sampling and analyses (biweekly and 6-mo composites) are provided in the Sampling and Analysis Plan (SAP). While sampling results are not used to demonstrate NESHAP compliance, annual compliance reporting will typically indicate how average annual radionuclide-specific sampling results compare to the values in 40 CFR 61, Appendix E, Table 2. Also, a comment is provided on how all average annual sample results compare to background. Doses from routine sample results are not typically reported. Dose should only be estimated for radionuclide-specific results, not from gross alpha and gross beta analyses.

When a dose estimate from ambient sampling is requested, the following method is recommended to estimate dose from particulate sample analyses. The CAP88-PC v4 model is used with annual meteorological data to report the air concentrations (*.CON file), at a specific monitoring station location for comparison with air sampling results. This comparison could substantiate the releases estimated by the Effluent Monitoring Program or indicate facility air emissions control systems functionality. If environmental surveillance data for the PNNL Richland Campus are unexpectedly high (discovered after the systemic time-lag due to sample analysis and sample compositing), environmental transport or dose evaluations could be performed using meteorological data and environmental models to consider the source and potential impacts. The reporting process of any identified anomalous results is indicated in the Data Management Plan (DMP).

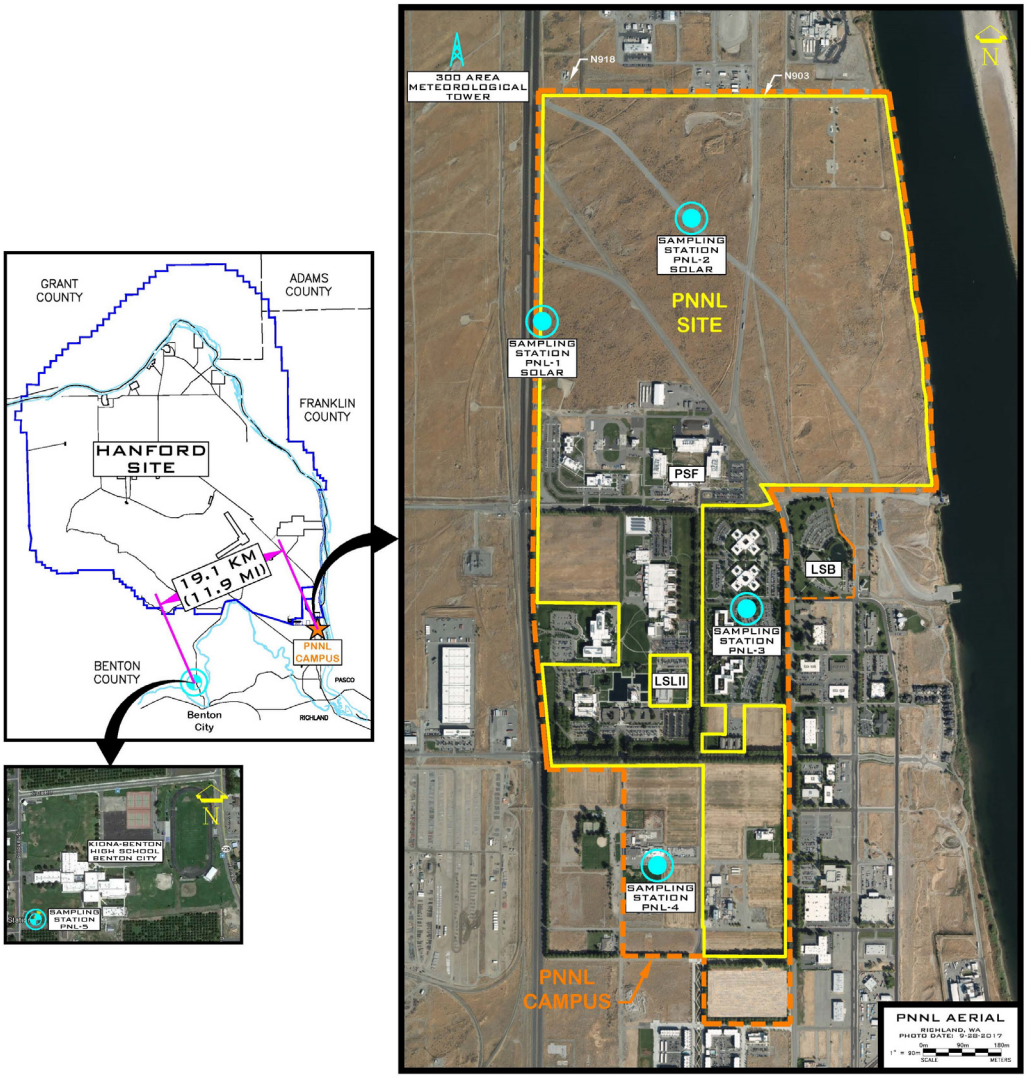


Figure 1. Ambient Air Monitoring Stations for the PNNL Richland Campus

Table 5. PNNL Richland Ambient Air Sampling Station Locations

Station ID	Distance and Direction from 3410 Building	Distance and Direction from 3420 Building	Distance and direction from 3430 Building	Distance and Direction from LSLII	Station Latitude	Station Longitude
PNL-1	720 m NW	620 m NW	590 m NW	1220 m NNW	46° 21' 22.41" N	119° 16' 59.67" W
PNL-2	800 m N	740 m N	840 m N	1525 m N	46° 21' 34.62" N	119° 16' 37.34" W
PNL-3	480 m SSE	570 m SSE	550 m SE or SSE	360 m NE	46° 20' 52.82" N	119° 16' 28.40" W
PNL-4	1310 m S	1380 m S	1280 m S	550 m S	46° 20' 26.14" N	119° 16' 41.92" W
PNL-5	19180 m WSW	19170 m WSW	19000 m WSW	18710 m WSW	46° 21' 49.85" N	119° 17' 12.45" W

2.5 Use of Ambient Dosimetry for Dose Assessment

Ambient external dose surveillance is measured with optically stimulated luminescence (OSL) dosimeters that are placed at each of the five Richland Campus ambient air sampling station locations (Figure 1). The SAP (EMP Attachment 1 [Rev 1]) provides details regarding the system and schedule implemented.

From the first full calendar year of operations, 2017, dosimeters are exchanged quarterly for surveillance of annual ambient external dose rates.

Richland Campus sampling stations were sited to best capture the greatest quantities of site radioactive emissions from air effluent (Snyder et al. 2017). The current PNNL Richland Campus radionuclide emissions are well characterized and administratively managed. No current Richland Campus radionuclide sources or radiation-generating devices are expected to increase direct radiation dose rates above background levels at station locations. Dosimeter results under routine operations report dose from natural sources of radioactive materials and from all regional contributors of radionuclide air emissions. In addition, the non-background dosimeters have the potential to be impacted by sources transported along nearby roadways (Stevens Drive for PNL-1; the reactor haul road for PNL-2; the parking lot for PNL-3; and 6th Street for PNL-4) when sources that are not compliant with U.S. Department of Transportation regulations are transported under roadway restrictions. Such restrictions are very infrequent.

The data were calculated under the assumption that any deeply-penetrating-gamma dose or lead-pig-generated dose detected with the control dosimeter while it was stored in the lead pig during the quarterly deployment period was NOT part of background. Results for ambient external dose are provided in Figure 2. Table 6 indicates the hourly rates detected above background at PNL-1 through PNL-4 for CYs 2017-2018, as well as the average hourly background rate each quarter. The monitoring system results provide an indication of variability.

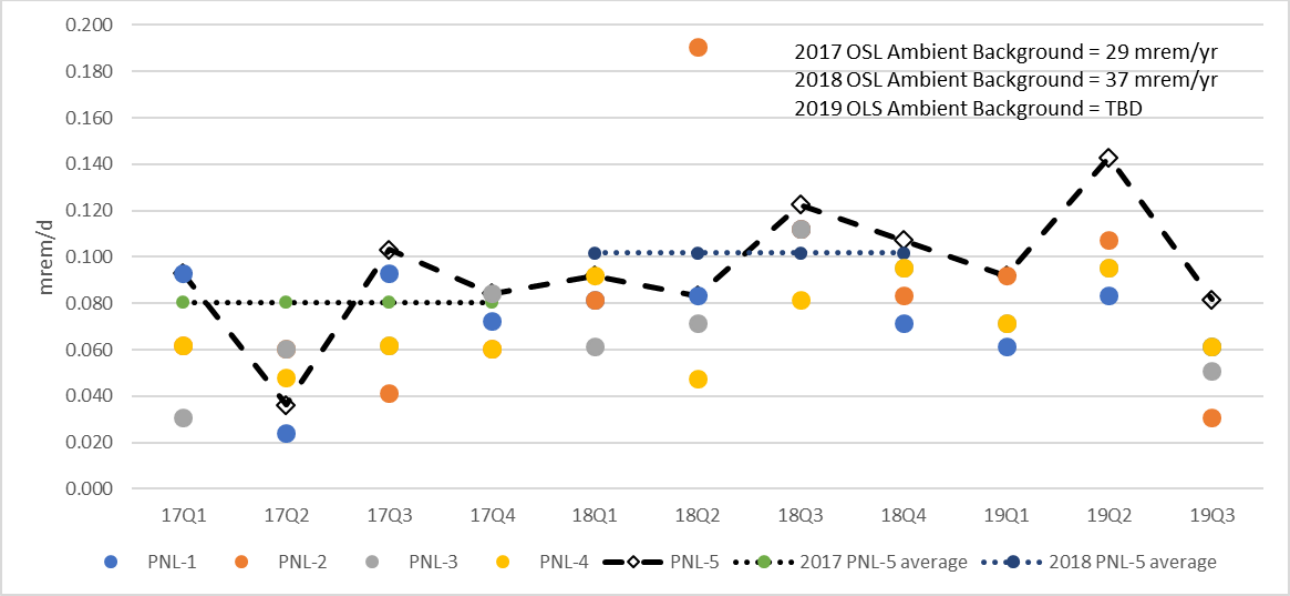
The total annual result at PNL-5 (background) is compared to the other stations, PNL-1 through PNL-4 each year. If on-site results for a specific location exceed the background value, then it is evaluated further. Doses to date are all well below the 100 mrem/yr all-pathways dose limit of DOE Order 458.1.

No potential radioactive material emissions to air at the Richland Campus are a specific concern due to external dose impacts. While ambient external dose results are not required to be included in 40 CFR 61, Subpart H, compliance reporting, the Richland Campus Radioactive Air Emissions Report (e.g., Snyder et al. 2019a) has provided a convenient location to publish dosimeter results. Ambient external dose results may be exclusively reported in the PNNL ASER, in the future.

Results can be reported on:

- an annual basis (mrem/yr) = sum of quarterly results;
- a (deployed) quarterly basis (mrem/quarter);
- a normalized 91-d period [as recommended in ANSI N13.37 (R2019)] basis (mrem/quarter$_{normalized}$);
- an average daily basis (mrem/d$_{deployed}$) (see Figure 2), or
- an average hourly basis (µrem/hr$_{deployed}$) (see Table 6).

Normalizing allows comparisons among other locations or when deployment periods vary at a site. PNNL deployment periods do not vary within a quarter, so a normalized quarterly period is not implemented. However, the lengths of a quarter can vary by about 12 days in a single year, so average daily and hourly data can be informative.



Missing station dots overlap other stations' results, see compliance reports for details.

Figure 2. Quarterly Ambient External Dose and Background Levels (2017–mid-2019)

Table 6. Hourly OSL Ambient Background and Critical Station Rates Above Background Based on Quarterly OSL Monitoring (microrem/hr)

µrem/hr	PNL-1	PNL-2	PNL-3	PNL-4	Back-ground PNL-5	2017 Annual Background Average [a]	2018 Annual Background Average [a]	2019 Annual Background Average
17Q1					3.9	3.3		
17Q2		1.0	1.0	0.5	1.5	3.3		
17Q3					4.3	3.3		
17Q4					3.5	3.3		
18Q1					3.8		4.2	
18Q2		4.5			3.5		4.2	
18Q3					5.1		4.2	
18Q4					4.5		4.2	
19Q1					3.8			TBD
19Q2					6.0			TBD
19Q3					3.4			TBD

(a) Surveillance days in 2017 = 360 d; and 2018 = 364 d.
If no data indicated, the quarterly result was below background.
TBD = to be determined.

3.0 MSL/Sequim Site Dose Assessment Guidance

The MSL/Sequim Site radionuclide releases to ambient air, dispersion and dose model, and the individual and collective dose reporting for 40 CFR 61, Subpart H, reporting are described. Radionuclide emissions to air are the only source of radionuclide releases[4] to the ambient environment, currently, so PNNL Annual Site Environmental Report dose impacts use Subpart H results.

3.1 Radionuclide Releases and Dispersion Modeling

Due to the current, very low emissions rates and fugitive nature of radioactive materials releases at MSL/Sequim Site, doses to individuals are calculated using computer models rather than direct measurements of radionuclide concentrations. The potential for greater health impacts from the potentially larger Richland Campus emissions necessitates the use of a more detailed atmospheric dispersion model for that location compared to MSL/Sequim Site. The lower potential impacts from smaller MSL emissions allows the use of a simpler, more conservative (i.e., over-estimating) dispersion model, COMPLY.

3.1.1 MSL/Sequim Site Radionuclide Releases

Radionuclide release rates and release locations are required to estimate receptor dose. Emissions are determined by PNNL operations staff using the Radioactive Material Tracking System (RMT) and 40 CFR 61, Appendix D methods. Final emissions estimates are provided to the dose assessor in a timely manner, typically in March of each year. Prior to CY2018 emissions' compliance reporting (Snyder and Barnett 2019), all radionuclide releases were assumed to occur from the MSL-5 building. With the implementation of the site-wide licensing of RAEL-014, renewal 1(WDOH 2018), and evaluations described in Snyder et al. 2019b, the emissions are assumed to be released from a Central MSL location (48º 4' 42.45" N, 123º 2' 48.51" W; Google Earth, image date July 30, 2017) at a height of 5 m from a 5 m by 5 m area source.

An alternative method of compliance determination is possible for MSL/Sequim Site if the annual *inventory* of radionuclides (Ci) is below 40 CFR 61, Appendix E, Table 1 radionuclide-specific values. Invoking this compliance reporting method would require prior approval from WDOH. Staff should consider schedule when attempting this simpler reporting option, bearing in mind that use of this method may not be granted.

3.1.2 MSL/Sequim Site Dispersion Modeling

The EPA-approved version of COMPLY model (version 1.7, EPA 1989) is used to demonstrate compliance with the NESHAP and State 10 mrem/yr dose standard. Background information for this code is summarized in Section 1.4.1 of Snyder et al. 2019b.

Exposure parameters used in the COMPLY Level 4 compliance calculations for the MSL/Sequim Site are indicated in Table 7. There are two Level 4 options that could be used

[4] Release of PNNL property having residual radioactive material is discussed in the Annual Site Environmental Report. The property can be released for onsite or public unrestricted use if criteria are met. Rather than dose criteria, these releases of both property, soil, and liquid effluent use authorized limits for surface contamination, soil, and liquids. Authorized limits are established based on appropriate public dose limits.

with the simplest implementation using a default wind speed of 2 m/s. If a more precise receptor dose result is desired, COMPLY Level 4 may be implemented with site-specific wind rose data. Use of the default wind speed (no wind rose) in COMPLY Level 4 will result in a greater dose estimate compared to that resulting from the use of site-specific wind rose data.

Any changes to these inputs will be explained in the NESHAP compliance report. The data needed to perform MSL compliance calculations are documented in the most recent annual compliance report.

Table 7. COMPLY Level 4 Input Parameters for MSL/Sequim

Parameter	Default Value	MEI Option 1 – NWR MSL/Sequim Site	MEI Option 2 – With Meteorological File (2013–17 or current year)
Nuclide Names	none	<varies by year>	<varies by year>
Release Rates (Ci/yr *or* Ci/s)	none	<varies by year>	<varies by year>
Release Height (m)	none	5 m	5m
Building Height (m)	none	5 m	5m
Stack or Vent Diameter (m)	none	NA	NA
Volumetric Flow Rate (m^3/s)	0.3	NA	NA
Distance from Source to Receptor (m)	none	234 m[(a)]	Direction-specific (see Table 4.4 of Snyder et al. 2019b for Central MSL emission)
Building Width (m)	none	30 m	5m
Wind Speed (m/s)	2	2 m/s	<Use wind rose> e.g., see Figure 3
Distances to Sources of Food (m) (m)production	none	234 m[(a)]	NA
Stack Temperature (°F)	55[(b)]	NA, N	NA
Ambient Air Temperature (°F)	55[(b)]	NA	NA
Wind Rose	none	NA(nwr)	Use wind rose data, e.g., see Figure 3
Building Length	none	NA(nwr)	5m

(a) Smallest receptor distance assumed for either MSL-1 or MSL-5 applied to both emission units.
(b) A stack temperature of 72.0°F and ambient air temperature of 50.4°F, based on Washington State University (WSU) monitoring station data, would be more precise. However, the use of 55°F for both parameters reduces dispersion and provides a conservative (overestimating) dose factor result.
NA = not applicable.
nwr = no wind rose.

The site-specific information needed to perform compliance dose calculations for the year of interest at MSL/Sequim Site include radionuclide release rates, receptor location(s), and (if a wind rose is used) meteorological data applicable to the year of interest. These data are used as input to COMPLY version 1.7 code and are documented in the annual compliance report.

The COMPLY code output does not provide a great deal of detail. If all releases are input in a single run, only the total receptor dose will be provided without individual nuclide contributions. Multiple COMPLY cases can be run for individual nuclides.

3.1.2.1 COMPLY Meteorological Data

As a general description, COMPLY uses simplified dispersion models in Level 4. Using the software vernacular, a site-specific "wind rose" can be used, though it is not required. The wind rose of COMPLY is a list of frequencies and average speeds of winds in 16 directions; also the distance from the release point to the meteorological station is indicated. If no wind rose is entered, a default assumption is applied wherein an average (or default) wind speed is entered and the emission is assumed to blow toward a single, indicated receptor 25% of the year. If a wind rose is entered, distances to receptors in each of 16 directions (one receptor in each direction) are entered.

As discussed in Snyder et al. 2019b, meteorological data appropriate for the MSL/Sequim Site is available from a WSU agricultural meteorological monitoring station (AgWeatherNet) located just north of the site (WSU station link, see Weather Data and choose Sequim location). These data are representative of the upland region of the site and are provided in COMPLY format in Figure 3.[5] In addition, Figure 4 is provided to illustrate 5 years of meteorological data from AgWeatherNet monitoring because the MSL meteorological data do not have an extensive historical record published elsewhere.

The AgWeatherNet instrumentation sited at 46.26°latitude/-119.74°longitude provides temperature data over, at least, the range from -35°C–50°C with a 0.2°C tolerance over the range 0–50°C. The anemometer continuously operates over a range of 0–45 m/s (0–100 mph) with an accuracy of 0.11 m/s (0.25 mph) and a starting threshold of 0.45 m/s (1 mph). The wind direction sensor operates from 0–360 degrees with a 5 degree accuracy specification. Rainfall is measured with a tipping bucket gauge that measures 0.2 mm of liquid precipitation for every bucket tip, with an accuracy of 1.0% up to 50 mm/hr (1.97 in/hr). While rainfall is not required in the COMPLY model, it should be indicated in compliance reporting.

```
 WIND ROSE FILE CREATED FROM KEYBOARD.
 WSU Ag Met 2013-17
 2013-2017
 Sequim Met Station-WSU
 1290
 miles/hr
 0.00E-00
 DIR-FROM  FREQUENCY   SPEED
'N  '      6.35E-02    3.26E+00
'NNE'      3.17E-02    3.09E+00
'NE '      3.00E-02    2.83E+00
'ENE'      3.50E-02    2.90E+00
'E  '      3.76E-02    3.06E+00
'ESE'      4.01E-02    4.11E+00
'SE '      5.10E-02    5.46E+00
'SSE'      4.72E-02    3.50E+00
'S  '      5.45E-02    3.21E+00
'SSW'      5.55E-02    2.15E+00
'SW '      6.30E-02    2.19E+00
'WSW'      9.49E-02    2.95E+00
'W  '      1.63E-01    4.56E+00
'WNW'      1.30E-01    4.95E+00
'NW '      5.81E-02    4.05E+00
'NNW'      4.53E-02    3.87E+00
```

Figure 3. COMPLY 1.7.1 2013–2017 Sequim Meteorology File Created by Keyboard Entry in the Code

[5] These data differ from that provided in Snyder et al. 2019b because wind speed instrumentation thresholds were taken into account in the data presented herein.

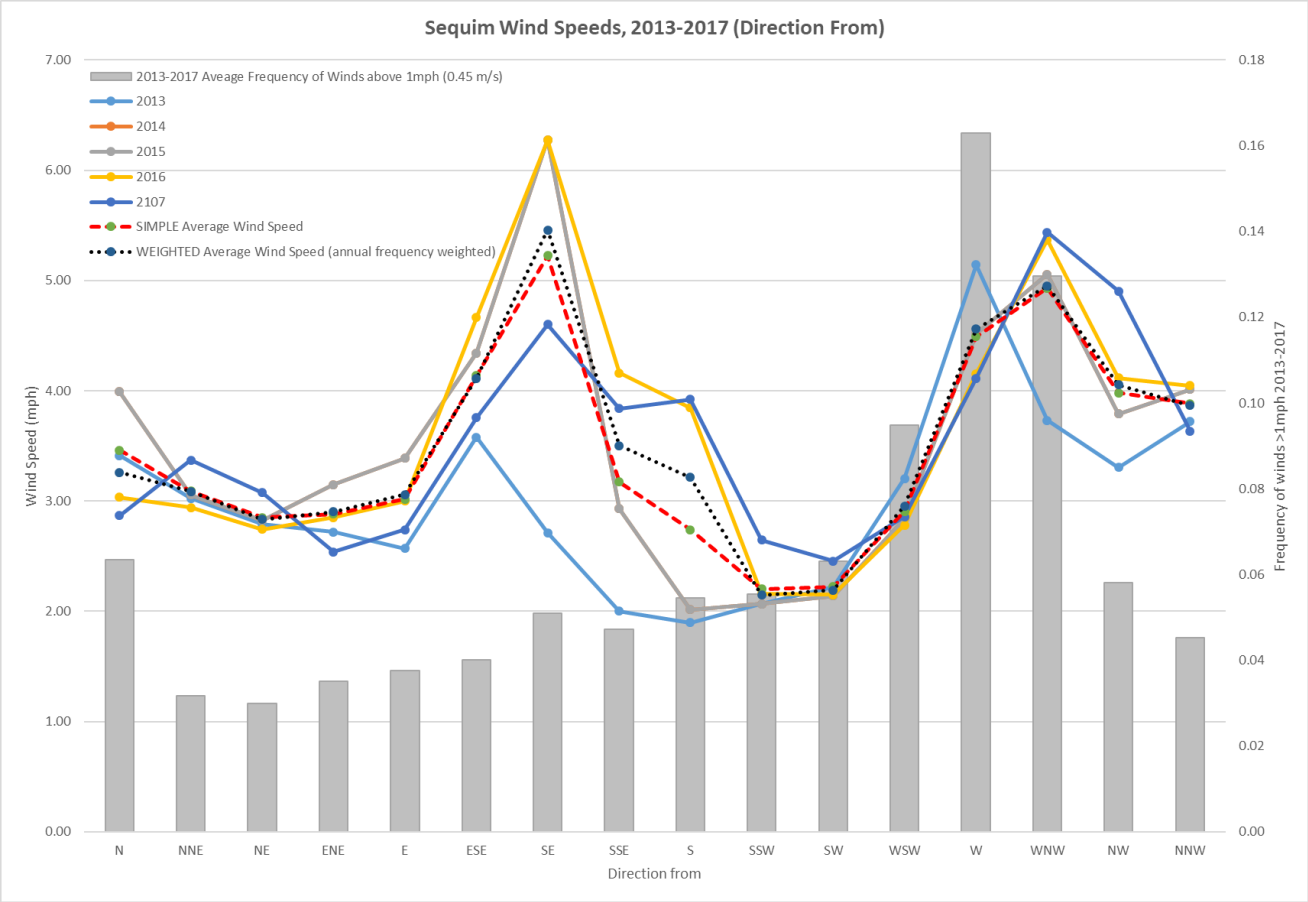


Figure 4. Sequim Meteorological Characteristics 2013-2017.

3.1.2.2 MEI and MA Location Determination

Snyder et al. 2019b provides a thorough discussion of potential MEIs in each of 19 compass directions. For the simpler COMPLY Level 4 approach with no wind rose, only one distance receptor distance is input, the smallest distance from Central MSL to a receptor, 234 m (768 ft) (see Snyder et al. 2019b). Site boundaries that are shoreline locations are not considered to be potential MEI locations for the MSL/Sequim Site. For the more precise result, the distance to the nearest receptor in all 16 directions from Central MSL is input (Table 8; also see Snyder et al. 2019b).

For the MA location, the closest distance to the site boundary is used in the model, whether it is a site shore boundary or not. However, if this closest boundary distance is a shore location, the receptor's food is assumed to grow at an average distance to land boundary locations. For emissions year 2018 compliance reporting, food was assumed to be grown 355 m from the release point, which is the average distance from the release point to all Battelle-land Sequim land boundaries, considering 16 compass directions, as a conservative assumption. This approach for food source locations for the MA is not standardized.

Table 8. Potential MSL/Sequim Site MEI and MA Distances from Central Release Point to the Boundary

Direction from Central MSL	Smallest Distance to a Potential MEI Locations	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 4.9 of Snyder et al. 2019b).
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 Individual Receptor Dose Estimation

The transport of radionuclide emissions from the Central Release location to the receptor(s) is modeled by COMPLY for environmental transport pathways. Two points of individual member of the public exposure evaluated are the MEI and MA locations, which could be the same location. An MA may be on the shoreline, but their food is assumed to be grown only at a land boundary.

Section 3.1.2 discusses receptor parameters, meteorological data, and MEI/MA receptor location determinations. COMPLY can be run with unit releases of each radionuclide emitted for the MEI location. Then spreadsheet calculations are used to link the actual release with the dose factor for the MEI. The prior year's spreadsheet can be updated for the current year's calculation.

A generic alpha nuclide can be substituted for all MSL/Sequim Site alpha activity emissions. The same can be done with a generic beta nuclide. This simplifies the spreadsheet calculations. Am-241 and Cs-137 are selected as the generic nuclides due to their higher-than-typical dose results.

There are two caveats to this generic nuclide approach. First, if the dose is too greatly overestimated, the specific nuclide dose factor can be used; this was done in Snyder and Barnett 2019 for I-125 emissions. Second, if the generic nuclide dose factor underestimates the specific nuclide's dose factor for a nuclide available in COMPLY, the specific nuclide dose factor is used; this was done in Snyder and Barnett 2019 for Th-232 emissions.

For this second caveat, Snyder and Barnett 2016 can be used as a ready reference for initially determining if the specific nuclide dose factor is much greater or lower than would be expected from a COMPLY run. If the dose factors in Snyder and Barnett 2016 are close, the COMPLY nuclide-specific dose factor should be determined. However, COMPLY does not include all radionuclides that are estimated to be emitted at the MSL/Sequim Site. Snyder and Barnett 2016 can be consulted as a check to review if the Cs-137 or Am-241 dose relative to the COMPLY-unavailable nuclide's dose indicates that use of these substituted nuclides are conservative.

Dose basis information for the COMPLY, version 1.7, and as appropriate for Subpart H compliance determinations is summarized. COMPLY version 1.7 uses radiation- and tissue weighting factors consistent with ICRP Publications 26 and 30 (ICRP 1977, 1979-1988) for all exposure pathways evaluated (inhalation, ingestion, and external exposure). Radionuclide transformation information applied in COMPLY is from ICRP Publication 38 (ICRP 1983). COMPLY code doses are reported in units of mrem TEDE.

Reviews of dose results (individual and collective) are based on criteria developed in Schreckhise et al. 1993 and documented using the review checklist in Appendix D of that document and PNNL Information Release reviews.

3.3 Collective Dose Estimation

Collective dose calculations consider the same pathways as those evaluated for an individual. Regulatory dose standards have not been established for collective dose under the DOE Orders, or WDOH and EPA regulations. However, evaluation of the collective doses (expressed in person-rem) to all residents within a declared radius of the site is required by DOE Order 458.1, CRD, paragraph 2.e(1)(d) and DOE 1995. MSL/Sequim Site reports a 50-mi (80-km) collective dose, which includes U.S. and Canada receptors, and represents the summed individual doses for the number of individuals involved for all potential exposure pathways. The pathways assigned to the MEI are also applied to the offsite population. The home-produced vegetables, milk, and meat option is indicated, so that ingestion dose is conservatively assigned.

The MSL collective dose is calculated with a spreadsheet because COMPLY will not calculate a collective dose. Zuljevic et al. (2016) indicate the 50-mi (80 km) population from MSL/Sequim Site based on the 2010 U.S. Census and the 2011 Canada Census. The populations at 10 radii in each of 16 directional sectors from the site are provided in Table 9. Use of the data shown in the figure will provide output that indicates collective dose for sectors with midpoint-distances from the emission point origin of 0.8 km, 2.4 km, 4.0 km, 5.6 km, 7.2 km, 12.05 km, 24.15 km, 40.25 km, 56.35 km, and 72.45 km. These correspond to sectors of 0–1 mi, 1–2 mi, 2–3 mi, 3–4 mi, 4–5 mi, 5–10 mi, 10–20 mi, 20–30 mi, 30–40 mi, and 40–50 mi radii.

As an example, the 234 m MSL MEI (Snyder and Barnett 2019) is located at W radii 1. For this collective dose estimation, the plume is assumed to be released in only one directional sector for the entire year. That sector is determined by the maximum sum of the population-weighted plume dilution value and the MEI dose, regardless of the direction where the MEI is located. The collective dose is determined by calculations that consider a conservative dilution of the source term based on the ever-expanding area of the radial sectors that are populated by individuals in those sectors. All receptors in radii 1 are assumed to incur the MEI dose. Dilution is based on the area in each sector. Total collective dose and Canadian-only maximum collective dose are indicated in compliance reporting. Until the MSL population table is updated, the west sector currently produces the maximum result (U.S. only) and the NNW Canadian sector produces the maximum result for that country.

Table 9. MSL/Sequim Site 50-mi Population Data

Radii (mi)	Direction toward N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0-1	17	8	1	5	0	0	0	1	65	74	83	72	38[a]	70	46	29	**509**
1-2	30	0	0	23	54	10	0	2	127	104	250	474	459	217	110	107	**1,967**
2-3	1	0	0	51	108	102	53	8	22	18	92	468	2,070	938	956	162	**5,049**
3-4	0	0	0	59	151	150	123	12	25	25	50	404	1,838	914	929	103	**4,783**
4-5	0	0	0	51	194	118	40	29	32	32	32	578	1,052	843	572	38	**3,611**
5-10	0	38	285	324	492	579	402	257	264	219	441	1,118	3,087	3,916	1,662	94	**13,178**
10-20	0	895	3,098	9,162	7,014	5,256	1,998	1,016	567	402	384	1,150	23,816	775	0	0	**55,533**
20-30	1,885	1,143	34,786	14,409	12,559	7,997	18,210	2,056	278	267	245	308	5,640	93	8,889	131,546	**240,311**
30-40	7,699	13,453	20,783	19,507	52,020	243,602	65,783	95,217	3,023	304	113	128	1,070	5,029	71,220	102,200	**701,151**
40-50	2,570	6,376	61,843	16,037	142,754	359,840	592,650	87,615	8,354	635	155	151	487	1,570	5,153	36,809	**1,322,999**
Total	**12,202**	**21,913**	**120,796**	**59,628**	**215,346**	**617,654**	**679,259**	**186,213**	**12,757**	**2,080**	**1,845**	**4,851**	**39,557**	**14,365**	**89,537**	**271,088**	**2,349,091**

(a) The current MEI/MA location.
Blue cells are sea locations. Light green cells are partially Canadian. Dark green cells are wholly Canadian.

3.4 Use of Ambient Air Particulate Samples for Dose Assessment

Snyder et al. 2019b, *Data Quality Objectives Supporting Radiological Air Emissions Monitoring for the Marine Sciences Laboratory, Sequim Site*, recommended establishing a single particulate air sampling station at MSL/Sequim, in order to establish baseline background levels of gross alpha and gross beta particulates. This sampling program has not yet been established (as of December 2019). As with the PNNL Richland Campus ambient air sampling, MSL/Sequim Site sampling results would not be used to demonstrate compliance. The initial sampling would be conducted to capture background levels of gross alpha and gross beta.

3.5 Use of Ambient Dosimetry for Dose Assessment

No ambient external dose surveillance is conducted at MSL. However, Snyder et al. 2019b, *Data Quality Objectives Supporting Radiological Air Emissions Monitoring for the Marine Sciences Laboratory, Sequim Site*, recommended establishing several ambient air dosimetry locations, in order to establish baseline background levels of external dose. This environmental dosimetry program has not yet been established (as of December 2019). Once established, it would not be used for public dose impacts from site operations since it would be capturing background levels.

4.0 Biota Dose Assessment – Richland Campus and MSL

The prior sections of this DAG discuss dose assessment to an adult human. DOE Order 458.1 requires the annual assessment of dose impacts to non-human biota. Biota dose assessment evaluates whether DOE site operations may be adversely impacted from radiation and radioactive material releases. Biota dose assessment includes the generic categories: aquatic animals, riparian (riverbank) animals, terrestrial plants, and terrestrial animals. Biota dose guidance followed DOE-STD-1153-2002 (DOE 2002) through CY2018 ASER reporting. In 2019, this guidance was updated in DOE-STD-1153-2019 (DOE 2019). Biota dose is assessed against the daily dose rate standards indicate in the DOE standard (see Table 10).

Table 10. Biota Dose Standards

Biota Category	Biota Dose Standard [(a)]
Aquatic animals	1 rad/d (10 mGy/d)
Terrestrial plants	1 rad/d (10 mGy/d)
Riparian animals	0.1 rad/d (1 mGy/d)
Terrestrial animals	0.1 rad/d (1 mGy/d)

(a) DOE Order 458.1 Chg3 indicates use of Table 2.2 of DOE 2002 dose standards; DOE 2019, Table 1-1, indicates these same dose criteria.

A graded approach is suggested in the DOE standard. Due to the low levels of radioactive material emissions and lack of high radiation sources at the Richland Campus and MSL/Sequim Site, both sites implement the least complex implementation of the standard.

Biota Concentration Guides (BCGs) are provided in the DOE 2019 for aquatic systems (water and sediment evaluations for aquatic and riparian animal assessment) and for terrestrial systems (water and soil evaluations for terrestrial animals and plant assessments). A BCG is the limiting concentration of a radionuclide in soil, sediment, or water that would not cause dose rate criteria for protection of populations of aquatic and terrestrial biota, per DOE 2019, to be exceeded. BCGs are used to demonstrate compliance with the biota dose rate criteria based on the fact that biota dose is a function of the contaminant concentration in the environment and biota dose results from the sum of internal and external contributions

To assess biota dose at the PNNL Richland Campus and MSL/Sequim Site, the calendar year's air emissions are all conservatively assumed to be deposited in soil/sediment or water. Radioactive emissions to the ambient environment only occur via air effluent. Emissions of noble gases would not incorporate into soil, sediment, or water over a long term; no biota dose evaluations are performed for noble gas emissions. For soil/sediment depositions, site particulate and liquid-form emissions are assumed to be mixed into 1 m^3 of soil (density 224 kg/m^2 to a depth of 15 cm (6 in.) (Napier 2006). For water depositions, site particulate and liquid-form emissions are assumed to be mixed in 1 m^3 (35 ft^3) of an ambient non-circulating, waterbody. The resulting nuclide-specific concentrations are evaluated against the BCGs in the standard, with the sum of fractions applied. If the sum of fractions is less than 1, then the standard is not exceeded. Table 11 and Table 12 indicate recent biota dose estimates. Gross alpha and gross beta measurements, assumed to be Ra-226 and Co-60, respectively, are conservatively included.

Table 11. PNNL Richland Campus Biota Dose Trends

Biota Category	Biota Dose Standard [a]	CY2015	CY2016	CY2017	CY2018
Aquatic animals	1 rad/d	<1E-3	<1E-3	<9E-4	<9E-3
Terrestrial plants	1 rad/d	<1E-3	<1E-3	<9E-4	<9E-3
Riparian animals	0.1 rad/d	<1E-2	<1E-2	<8E-3	<8E-2
Terrestrial animals	0.1 rad/d	<1E-2	<1E-2	<8E-3	<8E-2

(a) DOE Order 458.1 Chg3 indicates Table 2.2 of DOE 2002 dose standards; DOE 2019, Table 1-1, indicates these same dose criteria.

Table 12. MSL/Sequim Site Biota Dose Trends

Biota Category	Biota Dose Standard [a]	CY2015	CY2016	CY2017	CY2018
Aquatic animals	1 rad/d	<2E-3	<7E-5	<7E-5	<7E-5
Terrestrial plants	1 rad/d	<2E-3	<7E-5	<7E-5	<7E-5
Riparian animals	0.1 rad/d	<5E-2	<7E-4	<6E-4	<6E-4
Terrestrial animals	0.1 rad/d	<5E-2	<7E-4	<6E-4	<6E-4

(a) DOE Order 458.1 Chg3 indicates Table 2.2 of DOE 2002 dose standards; DOE 2019, Table 1-1, indicates these same dose criteria.

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