Pacific Northwest
NATIONAL LABORATORY

PNNL-20919-3, Rev. 4

EMP, Attachment 3

Dose Assessment Guidance

February 2024

SF Snyder
SK Cooley

U.S. DEPARTMENT OF ENERGY

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

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Pacific Northwest National Laboratory
Richland, Washington 99354

Summary

This Dose Assessment Guidance (DAG) describes methods used to comply with the reporting requirements for dose to an individual member of the public receptor, collective dose, and biota 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, and air permit requirements are the greatest drivers for the requirements. This PNNL DAG applies to public dose from radioactive material releases to the air from the PNNL-Richland campus and PNNL-Sequim campus (formerly indicated as Marine and Coastal Research Laboratory, MCRL) locations. Dose determinations from Richland campus surveillance of ambient external dose and ambient air particulates are also 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.
Rev 2	September 2020	• MSL/Sequim Site is now identified as PNNL Sequim Campus • Trending data for subject areas updated • Biota dose methods updated
Rev 3	September 2021	• PNNL Sequim Campus is now identified as the Marine and Coastal Research Laboratory (MCRL) • PNNL Richland Campus is now identified as PNNL-Richland Campus • LSLII and RTL facility references are removed. LSLII no longer has radiological operations and the RTL facility no longer exists after demolition. • Dose Assessment Review form is included as an Appendix for review of the adult receptor dose assessments. • Trending data for subject areas updated

Rev 4	February 2024	• The adopted nomenclature for MCRL is now PNNL-Sequim campus. • Updated the method for assessing external dose from dosimeter results to consider both the uncertainty in the background location and critical locations. The determination of whether the station dosimeter exceeds background is now statistically evaluated. Trend information for PNNL-Richland Campus is updated and presented for recent years using the new method. • Population data for the 50-mi regions were updated for the PNNL-Richland and Sequim campuses. • Biota dose trends are updated.

Acronyms and Abbreviations

ASER	Annual Site Environmental Report
BCG	Biota Concentration Guide
CAP88-PC	*Clean Air Act* Assessment Package 1988 – Personal Computer
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
HMS	Hanford Meteorological Station (station 21) in the 200 Area
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
PIC-5	potential impact category-5
PNNL	Pacific Northwest National Laboratory
RAGas	PNNL's Radioactive Air Gas Emissions webtool
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
MCRL	Marine and Coastal Research Laboratory
MSL	Marine Sciences Laboratory
PSF	Physical Sciences Facility (including Buildings 3410, 3420, 3425, and 3430)
WSU	Washington State University, Tri-Cities campus

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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 and reporting:

- 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*.

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 PNNL-Sequim campus[2] 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 Hanford Mission Integration Solutions and are not within the scope of this document (see Rhoads et al. 2008).

The State of Washington also regulates operations at both the Richland and Sequim campuses. 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 the Richland and Sequim campuses 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 shoreline (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.

DOE Order 458.1 requires the annual assessment of dose impacts to non-human biota where the 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, sediment) animals, terrestrial plants, and terrestrial animals.

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

[1] The PNNL Campus boundary is indicated in Figure 2 of the EMP (Snyder et al. 2020) including the site of the Laboratory Support Building (LSB) (Building 3350).
[2] The PNNL-Sequim Campus was referred to as MCRL in the prior revision of the DAG. The nomenclature represents terminology adopted in fiscal year 2022.

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.

1.1 Recent Dose Results

Recent PNNL MEI and MA doses from compliance reporting are presented in Table 1 (e.g., Snyder et al. 2021a and Snyder et al. 2021b) and Table 2 present the reported MEI dose for the PNNL Annual Site Environmental Report (e.g., Thompson et al. 2023). The Table 1 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 current PNNL radiological operations on the PNNL-Richland and Sequim campuses only result in potential public exposures as a result of radionuclide emissions to ambient air.

For CY2020 operations, an above-background ambient external beta/gamma dose result was identified at a single PNNL-Richland campus station. While no sources of external dose above background from site operations are anticipated, background variability may result in above-background measurements at surveillance locations. For CY2020 operations, because the above-background result was identified at the station nearest the air-emissions-MEI location, it was assigned as an “Other Pathway” dose to the ASER MEI.

The Richland campus sources emit radionuclides to air from both stack and fugitive emission units. The Sequim campus emits radionuclides to air from only a fugitive emission unit. The fugitive-only emissions at the Sequim campus allow a more conservative (i.e., over-estimating), less precise method to be used for evaluating compliance with the dose standard.

Reported doses for compliance are estimated in a manner such that they are larger than any actual dose incurred by the indicated receptor. Examples of Richland campus CAP88-PC modeling conservatism includes 24/7 occupancy at location; all milk, meat, and vegetable production at location; release height of emission may be lower than actual release; grouped releases model more distant stack location releases; for non-sampled emissions, the estimated radionuclide release rates are greater than actual release rates; PIC-5 dose estimates are greater than dose that would be estimated from actual releases for applicable sources; modeling includes 99 prior years of the reported current-year emissions to consider potential soil build-up; the chemical form and particle size of the radionuclide releases are, in most cases, the most conservative default assumption; and gross alpha and beta radionuclide assumptions are conservative. For COMPLY modeling used at the Sequim campus, examples include assuming the receptor produces their own vegetables, milk, and meat at home; when applied, the wind blows in the direction of the receptor 25% of the time for no wind rose entry; when applied, the default wind speed assumption is conservative; and gross alpha/beta radionuclide assumptions are conservative. For COMPLY modeling of 2020 emissions, wind rose information was used for the first time to estimate dose more precisely.

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				
2018	1.8E-05	2.1E-05	CAP88-PC	PNNL-20436-9
2019	1.5E-05	(a)	CAP88-PC	PNNL-20436-10
2020	1.7E-05	2.1E-05	CAP88-PC	PNNL-20436-11
2021	1.8E-05	2.1E-05	CAP88-PC	PNNL-20436-12
2022	2.3E-05	(a)	CAP88-PC	PNNL-20436-13
PNNL-Sequim Campus(b)				
2018	4.5E-04	1.0 E-03	COMPLY	PNNL-22342-7
2019	2.8E-04	7.8 E-04	COMPLY	PNNL-22342-8
2020	3.5E-05	4.0E-04	COMPLY	PNNL-22342-9
2021	5.4E-05	6.4E-04	COMPLY	PNNL-22342-10
2022	7.5E-07	9.3E-06	COMPLY	PNNL-22342-11

(a) See MEI dose, MEI and MA receptor are at the same location.
(b) Historic site names have included Marine Sciences Laboratory, Sequim Site, and Sequim Campus.

Table 2. Annual Site Environmental Report MEI Dose Summary for Recent Years (mrem/yr)

Year	Air Pathway (mrem/yr EDE)	Water Pathway (mrem/yr EDE)	Other Pathway (mrem/yr EDE)	Total (mrem/yr EDE)	Report
PNNL-Richland Campus					
2018	1.8E-05	0	-	1.8E-05	PNNL-29068
2019	1.5E-05	0	-	1.5E-05	PNNL-30262
2020	1.7E-05	0	3(a)	3	PNNL-31853
2021	1.8E-05	0	-	1.8E-05	PNNL-33213
2022	2.3E-05	0	-	2.3E-05	PNNL-34638
PNNL-Sequim Campus (b)					
2018	4.5E-04	0	-	4.5E-04	PNNL-29068
2019	2.8E-04	0	-	2.8E-04	PNNL-30262
2020	3.5E-05	0	-	3.5E-05	PNNL-31853
2021	5.4E-05	0	-	5.4E-05	PNNL-33213
2022	7.5E-07	0	-	7.5E-07	PNNL-34638

(a) Dose conservatively assigned from above-background ambient dosimetry result nearest the MEI location.
(b) Historic site names have included Marine Sciences Laboratory, Sequim Site, MCRL, and Sequim Campus.

1.2 Requirements

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, DOE Order 458.1, and DOE Order 231.1B. 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. DOE Order 458.1, CRD (2.b) indicates an all-pathways dose limit of 100 mrem/yr for a member of the public. 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 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. 2021b), 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, renewal 2) (WDOH 2020)

  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.

  RAEL section 2.3.2 (5) indicates that environmental measurements at critical locations may be used to demonstrate compliance with the standard. PNNL will report to the WDOH when an annual radionuclide-specific ambient air sample concentration meets or exceeds the 40 CFR 61, Appendix E, Table 2 value or when detection limits exceed 10% of the values.

  Though not specifically indicated in the license, reporting is done for the offsite location of maximum radioactive air concentrations ("MA location") resulting from stack emissions and the calculation of dose to a receptor at that location, whether that location is occupied by a member of the public or not.

- PNNL-Sequim Campus Radioactive Air Emissions License (RAEL-014, renewal 2) (WDOH 2022)

  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.

  Though not specifically indicated in the license, reporting is done for the offsite location of maximum radioactive air concentrations ("MA location") resulting from stack emissions and the calculation of dose to a receptor at that location, whether that location is occupied by a member of the public or not.

- DOE Order 458.1 Chg 4, *Radiation Protection of the Public and the Environment*[3]

  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), exceeding any limit or failing to meet any other requirement specified, or any other legal or applicable limits;

[3] This complete Order is not included in full in the current PNNL Site contract (November 21, 2023). However, application of some of its requirements herein is done as a good business practice.

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, which is reported in the ASER.

- 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. These emission units are identified in the site RAELs.

- 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

In addition to the requirements listed above, guidance for Subpart H is provided in DOE 2020 and guidance specifically for DOE Order 458.1 is provided in DOE 2022. Guidance for Annual Site Environmental Reports have been provided annually from the Office of Environment, Health Safety and Security (e.g., https://www.energy.gov/ehss/doe-annual-site-environmental-reports-aser).

1.3 Documentation of Dose Assessment Review

Once the dose assessment for human receptors is completed, the dose assessment is reviewed. A dose assessment involves compiling appropriate receptor, emission, meteorological input, environmental dispersion and dose estimation code input and output, and reporting results against the appropriate criteria. While individual parts of the dose assessment input data may use the EPRP-ADMIN-014 Single-use or Multiple use review forms, it is recommended that the compilation of the various pieces use the review form located in Appendix A of this report. This review form should be initially prepared by the dose assessor and completed by a trained dose assessment reviewer.

2.0 PNNL-Richland Campus Dose Assessment Guidance

The PNNL-Richland 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.[4]

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 relying on 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 of radioactive material emissions to ambient air and estimate receptor dose. The potential for greater health impacts from Richland campus emissions necessitates the use of a more detailed atmospheric dispersion modeling than that used for the Sequim campus.

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 2021. Annual release rates could be determined by continuous stack sampling, periodic sampling, RAGas 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, as 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, for example, if release heights are assigned different values. Release rates from stack sampling are entered in the dose calculation spreadsheet as reported. The list of radionuclide release rates calculated by Appendix D methods can be lengthy.

[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.

2.1.2 Richland Campus Dispersion Modeling

An EPA-approved version of the CAP88-PC software (version 4.0, Rosnick 2014) is used to demonstrate compliance with the Subpart H and Washington State 10 mrem/yr dose standard. Receptor exposure parameters used in CAP88-PC v4.0 compliance calculations for the PNNL-Richland campus MEI are typically default values (Table 3). 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. These data are used as input to the CAP88-PC v4.0 code and are documented in the annual compliance report.

An updated version of CAP88-PC (version 4.1, EPA and TEA 2019) became available for use in 2020 (Federal Register 2020). This version may be used for future dose assessments. This newer version updates the dose conversion factors for a number of existing and newly available radionuclides.

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.

Prior to running compliance determination cases, the code is quality-checked for proper operation. This is accomplished by running the MODTEST case supplied with CAP88-PC and by running one case with numerous nuclide emissions from the previous year's compliance runs. Output from each of these cases is reviewed against expected results.

Table 3. CAP88-PC Version 4.0 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	Google Maps used for distance and direction determinations.
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
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 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 4. 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	735 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	750 m	Stevens Dr	730 m	Stevens Dr	590 m	Stevens Dr
WSW	655 m	Stevens Dr	560 m	Stevens Dr & HRRd	430 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	760 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 6 for distances from PSF buildings to sampling stations.

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.

Meteorological data (300 Area Station 11) is processed using formatted data from Hanford Site meteorological staff. The Hanford Site data format is that of an older DOS code, GENII v1.485 (Napier 1988). A PNNL desk instruction (DI-AIR-003) is used to further format the data as required for CAP88-PC v4.0.

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. The process is generally described as follows. Assuming no significant new emission sources are now operational in the new year of evaluation, the effective release heights of the sampled (PSF) stacks are determined using the "Effective Stack Release Height Calculation Version 1.0 worksheet" spreadsheet. Fugitive and diffuse emissions at PNNL would assume a release height of 10 m.

Based on the evaluation of Snyder et al. 2024, the mid-sector distances from each PSF facility to the PNNL campus boundary are indicated in Table 4. These distances provide a starting point for MEI (and later MA) determinations. If sources and emissions have not changed significantly from the prior year, the prior year's locations provide an efficient starting point. The significant emission source file is copied from the prior evaluation year to a new CAP88-PC dataset (e.g., loc-new.dat). The MEI receptor location in that file is noted and the distances in the Population tab are changed to read the same MEI distance with several added distances incremented 20 meters smaller and larger. Then, a 1-Ci-release case of H-3 (gas), Pu-239 (M), and I-129 (F) is run with the new meteorology (new file with its associated precipitation and temperature).

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

Finally, if there are more significant gas or iodine emissions for the current calendar year, these are additionally considered. The analyst would 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.

While the MEI dose in most recent years has been predominantly from sampled emission units, spreadsheet calculations may indicate that fugitive/diffuse sources may impact a different

potential MEI location to a greater extent. Such an instance occurred in 2020, during COVID-19 reduced site operations.

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 campus radiological facilities. PNNL facilities are proximately located next to different boundaries. Therefore, transport analyses may be 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 discussed 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 pre-determined 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 its progeny. When determining unit-release dose factors, 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 organize and 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. 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 may be modeled separately because they are regulated by WDOH but not included in Subpart H regulations.

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 Richland 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.

Compliance reports summarize information from the CAP88-PC, version 4.0 cases, and appropriate Subpart H compliance information. Dose quantities are reported in units of mrem/yr for individuals to be consistent with the regulatory standard, which is indicated in non-SI units. Units of person-rem are reported for collective dose.

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 internal and external dose factors from DCF-PAK 2.2 (Eckerman and Leggett 2008) with 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). CAP88-PC v4.0 indicates dose in terms of mrem organ dose and TEDE. For external exposure dose factor calculation DCF-PAK 2.2 is based on models of Federal Guidance Report No. 12 (FGR12) (EPA 1993) for adults and updated nuclear decay data of ICPR Publication 107. External dose is indicated in CAP88-PC v4.0 output in terms of mrem/yr 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 and terminology.

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

Radioactive air emissions 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, nor WDOH and EPA regulations. However, evaluation of the collective doses (expressed in person-rem/yr) 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 ”regional” food option is assigned for collective dose estimation. No PIC-5 doses are assigned for collective dose estimation because these doses are administratively assigned from site-wide activities with very little to no potential radionuclide emissions.

The 80-km population distribution for the campus collective dose calculations uses 2020 U.S. Census data (Rose et al. 2023). 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.

The Richland campus population data for 2020 Census results is shown in Table 5, with a total of 605,419 people within the 80-km (50-mile) radius of the campus (Rose et al. 2023). 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 5. 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	0	196	196	239	288	217	146	21	21	11	0	0	0	0	**1,335**
1-2	0	73	222	417	302	252	413	654	1,313	37	10	10	0	0	0	0	**3,703**
2-3	0	171	385	340	166	424	425	2,228	5,362	362	2,217	863	0	0	0	0	**12,943**
3-4	19	118	351	332	313	156	296	845	9,321	1,191	2,663	1,132	5	0	0	0	**16,742**
4-5	30	124	314	297	162	131	313	1,447	8,655	2,884	2,356	223	21	0	0	0	**16,957**
5-10	191	442	712	690	415	989	34,271	26,603	36,420	14,491	13,155	2,632	932	388	0	0	**132,331**
10-20	849	2,744	1,006	694	338	1,429	55,682	69,680	12,881	4,013	3,042	7,932	640	34	0	100	**161,064**
20-30	2,681	1,715	6,297	140	1,149	412	836	69	4,449	332	189	19,787	1,727	146	54	26	**40,009**
30-40	15,921	998	2,743	338	170	512	1,219	336	36,782	5,041	168	12,896	26,709	539	7,760	1,423	**113,555**
40-50	2,750	3,194	168	92	659	54,765	5,820	437	1,440	4,905	383	265	24,613	845	1,842	4,602	**106,780**
Total	**22,441**	**9,579**	**12,198**	**3,536**	**3,870**	**59,309**	**99,563**	**102,516**	**116,769**	**33,277**	**24,204**	**45,751**	**54,647**	**1,952**	**9,656**	**6,151**	**605,419**

To convert from mi to km, multiply by 1.609.

2.4 Ambient Air Particulate Samples for Dose Assessment

Environmental surveillance of radionuclides (particulates, only) in ambient air is performed at the PNNL-Richland campus. Richland campus sampling stations were sited to best capture the greatest quantities of site radioactive emissions from air effluent (Snyder et al. 2017). Several stations (PNL-2 and PNL-3) are due to be relocated (Snyder et al. 2024). The current PNL-2 is no longer situated at a boundary location due to land acquisition. 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 ambient air stations sample for site emissions within and along the perimeter of the PNNL-Richland campus and at a background station located in Benton City, WA (see Figure 1). Table 6 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 gross alpha/beta and 6-mo composites for specific radionuclides) are provided in the Sampling and Analysis Plan (SAP). While sampling results are not used to demonstrate NESHAP compliance under normal operations, annual compliance reporting will typically state whether average annual radionuclide-specific sampling results exceed a sum-of-fractions of 1.0, when applying nuclide-specific values in 40 CFR 61, Appendix E, Table 2. Also, comments are provided regarding how all average annual sample results compare to background. Doses from routine ambient air sample results are not typically reported. However, if reported, dose should only be estimated for radionuclide-specific results, not from gross alpha and gross beta analyses.

If a dose estimate from ambient sampling is requested, the following method is recommended to estimate dose from particulate sample analyses. The CAP88-PC 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 of modeled and sampled station air could substantiate the releases estimated by the Environmental Radiation Task staff 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 suspect sampling result is indicated in the Data Management Plan (DMP).

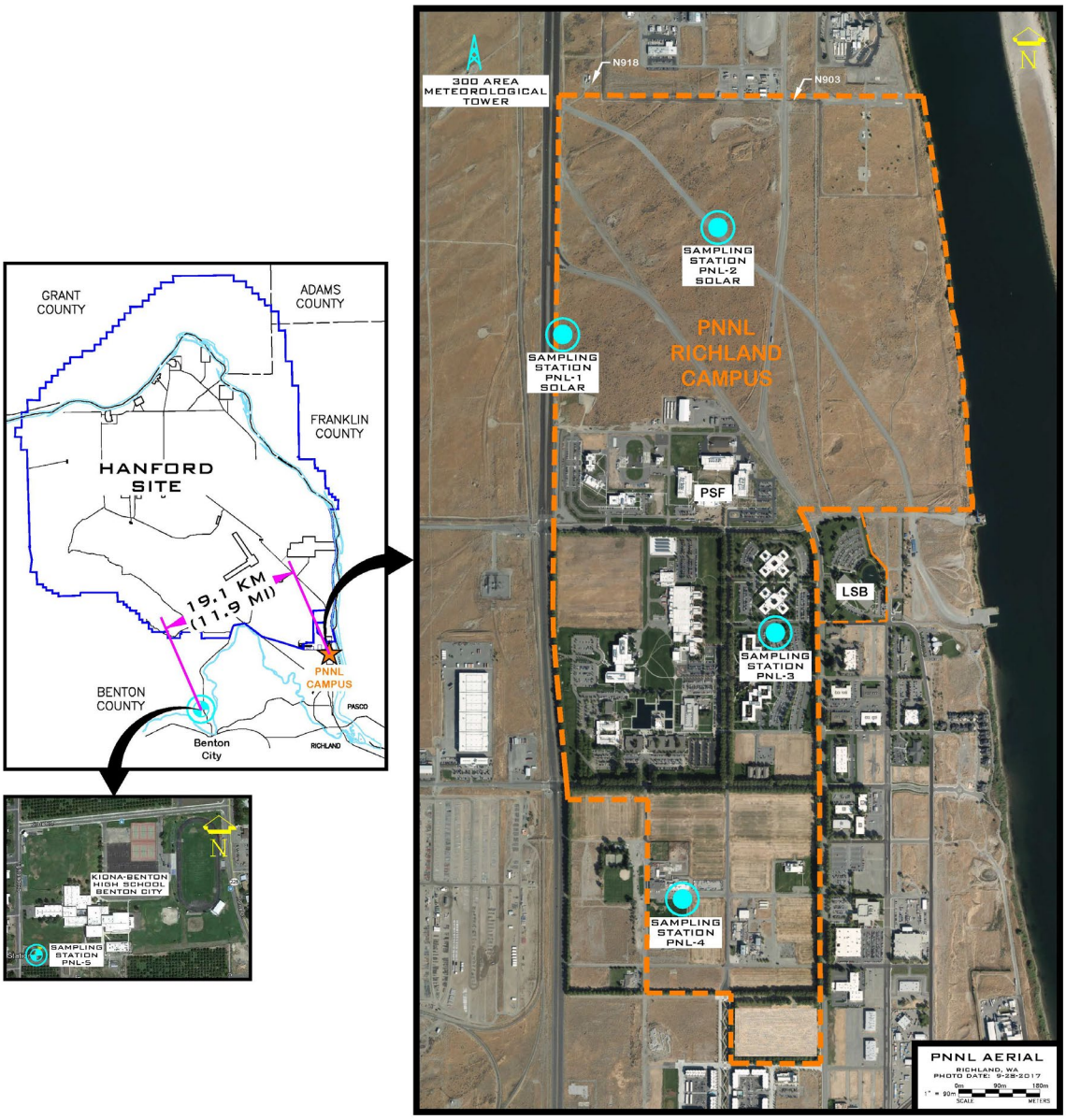


Figure 1. Ambient Air Monitoring Stations for the PNNL-Richland Campus

Table 6. PNNL-Richland Campus 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	Station Latitude	Station Longitude
PNL-1	720 m NW	620 m NW	595 m NW	46° 21' 22.41" N	119° 16' 59.67" W
PNL-2	800 m N	740 m N	800 m N	46° 21' 34.62" N	119° 16' 37.34" W
PNL-3	480 m SSE	570 m SSE	555 m SE or SSE	46° 20' 52.82" N	119° 16' 28.40" W
PNL-4	1310 m S	1380 m S	1313 m S	46° 20' 26.14" N	119° 16' 41.92" W
PNL-5	19180 m WSW	19170 m WSW	19000 m WSW	46° 16' 32.68" N	119° 29' 56.87" W

2.5 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. Dosimeter results are reported in mrem. Each sample result has an uncertainty of 12%.

2.5.1 Ambient Dosimetry 2023

Richland campus sampling stations were sited to best capture the greatest quantities of site radioactive emissions from air effluent (Snyder et al. 2017). Station siting decisions may be reviewed using a data quality objective (DQO) process for significant emission unit changes (operational modifications or number) or station geography impacts. In 2024, a DQO revision was completed (Snyder et al. 2024) due to upcoming construction project impacts to some station locations. 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. As a result, dosimeter results are reported only in the PNNL Annual Site Environmental Report (ASER). If radioactive material emissions to air during routine operations or an unplanned event resulted in a detectable external dose above background, dosimeter results would be reported in the Subpart H report. .

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). Examples include when transiting source configurations are either not compliant with U.S. Department of Transportation regulations or sources are being transported under roadway restrictions. Such restrictions are very infrequent. Routine source transports would not be expected to register on these ambient dosimeters.

In addition to sampling location monitoring, two control dosimeters are included for each sampling period. Both will measure dose received during transit between PNNL and current service provider, Landauer[5], and will remain in the lead pig while station monitors are deployed. The second (PNL-T) will make the round trip during initial deployment of new dosimeters then be returned to the lead pig. Sampling station external dose data were calculated under the assumption that any deeply-penetrating-gamma dose or lead-pig-generated dose detected with the control (and transit) dosimeter while in the lead pig storage was NOT part of background. The actual ambient external background dose at the PNNL-Richland campus is unavailable due to the lack of lead-pig-generated dose to the control. This does not impact the determination of ambient external dose above background at critical stations because a lead-pig dose contribution is uniformly assessed to all background (PNL-5) and critical dosimeters.

Ambient external doses to date are all well below the 100 mrem/yr all-pathways dose limit of DOE Order 458.1. The 2018–2022 ambient external dose results are provided in Table 7, Table 8, and Figure 2. Table 7 indicates results normalized to a 91-day quarter. A new analytical method is used, starting with 2022 reporting to evaluate whether critical station results are

[5] Landauer, 2 Science Rd, Glenwood, IL 60425-1586. www.landauer.com.

above background (PNL-5 station). The new method (see Section 2.5.2)considers the uncertainty in dosimeter results in a more precise manner. This calculational improvement would consequently indicate that the elevated PNL-3 result in 2020 (Duncan et al. 2021) was within the uncertainty of the background measurement of PNL-5. Table 8 indicates the average hourly background rates. The monitoring system results provide an indication of variability. Figure 2 graphically indicates average daily dose rates per quarter at each sampling station.

When reviewing total annual doses from 2018–2022, the delta for critical station values ranged from 6–14 mrem within a year; a critical station value varied as much as 22 mrem over all the years; and the PNL-5 background value varied as much as 8 mrem over this same time period.

No potential radioactive material emissions to air at the Richland campus are a specific concern due to external dose impacts. Ambient external dose results are reported in the PNNL ASER starting with the CY2019 reporting. Prior to that, they were published in the Subpart H compliance report.

Results can be reported on:

- an annual basis (mrem/yr) = sum of quarterly results, either sum of raw data or sum of normalized quarter data;
- a (deployed) quarterly basis (“raw data”) (mrem/quarter);
- a normalized 91-d period [as recommended in ANSI N13.37 (R2019)] basis ($mrem/quarter_{normalized}$) (see Table 7);
- an annual average hourly basis ($\mu rem/hr_{deployed}$) (see Table 8); or
- an average daily basis ($mrem/d_{deployed}$) (see Figure 2).

Normalizing might allow comparisons among other locations or when deployment periods vary at a site. PNNL deployment periods vary from one quarter to the next, so a normalized quarterly period is preferred. Quarterly deployments can vary by about 12 days.

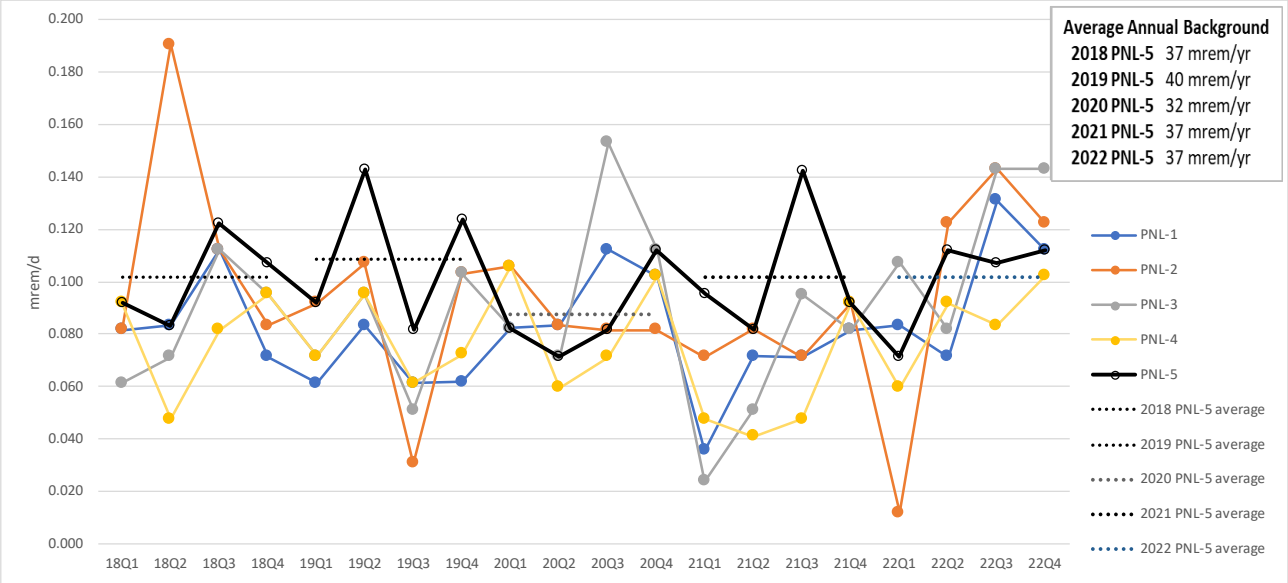
Table 7. Trends in Quarterly (91-d normalized) OSL Ambient Background and Critical Station Rates (mrem/Quarter)

Calendar Year	mrem/Q	PNL-1	PNL-2	PNL-3	PNL-4	PNL-5
2018	Q1	7.4	7.4	5.6	8.4	**8.4**
	Q2	7.6	17.3	6.5	4.3	**7.6**
	Q3	10.2	10.2	10.2	7.4	**11.1**
	Q4	6.5	7.6	8.7	8.7	**9.7**
	2018 TOTAL (mrem/yr)	**32**	**43**	**31**	**29**	**37**
2019	Q1	5.6	8.4	6.5	6.5	**8.4**
	Q2	7.6	9.7	8.7	8.7	**13.0**
	Q3	5.6	2.8	4.6	5.6	**7.4**
	Q4	5.6	9.4	9.4	6.6	**11.3**
	2019 TOTAL (mrem/yr)	**24**	**30**	**29**	**27**	**40**
2020	Q1	7.5	9.6	7.5	9.6	**7.5**
	Q2	7.6	7.6	6.5	5.4	**6.5**
	Q3	10.2	7.4	13.9	6.5	**7.4**
	Q4	9.3	7.4	10.2	9.3	**10.2**
	2020 TOTAL (mrem/yr)	**35**	**32**	**38**	**31**	**32**
2021	Q1	3.3	6.5	2.2	4.3	**8.7**
	Q2	6.5	7.4	4.7	3.7	**7.4**
	Q3	6.5	6.5	8.6	4.3	**13.0**
	Q4	7.4	8.4	7.4	8.4	**8.3**
	2021 TOTAL (mrem/yr)	**24**	**29**	**23**	**21**	**37**
2022	Q1	7.6	1.1	9.8	5.4	**6.5**
	Q2	6.5	11.1	7.4	8.4	**10.2**
	Q3	11.9	13.0	13.0	7.6	**9.8**
	Q4	10.2	11.1	13.0	9.3	**10.2**
	2022 TOTAL (mrem/yr)	**36**	**36**	**43**	**31**	**37**

PNL-1 through PNL-4 include station background.

Table 8. Trends in Average Hourly Dose Rates Based on Quarterly OSL Monitoring (µrem/hr)

Annual average µrem/hr	PNL-1	PNL-2	PNL-3	PNL-4	Background PNL-5
2018	**3.6**	**4.9**	**3.5**	**3.3**	**4.2**
2019	**2.8**	**3.5**	**3.3**	**3.1**	**4.6**
2020	**4.0**	**3.7**	**4.4**	**3.5**	**3.6**
2021	**2.7**	**3.3**	**2.6**	**2.4**	**4.3**
2022	**4.1**	**4.2**	**4.9**	**3.5**	**4.2**



Missing station dots overlap other stations' results, see compliance reports or ASERs for details.[6] PNL-1 to PNL-4 results include background.

Figure 2. Quarterly Ambient External Dose and Background Levels (2018–2022) (mrem/d)

2.5.2 Ambient Dosimeter Data Evaluation

Beginning with CY23 operations reporting, the method used to determine whether a critical station result was above background was updated. A statistical approach is to be used to determine if the critical station annual external dose result is above the background station annual result, with 95% confidence.

While it hasn't happened to date (DEC 2023), there may be a case where a dosimeter is missing or damaged prior to processing. In these cases, it is recommended that the dosimeter value be replaced with the most recent 5-year average annual value for that station location. Document any issue resolution in project records.

Surveillance of ambient air external dose is done quarterly via optically-stimulated luminescence (OSL) dosimetry. The vendor provides dose results as an integer mrem, with no indicated uncertainty. The vendor indicates a 95% uncertainty level (2 standard deviations [SD]) of reported results are 12%. That is, according to the vendor, 2 relative standard deviations (2 RSDs) are 12% of reported values. This implies that the RSD, describing uncertainty in reported values (1 SD) can be assumed to be 0.06 (i.e., 6%), where the denominator in the following RSD expression is typically a mean value but could also be a specified nominal value:

$$1\ RSD = 0.06 = \frac{SD(reported\ values)}{reported\ values}$$

To determine whether the ambient air external dose (mrem/yr) at each critical sampling station (PNL-1 through PNL-4) is above that of the background station (PNL-5), the following process is used. The method considers the uncertainty in each dosimeter sample result. The uncertainty in

[6] Annual background dose can differ from previous revision because current revision sums 91-d normalized quarter results to calculate annual average value.

the control dosimeter result (dose incurred during transit to and from the dosimeter provider) can also be considered in the calculations (see details in Equ. 8). Finally, to determine whether critical station results are above or are equal to or less than background, the difference between the background result (PNL-5) and critical station results are evaluated using a 95% confidence level.

The OSL results are evaluated by calendar year. First the control dosimeter results are subtracted from the critical station dosimeter result. For the PNNL surveillance program, there are two control dosimeter values to consider, PNL-CONTROL and PNL-T.

- PNL-CONTROL is the classically defined control dosimeter for each quarterly shipment of dosimeters. The PNL-CONTROL result indicates exposure during transit to and from the vendor, only. The PNL-CONTROL is stored in a lead pig while the quarterly dosimeters are monitoring the ambient environment. The vendor (Landauer[7]) is instructed NOT to subtract the PNL-CONTROL result from the other quarterly results reported.
- PNL-T is the additional control dosimeter, based on a modified application of the ANSI/HPS N13.37 (2019) standard. The most recently received PNL-T ("T" for transit) dosimeter travels with the technician when the dosimeters are exchanged, then after all exchanges are made it is placed in the lead pig with the PNL-CONTROL until that quarterly round of dosimeters are sent back to Landauer for analysis.
  Modified application of ANSI/HPS N13.37 standard explained: The PNL-T purpose, per ANSI/HPS N13.37 (2019), is to measure any significant dose during transit from the lead pig location to the sampling location. However, once the dosimeter is dropped at the sampling station, PNL-T remains in transit as the other sampling station dosimeters are exchanged, then it also transits back to the lead pig. Any elevated PNL-T result is effectively assumed to occur between the technician pickup of all dosimeters and exchanging a dosimeter at its station. Under this adopted practice, there is no accounting for any transit dose incurred at the end of the quarterly sampling period, for dosimeters sampled during the quarter.

Commonly differing by up to plus or minus 2 mrem, the variability in the PNL-CONTROL and PNL-T values may be higher than anticipated. This is believed to result because of the low dose rate incurred in the PNNL ambient environment. Therefore, the practice has been adopted to only assign the PNL-T dose as the control dose (C_q in Equ. 1) if the quarterly PNL-T result is more than 2 mrem above the PNL-CONTROL result.

Calculations:

$$R_q = D_q[X_q - C_q] \qquad \text{Equ. 1}$$

where

R_q= Resultant (reported) dose for a station for quarter q, with the control dosimeter result (C) subtracted (mrem/quarter).

D_q= Fraction of days for each quarter (either: d/d=**1.0** [using actual number of sampled days (d)] or **91/d** [91-d normalized quarter divided by d])

[7] Landauer, 2 Science Rd, Glenwood, Illinois 60425-1586; https://ww.landauer.com.

X_q= reported sample result for a station for quarter q (mrem/quarter)

C_q= reported Control badge dose for quarter q (mrem/quarter). This is PNL-Control result unless the PNL-T value for the quarter is more than 2 mrem above the PNL-Control value for the quarter, then the PNL-T value is used.

Summing all R_q for a single station indicates the annual ambient air external dose (R) for the year (mrem/yr) (Equ. 2).

$$R = \sum_{q=1}^{4} R_q \qquad \text{Equ. 2}$$

The variance (Equ. 3) of the annual station dose is the sum of the variance from each quarterly dose. The standard deviation (Equ. 4) is also indicated.

Variance

$$V(R) = \sum_{q=1}^{4} V(R_q) \qquad \text{Equ. 3}$$

Standard Deviation

$$SD(R) = \sqrt{V(R)} = \sqrt{\sum_{q=1}^{4} V(R_q)} \qquad \text{Equ. 4}$$

where

V(R) = total variance of the annual ambient air external dose for a station, and

SD(R) = standard deviation of the annual ambient air external dose for a station.

From Equ. 1 with D_q viewed as a constant when each quarterly result is considered, the variance of the quarterly results is represented in Equ. 5.

$$V(R_q) = D_q^2[V(X_q) + V(C_q)] \qquad \text{Equ. 5}$$

Returning to the assumption that the RSD of reported values is 0.06, Equ. 6 and Equ. 7, describe the SD and variance of the quarterly dosimeter results.

Station dosimeter RSD and SD

$$RSD(X_q) = \frac{SD(X_q)}{X_q} = 0.06$$

$$SD(X_q) = 0.06 \cdot X_q \qquad \text{Equ. 6}$$

Station dosimeter Variance

$$V(X_q) = (0.06 \cdot X_q)^2 \qquad \text{Equ. 7}$$

The assessor considers whether values of the Control dosimeter (C_q) should be viewed as constants (RSD=0) or as having some uncertainty (RSD >0). Equ. 8 represents this

consideration in a similar manner to Equ. 6. The equation for the Control dosimeter variance is similar to that of the station dosimeter results (see Equ. 7 and Equ. 9).

Control dosimeter RSD and SD assignment.

$$RSD(C_q) = \frac{SD(C_q)}{C_q} = b \qquad \text{Equ. 8}$$

$$SD(C_q) = b \cdot C_q$$

Control dosimeter variance

$$V(C_q) = (b \cdot C_q)^2 \qquad \text{Equ. 9}$$

where

b = assumed RSD = 0.06 (=6%) or 0 (=where the uncertainty in the control dosimeter value is disregarded).

Then, when Equ. 7 and Equ. 9**.** terms are substituted into Equ. 5, the combined variances of the sampling station (i.e.,PNL-1 through PNL-5) and control dosimeter is indicated in Equ. 10.

$$V(R_q) = D_q^2 \left[(0.06 \cdot X_q)^2 + (b \cdot C_q)^2 \right] \qquad \text{Equ. 10}$$

For the final step, the user determines whether the annual critical station result (stations PNL-1 through -4; mrem/yr) differs from the annual background station result (PNL-5) (Equ. 11). This determination considers the uncertainty in the reported annual dose results, rather than simply using the best estimate reported by the analytical laboratory alone. To assess the statistical significance of the difference of the Equ. 11 term, a confidence interval on this difference is used (Equ. 12). If the upper and lower limits from Equ. 12 are both above 0 or both below 0, then the dosage for the particular station and the control station is considered to be statistically significant (either, well above or below background). If one limit from Equ. 12 is positive and the other is negative, then the result at the critical station is not considered to be significantly different from that of the control station (i.e., background). Note that statistically significant annual dose at a critical station that are well below background, represent results below background and indicate no additional dose impacts to a potential receptor.

Term representing the difference between the critical sampling station annual dose and the background station annual dose.

$$T_{[i]} = \mathrm{R}_{[\mathrm{i}]} - \mathrm{R}_{[\mathrm{PNL5}]} \qquad \text{Equ. 11}$$

Confidence interval for determining the difference from annual background.

$$\left(R_{[i]} - R_{[PNL5]}\right) \pm k \cdot SD(R_{[i]} - R_{[PNL5]}) \qquad \text{Equ. 12}$$

$$T_{[i]} \pm k \cdot SD(T_{[i]})$$

where

$T_{[i]}$ = the difference between the external dose at the critical station *i* and the background station

$R_{[i]}$ = the annual ambient external dose at critical sampling station *i* (PNL-1,-2, -3, or -4), mrem/yr,

$R_{[PNL-5]}$ = the annual ambient external dose at the background station PNL-5, mrem/yr,

k = a multiplier that reflects the intended confidence level; for a two-sided 95% confidence interval, *k* = 1.96.

The variances $V(R_{[i]})$ and $V(R_{[5]})$ terms for the entire year (all quarters of the year) are determined as indicated above for $V(R)$ (see Equ. 10).

Then, follows Equ. 13 and Equ. 14.

$$V(R_{[i]} - R_{[5]}) = V(R_{[i]}) + V(R_{[5]}) \qquad \text{Equ. 13}$$

$$SD(R_{[i]} - R_{[5]}) = \sqrt{V(R_{[i]} - R_{[5]})} = \sqrt{V(R_{[i]}) + V(R_{[5]})} \qquad \text{Equ. 14}$$

Because the variances $V(R_{[i]})$ and $V(R_{[5]})$ are ultimately determined using the vendor's estimated uncertainty described as a percent relative standard deviation (%RSD) of 6%, which is an estimate for which no degrees of freedom were specified, the *k* multiplier used was a z-statistic rather than a t-statistic. For a two-sided 95% confidence interval, the *k* multiplier is 1.95996 (and for a two-sided 99% confidence interval *k* is 2.57583). A 95% confidence interval is used for PNNL campus calculations. Then, implementing Equ. 12 the user can make the final determination of whether the critical station result is different from background.

Equivalently stated, the comparison of a critical sampling station dosimeter to the background dosimeter can be conducted as a two-sided test of hypothesis. In this approach, the null hypothesis is that there is no difference between annual ambient external dose levels at the two stations (so a hypothesized difference of 0) with the alternative hypothesis being that the dose levels are significantly different. The decision rule for the test is to reject the null hypothesis if the calculated test statistic (see Equ. 15) is beyond – in a positive direction -- the [statistically] critical values which correspond to the *k* multiplier described above. (Differences in a negative direction do not impart additional dose to a hypothetical receptor at the sampling station.) The [statistically] critical values reflect the significance level associated with the test. The significance level for the test is 1 minus the intended confidence level. Note that the test statistic formula is just a revision of Equ. 12.

$$z = \frac{T_{[i]} - 0}{SD(T_{[i]})} \qquad \text{Equ. 15}$$

As an example, if the test of hypothesis is conducted based on a 95% confidence level (i.e., a significance level of 5% or 0.05), the critical values for the test are ±1.95996, and the null hypothesis would be rejected in favor of the alternative hypothesis if the calculated test statistic z satisfies:

$$z < -1.95996 \quad \text{or} \quad z > 1.95996$$

3.0 PNNL-Sequim Campus Dose Assessment Guidance

The PNNL-Sequim 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. Radionuclide emissions to air are the only source of radionuclide releases[8] 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 released to ambient air at the Sequim campus, doses to individuals are calculated using computer models rather than direct measurements of radionuclide concentrations. (The greater potential dose from the potentially larger Richland campus emissions necessitates the use of a more detailed atmospheric dispersion model [see Section 2.0] for that location compared to the Sequim campus.) The lower potential dose from smaller Sequim campus emissions allows the use of a simpler, more conservative (i.e., over-estimating) dispersion model, COMPLY.

3.1.1 Sequim Campus 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), the RAGas database, 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. RMT does not perform radiological decay, currently. For overly conservative doses from non-decayed emissions of short-lived radionuclides, hand-calculations may be used to determine the decayed emission value for dose calculations.

Prior to CY2018 emissions' compliance reporting (Snyder and Barnett 2019), all radionuclide releases were assumed to occur from the MSL-5 building. Under the current site-wide licensing of RAEL-014, renewal 2 (WDOH 2022), the emissions are assumed to be released from a Central Sequim campus location (48º 4' 42.45" N, 123º 2' 48.51" W; Google Earth, image date July 29, 2021) at a height of 5 m from a 5 m by 5 m area source.

An alternative method of compliance determination is possible for the PNNL-Sequim campus 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 Sequim Campus 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. 2019.

[8] 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.

Exposure parameters used in the COMPLY Level 4 compliance calculations for the PNNL-Sequim campus are indicated in Table 9. There are two Level 4 options that could be used 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 the PNNL-Sequim campus compliance calculations are documented in the most recent annual compliance report.

Table 9. COMPLY Level 4 Input Parameters for the PNNL-Sequim Campus

Parameter	Default Value	MEI Option 1 – NWR Sequim Campus	MEI Option 2 – With Meteorological File (5-yr average 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	230 m[(a)]	Direction-specific (see Table 4.4 of Snyder et al. 2019 for Central campus 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 Production (m)	none	230 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 from the Central campus to nearest residence, business, or school.
(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 the PNNL-Sequim campus 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 nuclide results.

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. 2019, meteorological data appropriate for the PNNL- Sequim campus 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). Hourly data is used. These data are representative of the upland region of the site and are provided in COMPLY format in Figure 3.[9] In addition, Figure 4 is provided to illustrate 5 years of meteorological data from AgWeatherNet monitoring because the PNNL- Sequim campus meteorological data do not have an extensive historical record published elsewhere. While no-wind-rose is the default, over-estimating meteorological assumption, annual meteorological data may be included in an Appendix of the compliance report (e.g., see Table B.2 of Snyder et al. 2021b). This allows more precisely estimated doses to be readily calculated.

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 the annual precipitation rate is not required in the COMPLY model, it should be indicated in compliance reporting.

[9] Figure 3 data differ from that provided in Snyder et al. 2019b because wind speed instrumentation thresholds were taken into account in the data presented herein.

```
WIND ROSE FILE CREATED FROM KEYBOARD.
 SFS assessment of AWN-SmithFarm station
 Jan-Dec 2016, 2017, 2019, 2020, 2021
 SequimWA
 200
 miles/hr
 0.00E+00
 DIR-FROM  FREQUENCY   SPEED
'N   '      6.20E-02    3.25E+00
'NNE'       2.44E-02    3.19E+00
'NE  '      2.12E-02    2.70E+00
'ENE'       2.11E-02    2.50E+00
'E   '      2.88E-02    2.93E+00
'ESE'       3.29E-02    3.42E+00
'SE  '      6.10E-02    5.26E+00
'SSE'       5.30E-02    3.64E+00
'S   '      6.35E-02    3.27E+00
'SSW'       4.58E-02    2.12E+00
'SW  '      5.66E-02    2.11E+00
'WSW'       8.33E-02    2.49E+00
'W   '      1.61E-01    3.70E+00
'WNW'       1.64E-01    4.59E+00
'NW  '      7.81E-02    4.36E+00
'NNW'       4.35E-02    3.75E+00
```

Figure 3. COMPLY 1.7.1 2016–2017, 2019–2021 Average Sequim Meteorology File Created by Keyboard Entry in the Code

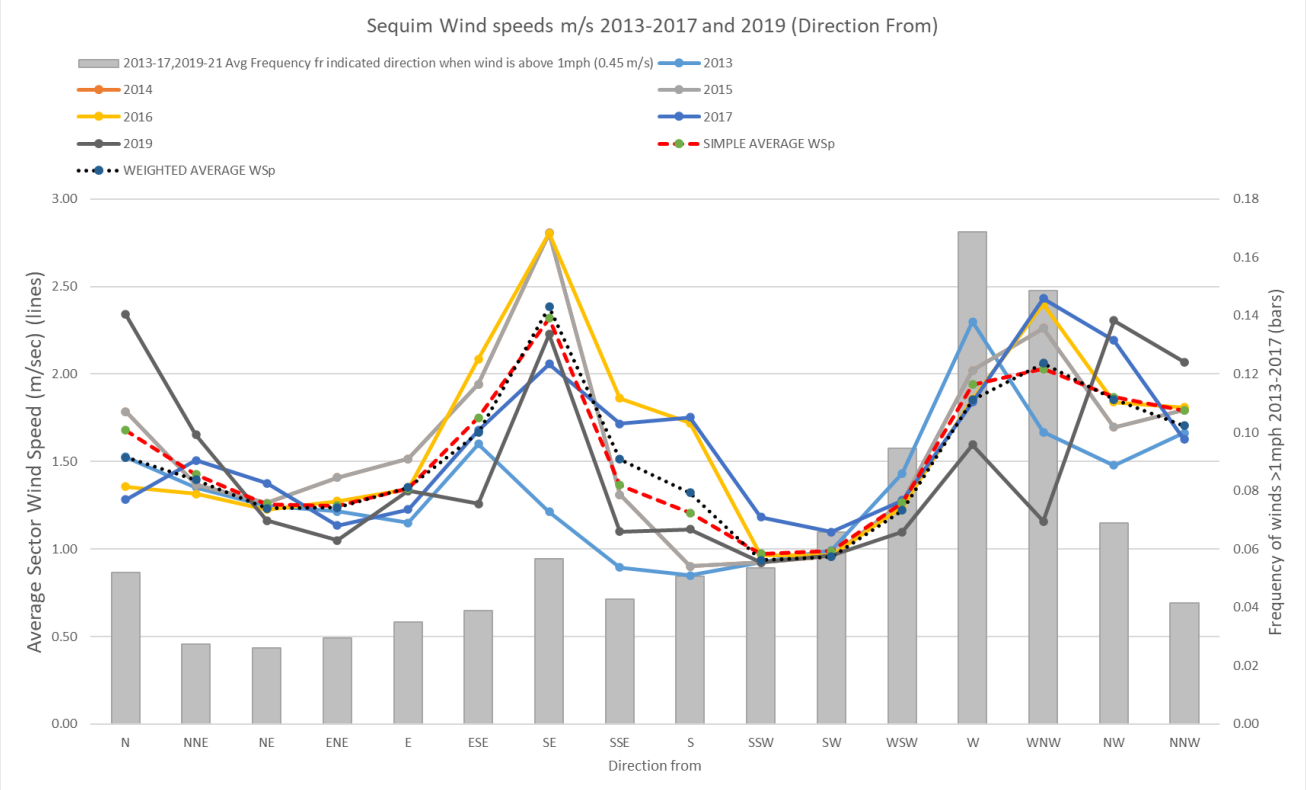


Figure 4. PNNL-Sequim Campus Annual Wind Characteristics 2013-2017 and 2019.

3.1.2.2 MEI and MA Location Determination

Snyder et al. 2021 provides a thorough discussion of PNNL-Sequim campus potential MEIs in each of 16 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 campus to a receptor, 230 m (755 ft) (see Snyder et al. 2021b). Site boundaries that are shoreline locations are not considered to be potential MEI locations for the Sequim campus. For the more precise result, the distance to the nearest receptor in all 16 directions from Central Sequim campus is input (Table 10; also see Snyder et al. 2021b). PNNL-Sequim campus boundaries are reviewed every year with knowledgeable PNNL staff. Land transfers and use agreements between Battelle and DOE may change the MEI and MA receptor locations from the prior year.

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 10. Potential PNNL-Sequim Campus MEI and MA Distances from Central Release Point to the Boundary

Direction from Central Sequim Campus	Smallest Distance to a Potential MEI Locations	Smallest Distance to the Sequim Campus 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	230 m, res (new in 2019)	202 m
NW	1,261 m, busi	290 m
NNW	840 m, res	220 m

Central release point and Sequim campus (see Figure 4.9 of Snyder et al. 2019).
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 Sequim Central campus 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 (average boundary distance is the measure adopted).

Section 3.1.2 discussed 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 Sequim campus 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 PNNL-Sequim campus. 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.

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. Sources for internal dose conversion factors are EPA 1988 (internal) and DOE 1988 (external).

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. PNNL-Sequim campus 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 Sequim campus collective dose is calculated with a spreadsheet because COMPLY will not produce a collective dose estimate. Rose et al. (2023) indicate the 50-mi (80 km) population from PNNL-Sequim campus based on the 2020 U.S. Census and the 2021 Canada Census. The populations at 10 radii in each of 16 directional sectors from the site are provided in Table 11. 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.

The Sequim campus collective dose is calculated as a function of the MEI dose result. As an example, the 230 m PNNL-Sequim campus MEI (Snyder, Thompson, and Barnett 2023) is located at WNW radii 1. For 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 a 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. The west sector currently produces the maximum result (U.S. only) and the NNW Canadian sector produces the maximum result for that country.

Table 11. PNNL-Sequim 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	18	0(*)	0(*)	0(*)	0(*)	0(*)	0(*)	2(*)	193	214	659	728	548	311	113	18	2,804
1-2	18	-	-	253	235	235	-	136	410	590	629	1,357	1,481	358	146	123	5,971
2-3	-	-	-	253	465	465	465	390	382	494	805	1,692	3,328	908	1,068	18	10,733
3-4	-	-	-	235	465	362	624	171	367	288	713	1,515	4,465	2,834	2,495	394	14,928
4-5	-	-	-	428	667	445	722	203	205	125	306	1,433	1,998	1,629	989	179	9,329
5-10	-	-	0(*)	1,796	4,119	887	411	123	130	127	491	1,644	6,339	5,855	2,497	365	24,784
10-20	-	0(*)	4,104	11,967	9,746	8,628	3,390	1,396	52	48	68	1,323	28,869	1,323	-	-	70,914
20-30	2,712	1,903	41,953	20,008	16,486	11,584	2,4110	3,866	536	0	0	0	8,243	**273**(a)	**13,608**	**150,199**	**295,481**
30-40	9,863	15,805	25,975	24,340	59,881	290,897	85,476	114,532	3,978	30	0	0	1,344	**10,534**(b)	**103,808**	**122,724**(c)	**869,187**
40-50	**5,295**(d)	1,784	74,647	21,251	177,233	430,979	750,624	101,179	14,192	238	2	36	202	**2,525**	**8,352**	**43,510**(e)	**1,632,049**
Total	**17,906**	19492	146679	80531	269297	744482	865822	221998	20445	2154	3673	9728	56817	**26550**	**133076**	**317,530**	**2,936,180**

To convert from mi to km, multiply by 1.609.

Bold values include Canadian populations

"-" = sea locations in the Strait of Juan de Fuca

(*) Predominantly a sea location but also contains some land.

(a) This WNW sector includes both Canadian and American populations. Fewer Canadians (55) and more Americans (218) are attributed to this sector.

(b) This WNW sector includes both Canadian and American populations. Fewer Americans (4) and more Canadians (10,530) are attributed to this sector.

(c) This NNW sector includes both Canadian and American populations. Fewer Americans (15) and more Canadians (122,709) are attributed to this sector.

(d) This N sector includes both Canadian and American populations. Fewer Canadians (1,150) and more Americans (4,145) are attributed to this sector.

(e) This NNW sector includes both Canadian and American populations. Fewer Americans (31) and more Canadians (43,479) are attributed to this sector.

3.4 Ambient Air Particulate Samples for Dose Assessment

Snyder et al. 2019, *Data Quality Objectives Supporting Radiological Air Emissions Monitoring for the Marine Sciences Laboratory, Sequim Site*, recommended establishing a single particulate air sampling station at PNNL-Sequim campus, in order to establish baseline background levels of gross alpha and gross beta particulates. The PNNL-Sequim campus ambient air program has not yet been authorized (as of January 2024). As with the PNNL-Richland campus ambient air sampling, PNNL-Sequim campus 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 Ambient Dosimetry for Dose Assessment

No ambient external dose surveillance is conducted at the PNNL-Sequim campus. However, Snyder et al. 2019, *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. The Sequim campus ambient dosimetry program has not yet been authorized (as of January 2024). 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 PNNL-Sequim Campus

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 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) but is essentially unchanged. Biota dose is assessed against the daily dose rate standards indicate in the DOE standard (Table 12).

Table 12. 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 Chg4 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 and Sequim campuses, both sites implement the least complex implementation of the standard.

Biota Concentration Guides (BCGs) are provided in 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). Specific dose calculations may alternatively be done with the Argonne National Laboratory RESRAD-BIOTA software. 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 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 and Sequim campuses, 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 particulate air effluent. Emissions of noble/radioactive gases would not incorporate into soil, sediment, or water over a long term; no biota dose evaluations are typically performed for gas emissions. For soil/sediment depositions, site particulate and liquid-form emissions are assumed to be mixed into 50 m^2 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 2500 m^3 (88,290 ft^3) of an ambient non-circulating, waterbody. These mixing areas are about the size of a large home garden for soil or sediment and an Olympic-sized swimming pool for water. Beginning in 2019, dose coefficients were determined using RESRAD-BIOTA V1.8, Level 2 (DOE 2004); and prior to 2019, the BCGs provided in DOE 2002 were used. Table 13 and Table 14 indicate recent biota dose estimates, which are indicated as "less-thans" to highlight the conservative calculations. Gross

alpha measurements (assumed to be Ra-226) and gross beta measurements (assumed to be Co-60 or Cs-137), respectively, are conservatively included.

Table 13. PNNL-Richland Campus Biota Dose Trends

Biota Category	Biota Dose Standard [(a)]	CY2018	CY2019	CY2020	CY2021	CY2022
Aquatic animals	1 rad/d	<9E-3	<6.3E-2	<7.9E-3	<9.0E-2	<9.8E-2
Terrestrial plants	1 rad/d	<9E-3	<1.6E-3	<2.0E-4	<1.7E-3	<1.9E-3
Riparian animals	0.1 rad/d	<8E-2	<8.7E-3	<1.1E-3	<9.6E-3	<1.1E-2
Terrestrial animals	0.1 rad/d	<8E-2	<1.2E-2	<1.7E-3	<1.2E-2	<1.3E-2

To convert to mGy/d, multiply rad/d by 10.
(a) DOE Order 458.1 Chg4 indicates Table 2.2 of DOE 2002 dose standards; DOE 2019, Table 1-1, indicates these same dose criteria.

Table 14. PNNL-Sequim Campus Biota Dose Trends

Biota Category	Biota Dose Standard [(a)]	CY2018	CY2019	CY2020	CY2021	CY2022
Aquatic animals	1 rad/d	<7E-5	<6.9E-3	<6.4E-4	<9.2E-3	<1.6E-4
Terrestrial plants	1 rad/d	<7E-5	<5.9E-5	<6.2E-6	<8.7E-5	<1.5E-6
Riparian animals	0.1 rad/d	<6E-4	<4.2E-4	<4.3E-5	<6.1E-4	<1.0E-5
Terrestrial animals	0.1 rad/d	<6E-4	<8.7E-5	<1.6E-5	<2.1E-4	<3.5E-6

To convert to mGy/d, multiply rad/d by 10.
(a) DOE Order 458.1 Chg4 indicates Table 2.2 of DOE 2002 dose standards; DOE 2019, Table 1-1, indicates these same dose criteria.

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Appendix A

A.1 Review Form for PNNL Radiological Dose Assessment

Dose to human receptors from radioactive material emissions from PNNL operations involves the use of meteorological data; determination of critical receptor location(s), and a computer code that models emission dispersion and dose estimation. The use of the review checklist developed a number of years ago by the Hanford Environmental Dose Overview Panel (HEDOP), suits the purposes of documenting the results of the dose assessment review. HEDOP Review Checklist (Appendix D, p7 of Schreckhise et al. 1993) is found on the next page.

A.2 Appendix A References

Schreckhise, RG, K Rhoads, JS Davis, BA Napier, JV Ramsdell. 1993. Recommended Environmental Dose Calculation Methods and Hanford-Specific Parameters. PNL-3777, Rev 2, Pacific Northwest Laboratory, Richland, Washington.

Review of Dose Calculations for <title, e.g., 2021 PNNL-Richland Campus Radionuclide Air Emissions Report (CY20 Emissions)>

A technical review of the radiological dose calculations for <preparer-provided text> was conducted. <describe how the dose assessment was done and where results will be documented, e.g., The review encompassed application of CAP88-PC results to releases of radionuclides from PNNL campus emission units to ambient air during calendar year (CY) 2020. The dose assessment determination is documented with modifications, as needed, for campus 2020 operating conditions and meteorology.> The attached technical review checklist, with supporting comments and their resolutions, document the topics covered by the review.

Review of Air Pathway Dose Estimates Prepared using <code name and version>
Output from the <code name> was reviewed for appropriate use with emission rates. <briefly describe any documents that drive input parameters; how code output is used> The methods and data were reviewed for appropriateness for the intended application and consistent with evaluations done previously for this purpose. Discrepancies, if any, found during the review process were corrected. Final dose results will be reported in <document number>.

<additional example text: MEI dose calculations were performed using CAP88-PC v4.0, which has been approved by EPA for use in demonstrating compliance with the radionuclide National Emissions Standards for Hazardous Air Pollutants (NESHAP). Unit-release Dose Factors (UDFs) are modeled in CAP88 for the receptor location. UDFs indicate the dose to the receptor from a 1 Ci release of a radionuclide, and UDF values include both the parent and its progeny dose.>

<other text that describes model, emissions, or dose assessment assumptions>

<state criteria the dose result is being compared against, e.g., Results demonstrate whether the PNNL campus impacts are above or below the 10 mrem/y standard for exposure of members of the public to radionuclides via air pathways. For CYyyyy emissions from the PNNL-Richland campus, impacts were well below the 10 mrem/y standard.>

References
<e.g., EPA—U.S. Environmental Protection Agency. 2015. *CAP88-PC Version 4.0 User Guide*, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

Snyder SF. 2021. EMP Attachment 3, Dose Assessment Guidance. PNNL-20919-3, Rev. 3, Pacific Northwest National Laboratory, Richland, Washington.>

Emissions data
<filename(s), date(s)>

Other data
<filename(s), date(s), purpose of *Other data*>
<dose code output file identification>

Other comments
<may describe supplemental calculations (e.g., Rn, collective dose) or any other topic>

TECHNICAL REVIEW CHECKLIST

Document reviewed (include title or description of calculation, document number, author, and date, as applicable): <some of this information was provided in the text, above>

Spreadsheet for Dose Calculations
<filename and date – preparer enters initial name and date, review confirms/edits for final>

System Information
<operating system, software>

Submitted by:
Fname Lname, date

Scope of Review:

YES	NO*	N/A		
[ ]	[ ]	[ ]	1.	A technical review and approval of the environmental transport and dose calculation portion of the analysis has been performed and documented.
[ ]	[ ]	[ ]	2.	Technical review(s) and approval(s) of scenario and release determinations have been performed and documented.
[ ]	[ ]	[ ]	3.	Appropriate computer software was used.
[ ]	[ ]	[ ]	4.	Receptor locations were appropriate for purpose of analysis.
[ ]	[ ]	[ ]	5.	All applicable environmental pathways and code options were included and were appropriate for the calculations.
[ ]	[ ]	[ ]	6.	PNNL Site data were used as applicable.
[ ]	[ ]	[ ]	7.	Any external adjustments to computer software output were justified and performed correctly.
[ ]	[ ]	[ ]	8.	The analysis is consistent with Site recommendations.
[ ]	[ ]	[ ]	9.	Supporting notes, calculations, comments, comment resolutions, or other information is attached.
[ ]	[ ]		**10.**	**Substantive comments have been resolved.**

Fname Lname <digital or written signature> mm/dd/yyyy
Technical Reviewer (Printed Name and Signature) Date

COMMENTS (add additional signed and dated pages if necessary):

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