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Capability Replacement Laboratory

Pacific Northwest National Laboratory Site Dose-per-Unit Release Factors for Use in Calculating Radionuclide Air Emissions Potential-to-Emit Doses

Pacific Northwest
NATIONAL LABORATORY

CRL-TECH-ESH-007 Revision 0

Approved for release by:

James K. McClusky, Project Director — Date: 9/29/08

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September 2008

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Abbreviations and Acronyms

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
CAP-88	Clean Air Act Assessment Package–1988
CAP88-PC	Clean Air Act Assessment Package 1988–Personal Computer
Ci	curies
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EMSL	Environmental Molecular Sciences Laboratory
EPA	U.S. Environmental Protection Agency
ERDA	Energy Research and Development Administration
FGR	Federal Guidance Report
HEPA	high-efficiency particulate air [filter]
ICRP	International Council on Radiation Protection
MEI	Maximally Exposed Individual
MPR	Maximum Public Receptor
NCRP	National Council on Radiation Protection
NDA	Nondestructive Assay
NESHAP	National Emission Standards for Hazardous Air Pollutants
NOC	Notice of Construction
PNNL	Pacific Northwest National Laboratory
PSF	Physical Sciences Facility
PTE	potential-to-emit
QA	quality assurance
TEDE	Total Effective Dose Equivalent
WAC	Washington Administrative Code
WDOH	(State of) Washington Department of Health

Definitions

Acute Release—A short-duration release of a radioactive air pollutant with a potentially significant dose consequence.

Aerodynamic Equivalent Diameter—The diameter of a sphere, with a density of 1 g cm^{-3}, that has the same terminal settling velocity under gravity as the airborne particle considered. Typically, a particle of arbitrary shape and density is modeled with the same aerodynamic diameter as that of a spherical water droplet having the same sedimentation velocity in quiescent air as the arbitrary particle under consideration.

Chronic Release—The nearly continuous release of small quantities of radioactive air pollutants from an emission unit over a period of at least 3 months.

Emission Unit—Any stationary source (e.g., a stack or vent) that emits or has the potential to emit regulated radioactive air pollutants. This may be a point source, non-point source, or source of diffuse or fugitive emissions.

Maximally Exposed Individual (MEI)—A hypothetical member of the public residing near the Pacific Northwest National Laboratory (PNNL) Site who, by virtue of location and living habits, could receive the highest potential radiation dose from radioactive effluents released from the PNNL Site during a past calendar year. The MEI dose calculation is retrospective in nature and uses actual emissions and meteorological data applicable to the year for which the evaluation is performed. Emissions affecting the MEI may originate from point sources (i.e., actively ventilated stacks and vents) as well as from fugitive and diffuse sources. Compliance with federal and state dose standards is determined by the MEI dose.

Maximum Public Receptor (MPR)—A hypothetical member of the public located near the PNNL Site who, by virtue of location and living habits, could receive the highest radiation dose from potential radionuclide emissions that may be released from a single emission source being considered for permitting purposes. The MPR dose calculation is prospective in nature and uses estimated potential radionuclide emissions from a proposed new or modified emission unit and long-term meteorological data applicable to the facility location.

Potential to Emit (PTE)—Radionuclide emissions estimated for purposes of permitting a new or modified emission unit. As defined in WAC 246-247-030(21), "…the rate of release of radionuclides from an emission unit based on the actual or potential discharge of the effluent stream that would result if all abatement control equipment did not exist, but operations are otherwise normal."

1.0 Introduction

U.S. Department of Energy (DOE) facilities are required to demonstrate compliance with the Clean Air Act National Emission Standards for Hazardous Air Pollutants (NESHAP) for radionuclides, as published in the 1989 amendments to Title 40 Code of Federal Regulations (CFR) Part 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities."

The Washington State Department of Health (WDOH) established regulations, corresponding to the federal regulations for radionuclide air emissions, in the Washington Administrative Code (WAC) Chapter 246-247, "Radiation Protection – Air Emissions." Additional Washington State Department of Ecology regulations are found in WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides." The WDOH is responsible for implementation and enforcement of regulations relating to radiological air quality.

Regulatory requirements for determining compliance with the radionuclide air emissions standards are specified by the U.S. Environmental Protection Agency (EPA) in 40 CFR Part 61, Subpart H, Section 61.92(a), which includes:

> …EPA-approved sampling procedures, computer models CAP-88 or AIRDOS-PC, or other procedures for which EPA has granted prior approval. DOE facilities for which the maximally exposed individual lives within 3 kilometers of all sources of emissions in the facility, may use EPA's COMPLY model and associated procedures for determining dose for purposes of compliance.

WAC 246-247 adopts by reference the approved methods specified in 40 CFR Part 61, Subpart H.

This report documents assumptions and inputs used to prepare the dose-per-unit-release factors for the Pacific Northwest National Laboratory (PNNL) Site (including the buildings that make up the Physical Sciences Facility [PSF] as well as the Environmental Molecular Sciences Laboratory [EMSL]) calculated using the EPA-approved Clean Air Act Assessment Package 1988–Personal Computer (CAP88-PC) Version 3 software package (Rosnick 2007). The dose-per-unit-release factors are used to prepare dose estimates for a maximum public receptor (MPR) in support of Radioactive Air Pollutants Notice of Construction (NOC) applications for the PNNL Site.

The PSF is a complex of five research facilities that will be constructed on the PNNL Site to replace existing research and development space currently occupied by PNNL in the Hanford Site 300 Area. The PSF will consist of the following buildings:

- 3410—Materials Sciences and Technology Laboratory
- 3420—Radiation Detection Laboratory
- 3425—Underground Laboratory
- 3430—Ultra-Trace Laboratory
- 3440—Large Detector Laboratory.

Of these five buildings, only the 3410, 3420, and 3430 buildings will house processes that use dispersible radioactive materials. Radioactive Air Pollutants NOC applications for these three buildings are prepared in accordance with WAC 246-247 and submitted to Washington Department of Health (WDOH) for review and approval. EMSL has previously been exempted from obtaining an NOC. Figure 1.1 shows the location of the PNNL Site and the Hanford Site 300 Area.

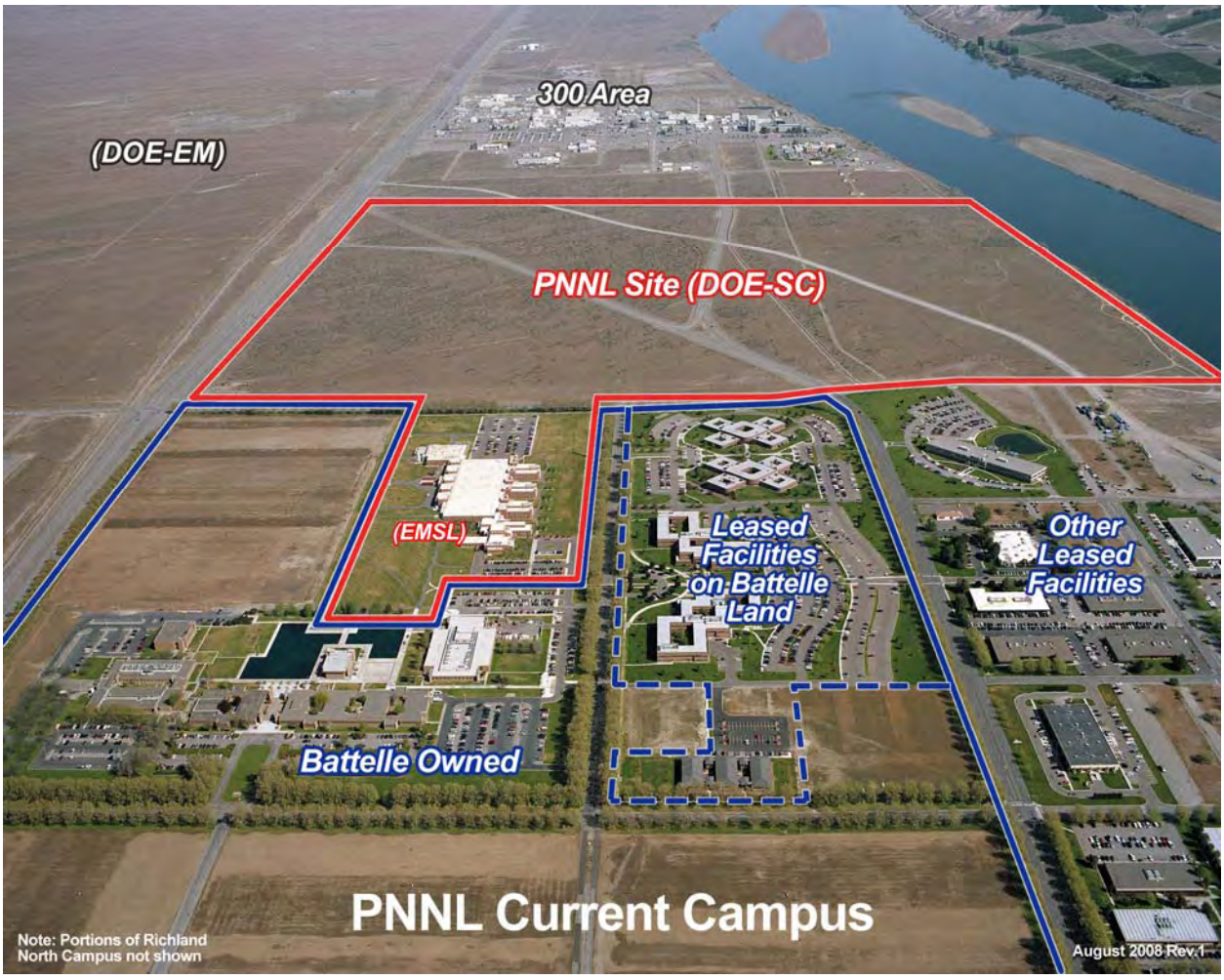

Figure 1.1. Location of the Department of Energy's PNNL Site

2.0 Estimating Potential Emissions

This section describes methods currently accepted by the WDOH and EPA Region 10 for estimating potential airborne radionuclide emissions. Potential radionuclide emissions from new or modified emission units are used to determine emission monitoring requirements and other operating parameters for the emission unit. In determining potential emissions, also referred to as "potential-to-emit" (PTE), the emission rates are estimated assuming normal operations, but in the absence of emission-abatement and control equipment.

2.1 Approved Methods

WAC Chapter 246-247-30(21) provides methods to determine the potential-to-emit. The methods are:

1. Multiply the annual possession quantity of each radionuclide by the release fraction for that radionuclide. Release fractions are provided in WAC 246-247-030(21)(a); they are the same as those specified in 40 CFR Part 61, Appendix D.
2. Perform a back-calculation using measured emission rates and *in situ* measurements of the control-equipment efficiencies.
3. Measure the quantities of radionuclides captured in each control device, coupled with *in situ* measurements of the control equipment efficiencies.
4. Sample the effluent upstream from all control devices.
5. Use an alternative method approved by the WDOH. Under this method (WAC 246-247-030(21)(e) and/or 40 CFR Part 61, Subpart H, Section 61.96), prior approval from WDOH and/or EPA Region 10 is required. As an example, the following alternative method has been previously used for estimating potential emissions:
    - Multiply the annual possession quantity of each radionuclide by material-specific spill-release fractions rather than using the release fractions identified in WAC 246-247-030(21)(a) and 40 CFR Part 61, Appendix D.

Method 1 is authorized by 40 CFR Part 61, Subpart H, for calculating potential emissions. Historically, EPA Region 10 has also approved the use of alternative Methods 2 through 4 as well as the example provided in 5.

Alternative methods (i.e., method 5) usually require a more extensive review and approval process. However, the use of previously approved methods should not require a review and approval cycle as extensive as a method that uses a new technology or methodology.

2.1.1 Method 1: Annual Possession Quantity

Method 1 is prescribed in 40 CFR Part 61, Appendix D, and in WAC 246-247-030(21). The methods described by these regulations are substantially the same, with the exception of a few minor differences. The method in WAC 246-247-030(21)(a) is:

- Multiply the annual possession quantity of each radionuclide by the release fraction for that radionuclide, depending on its physical state. Use the following release fractions:

  (i) 1 for gases;
  (ii) 10^{-3} for liquids or particulate solids; and
  (iii) 10^{-6} for solids.

- Determine the physical state for each radionuclide by considering its chemical form and the highest temperature to which it is subjected. Use a release fraction of one if the radionuclide is subjected to temperatures at or above its boiling point; use a release fraction of 10^{-3} (equivalent to 1.0 E-03) if the radionuclide is subjected to temperatures at or above its melting point, but below its boiling point. If the chemical form is not known, use a release fraction of one for any radionuclide that is heated to a temperature of 100 degrees Celsius or more, boils at a temperature of 100 degrees Celsius or less, or is intentionally dispersed into the environment.

This method is extremely conservative because many materials have release fractions for accident scenarios that are orders of magnitude lower than those provided in 40 CFR 61, Appendix D. Method 1 is typically used for the PNNL Site radioactive air pollutants NOC applications. Other release fractions may be used only with the WDOH's approval as provided by Method 5. Methods 2 through 5 are described below for completeness.

2.1.2 Method 2: Back-Calculating Emissions and *In Situ* Measurements

WAC Chapter 246-247-030(21)(b) states that, with approval, a back-calculation using measured emission rates and *in situ* measurements of the control-equipment efficiencies can be used to estimate potential emissions. Control-equipment efficiencies should be obtained using the methods prescribed by American Society of Mechanical Engineers/American National Standards Institute (ASME/ANSI) N509, *Testing of Nuclear Air Treatment Systems*.

Most of the Hanford emission-control equipment consists of high-efficiency particulate air (HEPA) filter systems. The *Nuclear Air Cleaning Handbook* (ERDA 76-21) provides a decontamination factor of $3{,}000^n$ for HEPA filter systems, in which "n" represents the number of HEPA filters in series. The use of a decontamination factor of $3{,}000^n$ has been allowed by WDOH and EPA for systems using n banks of HEPA filters in series. The potential emissions are then calculated by multiplying the actual annual emissions by the decontamination factor (i.e., $3{,}000^n$).

Method 2 can be extremely conservative for a contaminated system. When processing in a facility no longer occurs, the resuspension of contamination downstream of the HEPA filters can

dominate the airborne releases from that facility. Multiplying those releases by $3{,}000^n$ can overestimate the potential emissions by an order of magnitude or more (Barnett and Davis 1996).

2.1.3 Method 3: Control Device and *In Situ* Measurements

WAC Chapter 246-247-030(21)(c) states that, with approval, measurements of the quantities of radionuclides captured in the control device, coupled with *in situ* measurements of the control-equipment efficiencies, can be used to estimate potential emissions. Several variations of this method are available. Two variations are described below in Sections 2.1.3.1 and 2.1.3.2.

2.1.3.1 Method 3.1: Control Device Inventory

Representative samples taken from the collection media in a control device are used to estimate the total radionuclide inventory contained within that control device. Isotopic analyses are performed on the samples. The total radionuclide inventory in the control device is estimated using the sample results, operating history of the device, and the appropriate radioactive-decay corrections. An annual release rate is calculated based on the total radionuclide inventory in the control device, its operating history, and its collection efficiency. The potential emissions, in the absence of the control device, are then calculated by dividing the annual release rate by the collection efficiency of the control device (Rokkan, et al 2006).

2.1.3.2 Method 3.2: Control Device NDA

A nondestructive assay (NDA) measurement is used to determine the radionuclide inventory of a control device. The radionuclide inventory in a control device is derived using the NDA results, operating history for the device, and the appropriate radioactive-decay corrections. An annual release rate is calculated based on the radionuclide inventory of the control device, its operating history, and its collection efficiency. The potential emissions, in the absence of the control device, are then calculated by dividing the annual release rate by the collection efficiency of the control device.

The NDA method most frequently used at the Hanford Site, described in *Measurement of Gamma Activity from HEPA Filters* (Barnett 1993), uses either a sodium-iodide or high-purity germanium gamma-ray detector to quantify the gamma-emitting radionuclides collected by the control device. An annual release rate is calculated for each gamma-emitting radionuclide. Annual release rates for non-gamma-emitting radionuclides are calculated using ratios obtained from actual radionuclide-emissions measurements or inventory data.

2.1.4 Method 4: Measurement Upstream of Control Device

WAC Chapter 246-247-030(21)(d) states that with approval, effluent samples collected upstream from all control devices can be used to estimate potential emissions in the absence of the control devices.

Representative air samples are collected at a location upstream from all control devices. The samples are analyzed for expected radionuclides to determine their concentrations in the effluent stream. The potential emissions, in the absence of control devices, are then calculated by multiplying the radionuclide concentrations by the annual discharge volume.

2.1.5 Method 5: Alternative Methods

WAC Chapter 246-247-030(21)(a) states that with WDOH approval, other release fractions may be used to estimate potential unabated emissions. This would be similar to the example provided previously.

Other alternative methods need to be adequately documented and submitted to WDOH and/or EPA for approval. Additional time is required for the review and approval of alternative methods.

3.0 Dose-Per-Unit-Release Factors for Radionuclide Air Emissions

3.1 Overview

Dose-per-unit-release factors are prepared to facilitate the estimation of the PTE total effective dose equivalent (TEDE) to the MPR from the PNNL Site. CAP88 or other approved software is required for this purpose by EPA regulations in 40 CFR Part 61, Subpart H and by Washington State in WAC 246-247. The calculations were performed using the CAP88-PC Version 3 software package (Rosnick 2007). The CAP88-PC Version 3 software package incorporates several major changes over the previous versions, such as a greatly expanded radionuclide library, more rigorous methods for estimating dose from radioactive-decay chains, updated environmental transport factors from the National Council on Radiation Protection and Measurements Report No. 123 (NCRP 1996) and dosimetry and risk factors based on International Council on Radiation Protection (ICRP) Report 72 (ICRP 1996) and Federal Guidance Report (FGR) 13 (Eckerman et al. 1999).

Doses presented in this report represent prospective estimates of potential radiation dose rates to the MPR following release of radioactive effluents to the ambient air from the PNNL Site. Assumptions and input for the CAP88-PC software calculations consisted of the MPR location relative to the facility, long-term meteorological data appropriate for the facility location, release-point characteristics, food-production options, the list of radionuclides applicable to the facility, and their respective release rates. Inputs to the code are summarized in Table 3.1., along with the basis for each assumption as applicable. PNNL Site parameters used for the assessment are documented in Table 3.2; these parameters mirror those used for the Hanford Site 300 Area that have been previously accepted by the WDOH and EPA Region 10 (Conklin 2001; Hardesty 2001). Unless otherwise specified, the remaining parameters and radionuclide data used for the analysis were default assumptions provided with the CAP88-PC Version 3 software.

Table 3.3 (CAP88) and Table 3.4 (surrogates) list PNNL Site dose-per-unit-release factors, by radionuclide, for the MPR. The calculations were performed for a 1 curie per year (Ci/year) release rate for all radionuclides. Values in the tables are calculated to be conservative estimates for all emission unit locations on the PNNL Site including those associated with the PSF and EMSL and may be used for prospective estimates of radiation dose.

3.2 Use of Hanford Site-Specific Parameters and Data for Demonstrating Compliance With Air Pathway Radiation Dose Standards at the PNNL Site

As noted previously, Hanford Site-specific values for exposure and consumption were used for the CAP88-PC calculations reported herein. The following sections describe the history of the Hanford Site-specific data and parameters that have been applied in the PNNL Site calculations.

3.2.1 History of Data Used in Hanford Site Compliance Calculations

Beginning in the 1970s, DOE maintained a program that developed and recommended standard methods for performing environmental dose evaluations at the Hanford Site. As part of that program, a number of software packages and associated data libraries were developed to implement regulatory requirements based on recommendations of national and international standards organizations for radiological protection; for example, the GENII software package (Napier et al. 1988). In association with that effort, publications that described the recommended input parameters for various types of dose calculations were issued and periodically updated (Napier 1981; McCormack 1982; McCormack et al. 1984; Schreckhise et al. 1993). Those recommendations were based on data collected at the Hanford Site or on information obtained in surveys of the area and nearby communities.

Hanford Site-specific methods and parameters have historically been used to calculate the annual maximally exposed individual (MEI) dose for comparison with radionuclide air-emission standards in Subpart H of 40 CFR Part 61 and in WAC 246-247. They have also been used to calculate prospective doses in NOC applications. In addition, they have been used routinely for other types of Hanford Site assessments, such as the annual Hanford Site Environmental Report (Poston et al. 2007), the Hanford Site Radionuclide Air Emissions Report (DOE 2008a), and similar environmental evaluations. A more complete discussion of those methods is presented in *Methods for Calculating Doses to Demonstrate Compliance with Air Pathway Radiation Dose Standards at the Hanford Site* (DOE 2008b).

3.2.2 Site-Specific Parameters

PNNL Site-specific data used with CAP88-PC to calculate dose-per-unit-release factors include the following:

- Onsite meteorological data appropriate to the source location and type of evaluation. For the PNNL Site, long-term data collected at the 300 Area meteorology station were used. Data collection methods, as well as annual and historical summaries, may be found in Hoitink et al. (2005) and Duncan (2007). Data were formatted as required for use with CAP88-PC.
- Food production and consumption parameters (Schreckhise et al. 1993)
- Other exposure parameters (Schreckhise et al. 1993).

PNNL Site-specific parameters used to calculate the dose-per-unit-release factors are listed in Table 3.1. and Table 3.2. Values presented are used to calculate doses for a hypothetical offsite or onsite receptor who receives the highest exposure to airborne emissions. That individual is typically assumed to be a self-sufficient farmer located near the site boundary. In addition, Table 3.2 lists “average individual” parameters that are used for collective dose assessments and for evaluating doses to individuals whose exposure is more representative of the population as a whole. CAP88-PC defaults are also provided in the table for comparison. As appropriate, PNNL Site-specific values are generally consistent with the most recent recommendations in Schreckhise et al. (1993) for use in Hanford Site analyses. Other bases for the recommended parameters are presented as appropriate.

3.3 Calculating "Potential-to-Emit" Dose From the PNNL Site Using Dose-per-Unit-Release Factors

The dose-per-unit-release factors in Table 3.3 are used to estimate potential radiological dose from the PNNL Site for purposes of permitting the associated emission units. The dose is estimated using the PTE release rates [in Curies per year (Ci/year)] for radionuclides expected to be present in the facility, multiplied by the corresponding values in Table 3.3 for a 1-Ci/year release of each radionuclide. The doses for all radionuclides potentially released from the PNNL Site are combined to estimate the total annual PTE dose.

Many radionuclides decay into other radionuclides, creating a radioactive decay chain consisting of a parent nuclide and its radioactive progeny (i.e., decay products, or daughters). Contributions to the dose from ingrowth of decay products are included in Table 3.3 for each radionuclide as applicable. Doses listed as "+D" for the parent radionuclide of each decay chain include the contribution from other radionuclides produced by decay of the parent radionuclide following release from the emission unit to the environment. The "+D" values assume release of 1 Ci/year of the parent isotope with no other decay-chain members present initially. In cases where the ingrowth of decay products contributes substantially to the dose following release of the parent isotope, the dose contribution from the parent isotope alone is also listed in the table for information.

If multiple members of a single decay chain are included in the estimated emissions, the dose for each decay-product radionuclide is calculated separately in the same manner as for the parent isotope. The doses from each member of the chain and its decay products are then combined with doses from all other radionuclides included in the potential emissions to estimate the total dose.

The isotopes presented in Table 3.4 are not in the CAP88-PC V3 library, and surrogate radionuclides were selected to represent those isotopes when preparing dose calculations. There was no single method used in preparing the dose-per-unit-release factors for isotopes that were not in the CAP88-PC V3 library, and the approaches used are listed in order of preference below. A list of radioisotopes and their associated surrogates is listed in Table 3.4. Methods used to estimate dose for radionuclides not in the CAP88-PC V3 library include:

- Identify a chemically and radiologically similar isotope (i.e., same or related element, similar half-life, similar radiological decay mode) that should be conservative for the missing isotope.
- Where the missing isotope has a metastable variant in the CAP88-PC V3 database, the related isotope from the library was used because the beginning and end states, and the total decay energy are generally the same.
- For very short-lived isotopes (i.e., the half-life is less than about two hours) that have complex decay chains, the first longer-lived decay product is used as the surrogate. The dose-per-unit-release factor for the surrogate is then adjusted to account for the quantity of surrogate that would result from the decay of 1 Ci of the parent isotope.
- Where other options do not apply or are not viable, conservative isotope values of Sr-90 for beta/gamma emitters and Pu-239 for alpha emitters are used.

Table 3.1. Inputs and Assumptions used for PNNL Site Dose-per-Unit-Release Calculations with CAP88-PC

Parameter	Units	Assumptions or Values Used	Basis for Assumptions or Values
Facility Location	-	Richland, Washington	Used to determine food production rates—from CAP88-PC database
MEI Location	-	170 m SSE	Distance and direction from the PNNL Site's PSF to nearest residence, school, or business where a member of the public could be located (Information Sciences Building-2)
Buildup Time	years	50	Current lifetime expectancy of the PNNL Site buildings
Wind Data	meters/sec, Fraction of time	Hanford Site 300 Area Meteorology Station (Station 11) 1983–1996 Long-term average: Wind Speed Direction Atmospheric Stability	Nearest wind tower to PNNL Site - release location. Long-term data used for prospective assessments
Annual Precipitation	cm/year	16	Long-term average for Hanford Site (Poston et al. 2007)
Average Temperature	°C	12	Long-term average for Hanford Site (Poston et al. 2007)
Lid Height	meters	1000	CAP88-PC default
Absolute Humidity	grams/m^3	8	CAP88-PC default
Source Type	-	Stack or Vent	Emissions generally originate from a stack or vent. Sometimes the source type is characterized as a fugitive emission (i.e., not from a stack or vent).
Stack Dimensions	meters	10 (height) 1 (diameter)	Default effective stack height used for short stacks—consistent with PNNL Site emission units
Plume Rise Model	-	None	Establishes a conservative result
Food Source Scenario	-	"Local" food production option (all food produced at MEI location)	Conservative assumption consistent with the Hanford Site (see Table 3.2)
Beef Cattle Density	#/km^2	5.62E-2	CAP88-PC default for WA
Milk Cattle Density	#/km^2	1.50E-2	CAP88-PC default for WA
Fraction of land used for vegetable production	-	5.20E-2	CAP88-PC default for WA
Radionuclide release rates	Ci/y	1	Default basis for document to establish a dose per "unit" release factor
Radionuclide particle size, type, and chemical form	-	Isotope specific	CAP88-PC defaults for all isotopes

Table 3.2. Specific Parameters Adopted from the Hanford Site Used in Calculating Dose to Receptors from Radionuclide Air Emissions From the PNNL Site

Parameter	Units	CAP88-PC Default	Hanford Values		Basis for Assumptions or Values
			Average Individual	MEI	
Food-Consumption Parameters					
Ingestion Rate of Meat by Man	kg/year	85	79	98	Schreckhise et al. 1993; McCormack et al. 1984; Napier 1981 (sum beef, pork, poultry)
Ingestion Rate of Leafy Veg. By Man	kg/year	18	15	30	Schreckhise et al. 1993; McCormack et al. 1984; Napier 1981
Ingestion Rate of Milk by Man	L/year	112	230	270	Schreckhise et al. 1993; McCormack et al. 1984; Napier 1981
Ingestion Rate of Produce by Man	kg/year	176	140	220	Schreckhise et al. 1993 (vegetables other than leafy)
Fraction Produce Ingested From Garden of Interest	-	1.0	0.25	1.0	EPA 1989
Fraction Leafy Veg. Ingested From Garden of Interest	-	1.0	0.25	1.0	EPA 1989
Other Exposure Parameters					
Ground Surface Correction Factor	-	0.50	0.50	1.0	MEI uses original AIRDOS/CAP-88 (Clean Air Act Assessment Package–1988) default. Appropriate for relatively flat, unvegetated, arid site.
Inhalation Rate of Man	cm^3/h	9.167E+05	9.7E+05	9.7E+05	ICRP 23 (1975) daily average value for reference man
Period Long-term Buildup in Soil	years	100.0	50.0 or as appropriate for emission unit	50.0 or as appropriate for emission unit	Expected maximum operating life for Hanford facilities based on end of most Hanford Site operations by 2046. Original AIRDOS/CAP-88 default was 1 year.

Table 3.3. Dose-per-Unit-Release Factors for the PNNL Site Maximum Public Receptor

Nuclide or Decay Chain [a, b]	Dose Per Unit Release Factor (mrem/y per Ci/y released)
^{3}H elemental	1.36E-03
^{3}H vapor	1.64E-03
^{7}Be	2.57E-02
^{10}Be	2.21E-01
^{11}C	2.18E-03
^{14}C	1.56E-01
^{15}C [c]	[c]
^{13}N	1.47E-03
^{15}O	1.56E-04
^{18}F	3.31E-03
^{22}Na	4.43E+00
^{24}Na	3.55E-02
^{27}Mg	[c]
^{28}Mg+D	3.82E-02
^{26}Al	3.30E+00
^{28}Al	3.87E-04
^{31}Si	1.13E-03
^{32}P	9.77E-01
^{33}P	2.03E-01
^{35}S	3.48E-01
^{36}Cl	9.39E+01
^{37}Ar	0.00E+00
^{39}Ar	6.62E-06
^{41}Ar	3.36E-03
^{42}Ar	[c]
^{40}K	9.20E+00
^{42}K	7.25E-03
^{41}Ca	2.16E-01
^{45}Ca	5.89E-01
^{47}Ca+D	1.34E-01
^{46}Sc	1.36E+00
^{47}Sc	1.45E-02
^{44}Ti	1.70E+00
^{44}Ti+D	4.06E+00
^{45}Ti	3.52E-03
^{51}Ti	[c]
^{48}V	5.98E-01
^{49}V	1.61E-03
^{49}Cr+D	2.80E-03
^{51}Cr	1.09E-02
^{55}Cr	[c]
^{52}Mn	2.83E-01

Nuclide or Decay Chain [a, b]	Dose Per Unit Release Factor (mrem/y per Ci/y released)
^{54}Mn	1.13E+00
^{56}Mn	6.37E-03
^{55}Fe	4.19E-02
^{59}Fe	6.17E-01
^{56}Co	2.98E+00
^{57}Co	2.34E-01
^{58}Co	8.16E-01
^{60}Co	5.21E+00
^{56}Ni	1.59E-01
^{56}Ni+D	3.73E-01
^{59}Ni	4.46E-02
^{63}Ni	1.46E-01
^{65}Ni	2.03E-02
^{64}Cu	2.80E-03
^{65}Zn	5.73E+00
^{69m}Zn+D	6.49E-03
^{69}Zn	3.79E-04
^{67}Ga	9.55E-03
^{72}Ga	2.57E-02
^{68}Ge	8.20E+00
^{68}Ge+D	9.15E+00
^{74}As	2.30E-01
^{76}As	1.82E-02
^{75}Se	1.57E+00
^{79m}Se	[c]
^{79}Se	2.55E+00
^{82m}Br	[c]
^{82}Br	5.70E-02
^{83}Br+D	7.59E-04
^{84m}Br	[c]
^{84}Br	4.80E-03
^{85}Br	[c]
^{81m}Kr+D	0.00E+00
^{81}Kr	1.41E-05
^{83m}Kr	6.56E-08
^{85m}Kr+D	3.88E-04
^{85}Kr	1.38E-05
^{87}Kr+D	2.12E-03
^{88}Kr	5.41E-03
^{88}Kr+D	6.06E-03
^{89}Kr	[c]
^{90}Kr	[c]

Nuclide or Decay Chain [a, b]	Dose Per Unit Release Factor (mrem/y per Ci/y released)
^{83}Rb+D	1.57E+00
^{84}Rb	1.07E+00
^{86}Rb	5.45E-01
^{87}Rb	1.99E+00
^{88}Rb	1.68E-03
^{89}Rb+D	4.38E-03
^{90m}Rb	(c)
^{90}Rb	(c)
^{85}Sr	2.97E-02
^{87m}Sr+D	1.09E-03
^{89}Sr	9.75E-01
^{90}Sr+D	2.66E+01
^{91}Sr	8.91E-03
^{91}Sr+D	9.97E-03
^{92}Sr+D	6.90E-03
^{88}Y	1.86E+00
^{90m}Y+D	3.22E-03
^{90}Y	2.53E-02
^{91m}Y+D	1.41E-03
^{91}Y	1.97E-01
^{92}Y	3.28E-03
^{93}Y+D	6.87E-03
^{88}Zr	2.98E-01
^{88}Zr+D	9.40E-01
^{89}Zr	5.38E-02
^{93}Zr+D	2.08E-01
^{95}Zr+D	4.96E-01
^{97}Zr	1.54E-02
^{97}Zr+D	2.10E-02
^{91m}Nb	(c)
^{91}Nb	(c)
^{92}Nb	(c)
^{93m}Nb	1.55E-02
^{94}Nb	1.97E+00
^{95m}Nb	1.51E-02
^{95m}Nb+D	4.44E-02
^{95}Nb	3.14E-01
^{97m}Nb	5.90E-06
^{97m}Nb+D	3.67E-05
^{97}Nb	2.20E-03
^{93}Mo+D	6.54E-01
^{99}Mo	2.09E-02
^{99}Mo+D	2.44E-02
^{95m}Tc+D	2.27E+00
^{97m}Tc+D	2.30E+00

Nuclide or Decay Chain [a, b]	Dose Per Unit Release Factor (mrem/y per Ci/y released)
^{97}Tc	5.11E-01
^{98}Tc	1.62E+01
^{99m}Tc+D	6.62E-04
^{99}Tc	4.81E+00
^{101}Tc	7.01E-04
^{97}Ru+D	9.64E-03
^{103}Ru+D	2.45E-01
^{105}Ru+D	4.89E-03
^{106}Ru	9.56E-01
^{106}Ru+D	1.30E+00
^{102}Rh	2.53E+00
^{103m}Rh	3.58E-05
^{105m}Rh	(c)
^{105}Rh	6.34E-03
^{106}Rh	5.65E-09
^{107}Pd	7.80E-03
^{109}Pd	5.47E-03
^{108m}Ag+D	2.11E+00
^{108}Ag	6.28E-06
^{109m}Ag	1.45E-09
^{110m}Ag+D	2.71E+00
^{110}Ag	1.08E-10
^{111}Ag	3.23E-02
^{109}Cd	1.44E+00
^{113m}Cd	1.78E+01
^{113}Cd	1.93E+01
^{115m}Cd+D	1.03E+00
^{115}Cd	2.78E-02
^{115}Cd+D	3.19E-02
^{106}In	(c)
^{113m}In	8.98E-04
^{114m}In+D	2.40E-01
^{114}In	7.37E-08
^{115m}In+D	1.31E-03
^{115}In	4.41E+00
^{113}Sn	3.02E-01
^{113}Sn+D	4.84E-01
^{117m}Sn	1.01E-01
^{119m}Sn	1.95E-01
^{121m}Sn+D	2.91E-01
^{121}Sn	3.62E-03
^{123}Sn	9.20E-01
^{125}Sn+D	2.08E-01
^{126}Sn	3.12E+00
^{126}Sn+D	5.26E+00

Nuclide or Decay Chain [a, b]	Dose Per Unit Release Factor (mrem/y per Ci/y released)
^{122}Sb	2.52E-02
^{124}Sb	2.52E-03
^{125}Sb+D	6.05E-01
^{126m}Sb+D	3.26E-03
^{126}Sb	4.81E-01
^{127}Sb+D	6.23E-02
^{121m}Te	6.51E-01
^{121m}Te+D	1.03E+00
^{121}Te	1.35E-01
^{123m}Te+D	3.88E-01
^{123}Te	1.24E+00
^{125m}Te	1.60E-01
^{127m}Te+D	4.95E-01
^{127}Te	1.98E-03
^{129m}Te+D	3.52E-01
^{129}Te+D	6.79E-04
^{131m}Te	3.73E-02
^{131m}Te+D	1.52E-01
^{131}Te	1.23E-03
^{131}Te+D	8.07E-03
^{132}Te	4.90E-02
^{133m}Te+D	7.49E-03
^{133}Te	1.76E-03
^{133}Te+D	2.72E-03
^{134}Te	2.87E-03
^{134}Te+D	3.59E-03
^{122}I	5.02E-04
^{123}I+D	1.15E-02
^{125}I	2.32E+01
^{129}I	4.37E+02
^{130m}I	(c)
^{130}I	1.35E-01
^{131}I+D	3.25E+00
^{132m}I	1.66E-03
^{132m}I+D	2.25E-03
^{132}I	1.59E+00
^{133m}I	(c)
^{133}I+D	1.10E-01
^{134m}I	(c)
^{134}I	6.63E-03
^{135}I+D	3.03E-02
^{122}Xe	1.26E-04
^{122}Xe+D	9.38E-03
^{123}Xe	1.55E-03
^{123}Xe+D	3.44E-03

Nuclide or Decay Chain [a, b]	Dose Per Unit Release Factor (mrem/y per Ci/y released)
^{125}Xe	6.18E-04
^{125}Xe+D	2.74E-01
^{127m}Xe	(c)
^{127}Xe	6.51E-04
^{129m}Xe	5.28E-05
^{131m}Xe	2.01E-05
^{133m}Xe+D	7.43E-05
^{133}Xe	7.71E-05
^{135m}Xe+D	7.56E-04
^{135}Xe+D	6.32E-04
^{137}Xe	(c)
^{138}Xe	2.10E-03
^{138}Xe+D	3.04E-03
^{131}Cs	5.53E-03
^{132}Cs	4.60E-02
^{134m}Cs	2.59E-04
^{134m}Cs+D	3.41E-03
^{134}Cs	1.97E+01
^{135}Cs	2.08E+00
^{136}Cs	5.93E-01
^{137}Cs+D	1.46E+01
^{138}Cs	5.84E-03
^{139}Cs	(c)
^{131}Ba+D	8.40E-02
^{133m}Ba+D	7.95E-03
^{133}Ba	5.59E-01
^{137m}Ba	1.61E-04
^{139}Ba	9.47E-04
^{140}Ba	1.21E-01
^{140}Ba+D	4.72E-01
^{141}Ba+D	2.07E-03
^{142}Ba	1.80E-03
^{142}Ba+D	2.23E-03
^{138}La	2.35E+00
^{140}La	6.18E-02
^{141}La+D	2.56E-03
^{142}La	8.70E-03
^{139}Ce	1.48E-01
^{141}Ce	8.24E-02
^{142}Ce	(c)
^{143}Ce+D	1.74E-02
^{144}Ce+D	7.72E-01
^{143}Pr	4.09E-02
^{144m}Pr	5.69E-06
^{144m}Pr+D	8.66E-05

Nuclide or Decay Chain [a, b]	Dose Per Unit Release Factor (mrem/y per Ci/y released)
^{144}Pr	3.03E-04
^{144}Nd	(c)
^{147}Nd+D	5.54E-02
^{145}Pm	9.28E-02
^{146}Pm+D	1.16E+00
^{147}Pm+D	8.91E-02
^{148m}Pm+D	9.46E-01
^{148}Pm	7.45E-02
^{149}Pm	1.14E-02
^{151}Pm+D	1.12E-02
^{145}Sm+D	8.98E-02
^{146}Sm	1.68E+02
^{147}Sm	1.52E+02
^{151}Sm	6.66E-02
^{153}Sm	1.13E-02
^{157}Sm	(c)
^{150}Eu	8.21E-01
^{152m}Eu+D	4.06E-01
^{152}Eu+D	6.52E-01
^{154}Eu	8.22E-01
^{155}Eu	1.84E-01
^{156}Eu	1.54E+00
^{157}Eu	5.94E-02
^{148}Gd	1.81E+02
^{149}Gd+D	6.42E-02
^{151}Gd+D	6.19E-02
^{152}Gd	1.26E+02
^{153}Gd	1.28E-01
^{160}Tb	7.87E-01
^{166m}Ho	3.85E+00
^{166}Ho	8.25E-03
^{170}Tm	1.70E-01
^{171}Tm	2.69E-02
^{164}Yb	(c)
^{169}Yb	1.01E-01
^{175}Yb	1.23E-02
^{177}Yb+D	1.49E-03
^{177}Lu	1.98E-02
^{175}Hf	2.34E-01
^{178m}Hf	4.59E+00
^{181}Hf	3.26E-01
^{182}Hf	2.38E+00
^{182}Hf+D	2.87E+00
^{179}Ta	3.51E-02
^{182}Ta	1.05E+00

Nuclide or Decay Chain [a, b]	Dose Per Unit Release Factor (mrem/y per Ci/y released)
^{183}Ta	4.85E-02
^{181}W	1.27E-01
^{185}W	4.77E-01
^{187}W+D	1.20E-02
^{188}W+D	2.20E+00
^{186}Re	2.80E-02
^{187}Re	2.39E-03
^{188}Re	9.37E-03
^{191}Os	3.77E-02
^{192}Ir	6.19E-01
^{195}Au	1.15E-01
^{198}Au	2.71E-02
^{203}Hg	4.21E-01
^{204}Tl	6.55E-01
^{207}Tl	7.76E-06
^{206}Tl	5.74E-06
^{208}Tl	1.48E-03
^{209}Tl+D	4.11E-04
^{209}Pb	8.55E-04
^{210}Pb+D	5.70E+01
^{211}Pb+D	1.47E-01
^{212}Pb+D	2.69E+00
^{214}Pb	1.70E-01
^{214}Pb+D	2.22E-01
^{207}Bi	1.99E+00
^{210}Bi	1.45E+00
^{210}Bi+D	1.76E+00
^{211}Bi	7.89E-06
^{211}Bi+D	1.28E-05
^{212}Bi+D	4.38E-01
^{213}Bi+D	4.08E-01
^{214}Bi+D	1.72E-01
^{208}Po	(c)
^{209}Po	(c)
^{210}Po	5.97E+01
^{211}Po	0.00E+00
^{212}Po	0.00E+00
^{213}Po+D	0.00E+00
^{214}Po+D	0.00E+00
^{215}Po	0.00E+00
^{215}Po+D	1.20E-07
^{216}Po	0.00E+00
^{216}Po+D	1.05E-05
^{218}Po	3.64E-09
^{218}Po+D	2.13E-02

Nuclide or Decay Chain [a, b]	Dose Per Unit Release Factor (mrem/y per Ci/y released)
^{217}At	0.00E+00
^{217}At+D	4.81E-06
^{219}Rn	0.00E+00
^{219}Rn+D	2.68E-04
^{220}Rn	1.95E-09
^{220}Rn+D	3.89E-03
^{222}Rn	1.02E-06
^{222}Rn+D	1.22E-01
^{224}Rn+D	(c)
^{221}Fr	2.29E-05
^{221}Fr+D	3.16E-02
^{223}Fr	1.24E-01
^{223}Fr+D	1.61E-01
^{223}Ra+D	1.16E+02
^{224}Ra+D	4.62E+01
^{225}Ra+D	9.84E+01
^{226}Ra+D	8.65E+01
^{228}Ra+D	1.17E+02
^{225}Ac+D	1.15E+02
^{227}Ac+D	1.15E+03
^{228}Ac+D	1.90E-01
^{227Th}+D	1.62E+02
^{228Th}+D	6.21E+02
^{229Th}+D	1.14E+03
^{230Th}+D	2.26E+02
^{231}Th+D	5.34E-03
^{232}Th+D	3.97E+02
^{233}Th	(c)
^{234}Th	1.46E-01
^{234}Th+D	1.77E-01
^{231}Pa+D	1.48E+03
^{233}Pa+D	1.20E-01
^{234m}Pa+D	5.40E-07
^{234}Pa+D	1.24E-02
^{232}U+D	1.38E+02
^{233}U+D	5.76E+01
^{234}U+D	5.64E+01
^{235}U+D	5.04E+01
^{236}U+D	5.21E+01
^{237}U+D	3.71E-02
^{238}U+D	4.68E+01
^{239}U	3.71E-04
^{239}U+D	4.24E-04
^{240}U	8.38E-03
^{240}U+D	1.04E-02
^{235}Np+D	1.27E-02
^{236}Np+D	(c)
^{237}Np+D	3.60E+02
^{238}Np+D	4.80E-02
^{239}Np+D	1.92E-02
^{240m}Np+D	4.09E-04
^{240}Np+D	4.31E-03
^{234}Pu+D	3.26E-01
^{236}Pu+D	3.07E+02
^{237}Pu+D	2.66E-02
^{238}Pu+D	7.26E+02
^{239}Pu+D	7.89E+02
^{240}Pu+D	7.89E+02
^{241}Pu+D	1.42E+01
^{242}Pu+D	7.48E+02
^{243}Pu+D	1.32E-03
^{244}Pu	(c)
^{241}Am+D	6.56E+02
^{242m}Am+D	5.82E+02
^{242}Am+D	2.70E-01
^{243}Am+D	6.48E+02
^{245}Am+D	8.69E-04
^{241}Cm+D	7.58E-01
^{242}Cm+D	8.10E+01
^{243}Cm+D	4.95E+02
^{244}Cm+D	4.18E+02
^{245}Cm+D	6.67E+02
^{246}Cm+D	6.59E+02
^{247}Cm+D	6.07E+02
^{248}Cm	(c)
^{249}Bk+D	2.55E+00
^{250}Bk+D	1.80E-02
^{249}Cf+D	1.10E+03
^{250}Cf+D	5.22E+02
^{251}Cf+D	1.12E+03
^{252}Cf	(c)
^{254}Es+D	1.34E+02

Notes:

(a) "+D" indicates that listed radionuclide dose includes contribution from parent radionuclide plus decay products grown in during transit.

(b) Dose from the parent alone is only listed if ingrown decay products contribute 10% of the total dose or greater.

(c) Surrogate isotope utilized; see Table 3.4.

Table 3.4. Surrogate Isotopes for Use in Permitting at the PNNL Site

Isotope	Recommended Surrogate Isotope	Resultant Dose Per Unit Release Factor (mrem/y per Ci/y release)
^{15}C	^{11}C	2.18E-03
^{27}Mg	$^{28}Mg+D$ (a)	3.82E-02
^{42}Ar	^{42}K	7.25E-03
^{51}Ti	^{45}Ti	3.52E-03
^{55}Cr	$^{49}Cr+D$	2.80E-03
^{79m}Se	^{79}Se adj (b)	1.68E-11
^{82m}Br	^{82}Br	5.70E-02
^{84m}Br	^{84}Br	4.80E-03
^{85}Br	^{84}Br	4.80E-03
^{89}Kr	^{88}Kr (c)	5.41E-03
^{90}Kr	$^{90}Sr+D$ adj (a, b)	9.47E-07
^{90m}Rb	$^{90}Sr+D$ adj (a, b)	7.56E-06
^{90}Rb	$^{90}Sr+D$ adj (a, b)	4.63E-06
^{91m}Nb	^{94}Nb	1.97E+00
^{91}Nb	^{94}Nb	1.97E+00
^{92}Nb	^{94}Nb (c)	1.97E+00
^{105m}Rh	^{105}Rh	6.34E-03
^{106}In	$^{114m}In+D$ (a)	2.40E-01
^{130m}I	^{130}I	1.35E-01
^{133m}I	$^{133}I+D$ (a)	1.10E-01
^{134m}I	^{134}I	6.63E-03
^{127m}Xe	^{127}Xe	6.51E-04
^{137}Xe	^{135}Xe (c)	6.32E-04
^{139}Cs	^{138}Cs	5.84E-03
^{142}Ce	$^{144}Ce+D$ (a)	7.72E-01
^{144}Nd	^{147}Sm	1.52E+02
^{157}Sm	$^{145}Sm+D$ (a)	8.98E-02
^{164}Yb	^{169}Yb	1.01E-01
^{208}Po	^{210}Po	5.97E+01
^{209}Po	^{210}Po (c)	5.97E+01
$^{224}Rn+D$	$^{224}Ra+D$ adj (a, b)	9.38E-01
^{233}Th	$^{233}Pa+D$ adj (a, b)	6.89E-05
^{244}Pu	$^{239}Pu+D$ (a, c)	7.89E+02
^{248}Cm	$^{245}Cm+D$ (a, c)	6.67E+02
^{252}Cf	$^{250}Cf+D$ (a)	5.22E+02

Notes:

(a) "+D" indicates that listed radionuclide dose includes contribution from parent radionuclide plus decay products grown in during transit.

(b) "adj" indicates values for short-lived isotopes are based on dose from the isotope's first long-lived decay product, adjusted for quantity of the decay product that results from decay of the parent isotope. In mathematical terms:
$Ci_{(Surrogate)} = Ci_{(Parent)} * [t_{1/2\ (Surrogate)} / t_{1/2\ (Parent)}]$.

(c) EPA approved at Oak Ridge National Laboratory.

4.0 Quality Assurance

This section discusses quality assurance (QA) aspects of determining dose-per-unit-release rates for the PNNL Site. An approved technical review checklist for the PNNL Site calculations is also provided.

PNNL quality assurance requirements for sampling and analyzing radiological emissions are outlined in EM-QA-01, *Effluent Management Quality Assurance Plan*. This plan outlines the sampling requirements for the emission unit as well as agreements with PNNL Facilities and Operations to verify that sampling systems and radiological exhaust systems are adequately maintained. The effluent monitoring and quality assurance programs described by the plan are based upon one or more of the following documents:

- 10 CFR Part 830, *Nuclear Safety Management.*
- 40 CFR Part 61, Appendix B, "Method 114—Test Methods for Measuring Radionuclide Emissions from Stationary Sources."
- DOE Order 414.1C, *Quality Assurance*, "Contractor Requirements Document."
- DOE Order 450.1, *Environmental Protection Program.*
- DOE Order 5400.5, *Radiation Protection of the Public and the Environment.*
- DOE/EH-0173T, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, (DOE 1991).
- *EP*A *Requirements for Quality Assurance Project Plans* (QA/R-5).

Dose-per-unit-release estimates for the PNNL Site were reviewed in accordance with the requirements of the PNNL Standards Based Management System subject area for Software Application. Reports that contain technical analyses are reviewed internally at PNNL by subject matter experts, editorial staff, and management. PNNL also conducts periodic management and quality assurance self assessments of internal projects, commensurate with the level of risk and potential implications for public health associated with those projects. A technical review checklist for the PNNL Site radiological dose calculations is attached.

5.0 Technical Review Checklist

for
PNNL Site Radiological Dose Calculations

Document reviewed (include title or description of calculation, document number, author, and date, as applicable):

Pacific Northwest National Laboratory Site Unit Dose Factors For Use in Calculating Radionuclide Air Emissions Potential-to-Emit Doses, CRL-TECH-ESH-007

Submitted by: R.L. Aaberg, May 2007

Scope of Review: Calculations of radiological dose per unit release rate for a maximally exposed member of the public from radiological air effluents at the PNNL Site.

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

K. Rhoads K Rhoads 10/10/07
Technical Reviewer (Printed Name and Signature) Date

COMMENTS (add additional signed and dated pages if necessary):
None.

6.0 Bibliography

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