0069677

Department of Energy

Richland Operations Office
P.O. Box 550
Richland, Washington 99352

06-ESD-0098

MAY 16 2006

Mr. A. W. Conklin, Supervisor
Air Emissions and Defense Waste Section
Washington State Department of Health
P.O. Box 47827
Olympia, Washington 98504

RECEIVED
MAY 22 2006
EDMC

Dear Mr. Conklin:

RESPONSE TO HANFORD SITEWIDE ACTIONS IN NOTICE OF VIOLATION AND COMPLIANCE ORDER ON EMISSION UNIT 296-S-21 AT THE 222-S LABORATORY

Reference: WDOH ltr. to K. A. Klein, RL, and R. J. Schepens, ORP, from A. W. Conklin, "Notice of Violation and Compliance Order," AIR 05-1103, dtd. November 17, 2005.

The reference is a Notice of Violation (NOV) and Compliance Order issued to the U.S. Department of Energy (DOE) by the State of Washington, Department of Health (WDOH). The NOV was for the potential-to-emit (PTE) radiological dose for the 296-S-21 Stack at the 222-S Laboratory having been incorrectly calculated. Order No. 3 of the NOV required that DOE contractors assess their quality assurance programs to determine whether or not adequate processes and organizational safeguards exist to ensure that PTE determinations are accurately prepared. Enclosure 1 contains the completed assessments, which conclude collectively that each contractor currently has an adequate quality assurance program, processes, and organizational safeguards that meet the intent of Order No. 3.

In discussions with DOE and DOE contractor staff held December 7, 2005, WDOH agreed, that in addition to the contractor assessments, the quality assurance (QA) intent of Order No. 3 would be fully met by adding QA enhancements to a document used widely at the Hanford Site for calculating PTEs. The latest version of that document is DOE/RL-2006-29, "Calculating Potential-to-Emit Radiological Doses" (Enclosure 2); formerly, it was HNF-3602, Rev. 2, "Calculating Potential-to-Emit Releases and Doses for FEMPs and NOCs," which had been reviewed and accepted by WDOH. A QA section has been added to this new RL document.

Following WDOH's review of this transmittal, DOE requests a response from WDOH stating whether or not Enclosures 1 and 2 have been approved as meeting the applicable QA portions of Order No. 3.

If you have questions, please contact me, or your staff may contact Doug S. Shoop, Assistant Manager for Safety and Engineering, on (509) 376-0108.

Sincerely,

Keith A. Klein
Manager

ESD:MFJ

Enclosures:
1. DOE Contractor QA Assessments
2. DOE/RL-2006-29

cc w/encl:
Adminstrative Record (file: 222-S Laboratory Notice of Violation)
Environmental Portal, A3-01
D. Zhen, EPA Region 10, Seattle WA.

cc w/o encl:
B. P. Atencio, PNNL
J. M. (Matthew) Barnett, PNNL
G. Bohnee, NPT
N. Ceto, EPA
S. L. Clark, WDOH
B. L. Curn, BNI
L. P. Diediker, FHI
R. H. Engelmann, FHI
E. W. Fordham, WDOH, MSIN B1-42
L. L. Fritz, FHI
R. D. Haggard, BNI
S. Harris, CTUIR
D. W. Hendrickson, Ecology
N. A. Homan, FHI
R. Jim, YN
R. J. Landon, WCH
J. J. Martell, WDOH, MSIN B1-42
P. C. Miller, CH2M
L. L Penn, CH2M
K. A. Peterson, FHI
K. Rhoads, PNNL
D. J. Rokkan, FHI
J. W. Schmidt, WDOH, MSIN B1-42
L. H. Staven, PNNL
J. A. Voogd, CH2M
O. S. Wang, Ecology
P. A. Weiher, JCI
J. G. Woolard, WCH

FLUOR HANFORD QUALITY ASSURANCE PROGRAM ASSESSMENT IN RESPONSE TO ORDER NO. 3 OF 222-S NOTICE OF VIOLATION IN AIR 05-1103

Fluor Hanford
SURVEILLANCE REPORT

Surveillance No.: QA-ESA-EP-SURV-06-086	Page 1 of 3

Subject:
Evaluate FH QA Program with Respect to Potential-to-Emit Determinations

Surveillance Dates: January 9, 2006 through February 3, 2006 — ○ Scheduled ◉ Unscheduled

Team Lead / Team Members:
Darrin Faulk

Organization / Project / Facility Reviewed:
FH Environmental Protection

Personnel Contacted:
Larry Diediker, Don Rokkan, Jeannette Hyatt

Requirement(s) Reviewed:
Washington Administrative Code, WAC-246-247-075(6)
Washington Department of Health Compliance Order AIR-05-1103, Action #3
HNF-MP-599, Quality Assurance Program Description:
Section 2.0, Personnel Qualification and Training; 2.2 Training & Indoctrination #4
Section 4.0, Documents and Records; 2.1 Documents #1 and #3
Section 5.0, Work Processes; 2.1 Work Process Documents #1 and #3
HNF-RD-15332, Environmental Protection Requirements, Section 2.11 Item #1

Document(s) Reviewed:
HNF-3602, Rev. 1, Calculating Potential-to-Emit Releases and Dose for FEMPs and NOCs
HNF-1974, Rev. 1, Radionuclide NESHAPS Potential-to-Emit Assessment
HNF-EP-0528, Rev. 6, NESHAP Quality Assurance Project Plan for Radioactive Air Emissions Data
Management Assessment RC-EP-06-MA-02
Management Assessment RC-EP-04-MA-004
HNF-PRO-15333, Environmental Protection Processes, Section 5.5
HNF-PRO-15334, Effluent and Environmental Monitoring
HNF-PRO-15335, Environmental Permitting and Document Preparation, Section 5.2

Surveillance Results: ◉ Satisfactory ○ Unsatisfactory ☐ Corrected During Surveillance
OCRWM Related? ○ Yes ◉ No
DR / CAR No. (when applicable): N/A

Surveillance Summary:
Based on the WDOH compliance order (AIR-05-1103), Action #3, the FH processes governing determinations of potential-to-emit (PTE) were evaluated with respect to the above referenced sections of HNF-MP-599 and requirements of WAC 246-247-075(6). In addition, corrective actions identified as a result of Management Assessment RC-EP-06-MA-02 were evaluated to determine if they were adequate to prevent recurrence of the condition resulting in the Notice of Violation (NOV).

1. Does the FH QA Program meet the requirements of WAC-246-247-075(6)?

   WAC-246-247-075(6) requires licensed facilities to conduct and document a quality assurance program that is compatible with applicable national standards such as ANSI/ASME NQA-1, 1-1998, ANSI/ASME NQA-2, QA/R-2, and QA/R-5. FH has chosen ASME NQA-1, Quality Assurance Requirements for Nuclear Facility Application, as the applicable national consensus standard which is reflected in HNF-MP-599, Quality Assurance Program Description (QAPD). The QAPD defines the FH implementation of Title 10, Code of Federal Regulations, Part 830, Nuclear Safety Management (10 CFR 830), and DOE Order 414.1A, Contractor Requirements Document, Quality Assurance. Also, radioactive air emissions are covered by the NESHAP Quality Assurance Project Plan for Radioactive Air Emissions Data (HNF-EP-0528-6), which addresses the required elements of EPA QA/R-5.

Fluor Hanford
SURVEILLANCE REPORT (continued)

Surveillance No.: QA-ESA-EP-SURV-06-086 | Page 2 of 3

The FH QA Program meets the requirements of WAC-246-247-075(8).

2. Does FH have work processes in place for performing PTE determinations?

   HNF-PRO-15333 and HNF-PRO-15334 contain information in their glossaries on how PTE can be calculated, but do not provide any procedural steps. This may be an appropriate level of detail for these procedures. HNF-PRO-15335 contains minimal instructions for making PTE determination in support of notices of construction for radioactive emission sources. This procedure needs more detailed instructions.

   Environmental Protection staff use HNF-3602, Calculating Potential-to-Emit Releases and Dose for FEMPs and NOCs, which provides specific instructions for determining PTE. No references to this document are made in the environmental procedures.

   The PTE determination that resulted in NOV AIR-05-1103 was not part of a notice of construction, but was from a periodic stack assessment. In 1998, an assessment was performed of the Project Hanford Management Contract and Bechtel Hanford stacks. Since then, changes occurred in the location of the maximally exposed individual, in the status of onsite facilities, etc., that prompted an updated assessment in 2002. No instructions for these NESHAPs stack assessments could be found in HNF-PRO-15333, 15334, or 15335, except for in the records capture table in HNF-PRO-15333.

   Corrective actions identified from Management Assessment RC-EP-MA-06-02 (F-02, Actions 1 and 2) adequately address these issues. These corrective actions were established during this surveillance.

   See related information in item #5 below.

3. Does FH have processes in place to ensure knowledgeable staff review documents containing PTE determinations for correctness prior to document release?

   HNF-PRO-15335 directs that review and approval of NOC applications, which contain PTE determinations, be done in accordance with HNF-PRO-9679. HNF-PRO-9679 invokes technical review requirements of HNF-PRO-8635, Review and Approval of Technical Documents. Although these references meet requirements, corrective actions identified from Management Assessment RC-EP-MA-06-02 (F-02, Actions 1 and 2) will strengthen the review and approval process for documents containing PTE determinations.

   See related information in item #5 below.

4. Are staff performing PTE determinations adequately trained to perform the task?

   Environmental Compliance Officers have extensive training requirements defined and documented. However, there are currently no specific training requirements or recognized qualifications for Environmental Protection (EP) subject matter experts who perform or support PTE determinations. The lack of identified levels of training for EP subject matter experts was noted in Management Assessment RC-EP-04-MA-004. A corrective action resulting from this assessment (AR29021302) is to develop a training matrix for EP staff. This training matrix will define minimum requirements for job classes within the EP organization and will discuss minimum competency required to be exhibited for each job class. The Manager of Environmental Programs and Policies stated that this information will be incorporated into a revision of the environmental training program description.

FLUOR HANFORD QUALITY ASSURANCE PROGRAM ASSESSMENT IN RESPONSE TO ORDER NO. 3 OF 222-S NOTICE OF VIOLATION IN AIR 05-1103
(cont)

Fluor Hanford
SURVEILLANCE REPORT (continued)

Surveillance No.: QA-ESA-EP-SURV-06-086	Page 3 of 3

Corrective actions previously identified are adequate to address current gaps.

5. Are corrective actions identified as a result of Notice of Violation AIR-05-1103 adequate to prevent recurrence?

   Management Assessment RC-EP-06-MA-02, completed on 11/30/05, identified one finding and one opportunity for improvement related to NOV AIR-05-1103. Issue Identification Forms associated with this assessment were reviewed. Finding F-02, Actions 1 and 2, will address the issues identified in item #2 above. These actions include revising HNF-3602 to include a section on quality assurance that provides guidance on acceptable processes and safeguards for ensuring PTE determinations are accurately made and proceduralizing QA guidance in the appropriate environmental HNF-PRO. The due dates for corrective actions 1 and 2 are 4/24/06 and 7/26/06 respectively. Observation O-06, discusses including details in HNF-1974 related to stack PTE assessments. The associated corrective action (due date 12/1/06) will address other issues that partly led to the NOV. These corrective actions were established during this surveillance.

   No additional corrective actions are identified from this surveillance.

D. E. Faulk [signature]	3/2/06	D. G. Farwick [signature]	3/2/06
Team Lead (Print & Sign)	Date	Manager (Print & Sign)	Date

CH2M HILL QUALITY ASSURANCE PROGRAM ASSESSMENT IN RESPONSE TO ORDER NO. 3 OF 222-S NOTICE OF VIOLATION IN AIR 05-1103

CH2M HILL NESHAPS Quality Assurance Evaluation

Introduction

Washington Department of Health (WDOH) Notice of Violation (NOV) AIR-05-1103, Order #3 directs the Department of Energy to "[within] six months of receipt of this Notice of Violation and Compliance Order, re-evaluate your quality assurance program in accordance with WAC 246-247-075(6) to make certain that adequate processes and organizational safeguards are in place to ensure the adequacy of PTE determinations, and submit a copy of the document to DOH for review and approval." This document presents the results of an evaluation of the CH2M HILL NESHAPs Quality Assurance Program, as requested by the WDOH.

Background

Washington Administrative Code 246-247-075(6) requires licensed facilities to conduct and document a quality assurance (QA) program that is "compatible with applicable national standards such as ANSI/ASME NQA-1-1989, ANSI/ASME NQA2, QA/R-2, and QA/R-5." In compliance with this requirement, the CH2M HILL Quality Assurance Program Plan is based upon ASME-NQA-1-2000, *Quality Assurance Program Requirements for Nuclear Facility application.*

The following criteria from NQA-1 represent essential elements of a QA program:

- Requirement 2, Quality Assurance Program

  100 Basic (b): The program shall provide for indoctrination, training, and qualification as necessary for personnel performing or managing activities affecting quality to assure that suitable proficiency is achieved and maintained.

- Requirement 3, Design Control

  100 Basic: The design shall be defined, controlled, and verified. Design inputs shall be specified on a timely basis and translated into design documents. Design interfaces shall be identified and controlled. Design adequacy shall be verified by individuals other than those who designed the item or computer program. Design changes shall be governed by control measures commensurate with those applied to the original design.

- Requirement 6, Document Control

  100 Basic: The preparation, issue, and change of documents that specify quality requirements or prescribe activities affecting quality such as instructions, procedures, and drawings shall be controlled to assure that correct documents are being employed. Such documents, including changes thereto, shall be reviewed for adequacy and approved for release by authorized personnel.

CH2M HILL QUALITY ASSURANCE PROGRAM ASSESSMENT IN RESPONSE TO ORDER NO. 3 OF 222-S NOTICE OF VIOLATION IN AIR 05-1103 (cont)

Evaluation

The following Lines of Inquiry were used as guidance to evaluate the existing quality assurance program and to ensure that adequate processes and organization safeguards are in place to provide accurate potential to emit (PTE) determinations:

1. Does the CH2M HILL QA program meet the requirements of WAC 246-247-075(6)?

   The CH2M HILL Hanford Group, Inc. Quality Assurance Program is based on the requirements of Title 10 of the Code of Federal Regulation, Part 830, Subpart A (10 CFR 830, Subpart A), *Quality Assurance Requirements*, and DOE Order 414.1C, *Quality Assurance*. The TFC-PLN-02, *Quality Assurance Program Description*, is structured to capture and integrate into a single cohesive QA program, all necessary regulatory and contractual quality assurance requirements. It establishes implementing requirements, assigns responsibilities, and describes the management systems established to assure the quality of the Tank Farm activities and products. Inherent within this framework, are the appropriate national and international consensus standards. In this case ASME NQA-1-2000, *Quality Assurance Program Requirements for Nuclear Facility application* is used as the implementing standard, as prescribed by WAC 246-247-075(6).

2. Are work processes in place to perform PTE determinations in support of NOCs? (NQA-1 Requirements 2 and 3)

   Procedures are in place to ensure that permitting needs are considered when planning new activities or modifications to emission units. Emission Unit PTE determinations and Radioactive Air Notices of Constructions are prepared in accordance with WAC 246-247-030(21) "Potential to Emit" and WAC-246-247-110, Appendix A, respectively. Guidance is drawn from HNF-3602 Rev. 1, *Calculating Potential-to-Emit Releases and Doses for FEMPs and NOCs.*

   The predominating CH2M Hill derivational methods employed in PTE assessments are inventory based. Infrequently, Non-destructive Assay or HEPA Filter Assay are used to verify assumptions or by request of the Washington Department of Health.

3. Are processes in place to ensure that knowledgeable staff review documents for correctness prior to release? (NQA-1 Requirement 6)

   In order to maintain consistent quality, the final PTE or NOC documents are reviewed by Environmental management, Engineering, and a Regulatory subject matter expert in accordance with by TFC-ESHG-ENV-STD-03, *Air Quality – Radioactive Emissions*" Engineering and technical evaluations and calculations are validated in accordance with TFC-ENG-DESIGN-C-10, *Engineering Calculations*. Spreadsheets are reviewed and validated in accordance with TFC-ENG-DESIGN-C-32, *Spreadsheet Development and Verification.*

4. Are personnel performing PTE determinations adequately trained to perform the work? (NQA-1 requirement 2)

   Those quality elements ensuring the training, skills and competence of personnel designing, evaluating and determining status of NESHAPS emissions and controls are captured in the hierarchy of procedures identifying prescriptive measures for implementation of the QAPD. The requisite educational background, experience, certifications and site training for technical and engineering positions are controlled by TFC-PLN-61, *Tank Farm Contractor Training and Qualification Plan.* TFC-BSM-TQ-STD-01, *Technical Staff Qualification Requirements,* identifies the requisite qualification cards for all professionals. Immediate line managers determine position training requirements and a training matrix is maintained for each staff member.

5. Are corrective actions identified as a result of NOV AIR-05-1103 adequate to prevent recurrence?

   Since the date of occurrence, programs and procedures cited in items 1 through 4 have been updated to ensure full integration of 222-S Laboratories and Tank Farms quality assurance process. These programs and procedures are adequate to prevent recurrence. Additionally, to ensure the quality of existing PTE determinations, all previous Tank Farm stack designation determinations documented in HNF-SD-WM-EMP-031, *Tank Farm Stack NESHAP Designation Determinations* were reviewed and updated in the spring of 2006. No corrective actions or deficiencies were identified as a result of this assessment.

<u>Conclusion</u>

The CH2M Hill Quality Assurance Program meets the requirements of WAC 246-247-075(6). This program is based upon NQA-1-2000 standards providing guidance for training and qualification of personnel responsible for activities affecting quality, guidance for procedures to control and verify design adequacy, and guidance for document control sufficient to assure accuracy in the development and validation of documents. These processes and organizational safeguards are designed to ensure the adequacy of PTE determinations.

Signature of Evaluator — Date

Signature of Manager — Date

PACIFIC NORTHWEST NATIONAL LABORATORY QUALITY ASSURANCE PROGRAM ASSESSMENT IN RESPONSE TO ORDER NO. 3 OF 222-S NOTICE OF VIOLATION IN AIR 05-1103

EXHIBIT 2

SELF-ASSESSMENT RESULTS

Title: Effluent Management Quality Assurance for Potential-To-Emit Determinations	**I.D. Number:** ATS# 14932
Assessor: BC Barfuss	**Date:** 4/5/2006

Results
(Related to Associated Performance Expectations)

Concise and objective statements are the goal. Subjective comments may be added at the end and must be based upon a series of facts that supports the comments. Include strengths and improvement opportunities. Include date the information is obtained and list of line manager or points-of-contact during assessment. *(Use Additional pages if necessary.)*

Summary:

Washington Department of Health (WDOH) compliance order (AIR-05-1103), Action No. 3 of the "222-S" notice of violation (NOV) requires that the Department of Energy (DOE) and its prime contractors with stacks evaluate its quality assurance (QA) program in accordance with WAC 246-247-075(6) to make certain that adequate processes and organizational safeguards are in place to provide accurate potential-to-emit (PTE) determinations.

The assessor reviewed the Effluent Management quality assurance program for compliance with WAC 246-247-075(6). PTE calculational processes were reviewed for adequacy, and current organizational safeguards were reviewed to evaluate whether knowledgeable staff review documents prior to release. The assessor interviewed the Effluent Management staff responsible for providing PTE determinations and reviewed the organizational processes for providing and implementing training and qualification requirements. No corrective actions or deficiencies were identified as a result of this assessment.

Documents Reviewed:

- EM-QA-01, Rev. 5, *Effluent Management Quality Assurance Plan*
- PNNL-10855, Rev 3, *Assessment of Unabated Facility Emission Potentials for Evaluating Airborne Radionuclide Monitoring Requirements at Pacific Northwest National Laboratory*
- *Environmental Management Services Department Non-Reactor Nuclear Facility Training Plan Pacific Northwest National Laboratory*, April 2005.
- PNL-MA-834, Rev 2, *Training Implementation Matrix*
- EMS-AIR-013, Rev. 4, *Preparing Notice of Construction Applications for Radioactive Air Emissions*
- *Summary of Annual Radionuclide Inventory Assessment Review Process – 2005/6*
- *RPL Potential-to-Emit Determination 2005.*

Staff Interviewed:

- Todd Gervais

1. Does the PNNL quality assurance program meet the requirements of WAC-246-247-075(6)?

WAC-246-247-075(6) requires licensed facilities to conduct and document a quality assurance program that is compatible with applicable national standards such as ANSI/ASME NQA-1-1988, ANSI/ASME NQA-2-1986, QA/R-2, and QA/R-5. The PNNL QA program, as described in EM-QA-01, *Effluent Management Quality Assurance Plan*, is compatible with the applicable national standards of QA/R-5 and is based on the requirements defined in DOE Order 414.1A, *Quality Assurance*, and 10 CFR 830, *Energy/Nuclear Safety Management*, Subpart A, *Quality Assurance Requirements*. The quality assurance plan described in EM-QA-01 meets the WAC-246-247-075(6) requirement.

2. Does PNNL have work processes in place for performing PTE determinations?

PNNL-10855, Rev 3, *Assessment of Unabated Facility Emission Potentials for Evaluating Airborne Radionuclide Monitoring Requirements at Pacific Northwest National Laboratory* describes the methods and processes used by PNNL to determine the potential emissions of radioactive materials from PNNL operated facilities. WAC-246-247 prescribes several methods for projecting potential unmitigated annual emission quantities. PNNL employs an inventory-based calculational method in performing PTE determinations. Inventory information is managed and tracked using the Radioactive Material Tracking System (RMT).

PACIFIC NORTHWEST NATIONAL LABORATORY QUALITY ASSURANCE PROGRAM ASSESSMENT IN RESPONSE TO ORDER NO. 3 OF 222-S NOTICE OF VIOLATION IN AIR 05-1103 (cont)

3. Does PNNL have processes in place to provide that knowledgeable staff review documents containing PTE determinations for correctness prior to document release?

PNNL-10855, Section 2.3, *Potential Emission Dose Assessment*, directs that periodic PTE assessment documents be independently reviewed. Annual facility radionuclide assessments and PTE determinations are subsequently reviewed and approved by the assessment preparer, a reviewer, the divisional facility representatives of inventory custodians, and the relevant building managers.

EMS-AIR-013, Section 7.2, *Internal Review and Approval*, outlines the review and approval process for preparation of Notice of Construction (NOC) documentation containing PTE determinations. The EMS-AIR-013 process implements the technical review requirements of EM-QA-01.

The annual NESHAPs assessment prepared by Effluent Management for PNNL operated facilities is reviewed by the Radiological Air Task Lead prior to document release.

4. Are staff performing PTE determinations adequately trained to perform the task?

Effluent Management staff are responsible for performing PTE determinations for PNNL operated facilities. EM-QA-01, Section 2, *Personnel Training and Qualification* describes training requirements and qualifications of Effluent Management staff. Additionally, the training requirements for EM staff working in nuclear facilities are defined in the *Environmental Management Services Department Non-Reactor Nuclear Facility Training Plan.*

EM-QA-01, Section 2.5, *Project-Specific Training*, details the responsibilities and methods of developing task specific training. Training may be in the form of classes, reading assignments and briefings. Training is documented and forwarded to Laboratory Training Coordination and maintained in each staff members training and qualification records.

Effluent management utilizes the Staff Development and Review (SDR) Process to continually assess staff performance, qualification, and training requirements. Immediate line managers determine staff training requirements and request additional training, courses, and skill enhancements necessary to effectively perform specific tasks. SDR annual review documents describe staff member's position scope, accountabilities and the level of knowledge, skill, and education required to perform the position.

Conclusion: No corrective actions or deficiencies were identified as a result of this assessment.

Subsequent Actions
(*Related to Associated Results*)

Assigned Action	Action Owner	Due Date	ATS Tracking ID
1. N/A			
2.			
3.			
4.			
5.			
6.			

Actions Assigned By: Date:

Completion (*To be signed by lead assessor when assessment is completed.*)
Signature: Brad C. Barfuss
Date: 4/7/2006

Completion (*To be signed by manager when assessment is completed and all actions have been entered into ATS*)
Signature: Brad Ateuncio
Date: 4/7/2006

WASHINGTON CLOSURE HANFORD QUALITY ASSURANCE PROGRAM ASSESSMENT IN RESPONSE TO ORDER NO. 3 OF 222-S NOTICE OF VIOLATION IN AIR 05-1103

Background

The Washington Department of Health (WDOH) issued a Notice of Violation and Compliance Order, AIR 05-1103, on November 17, 2005. The notice of violation (NOV) was issued for incorrectly designating the 296-S-21 emission unit at the 222-S laboratory as a "minor" emission unit based on a miscalculation of the emission unit's potential-to-emit. The NOV and Order identified some actions that apply to the entire Hanford Site. The Department of Energy requested FH to work jointly with to other site contractors to coordinate input.

Item #3 of Section II, Order, requires the following:

"Within six months of receipt of this Notice of Violation and Compliance Order, re-evaluate your quality assurance program in accordance with WAC 246-247-075(6) to make certain that adequate processes and organizational safeguards are in place to ensure the accuracy of PTE determinations, and submit a copy of the document to DOH for review and approval."

Washington Administrative Code 246-247-075(6) requires licensed facilities to conduct and document a quality assurance (QA) program that is "compatible with applicable national standards such as ANSI/ASME NQA-1, 1-1998, ANSI/ASME NQA-2-1986, QA/R-2, and QA/R-5". The WCH QA program is documented in ENV-1-1.15, *Quality Assurance Project Plan for Radiological Air Emissions Monitoring* that is selectively modeled after QA/G-5. The EPA document QA/G-5 addresses the specifications of QA/R-5 and provides guidance in developing quality assurance project plans.

Evaluation

The WCH has an existing process for preparing and documenting calculations that is defined in EDPI-4.37-01, *Project Calculations*. This procedure will be replaced with WCH procedure ENG-1-4.5, *Project Calculations*. The project calculation procedure identifies the method and format for preparing, checking, reviewing, revising, filing, retaining, and releasing calculations. The procedure calculation also identifies the requirement to assign qualified personnel to originate and check calculations.

The new WCH Procedure ENV-1-1.15, *Quality Assurance Project Plan*, requires that PTE determinations are to be prepared in accordance with ENG-1-4.5, *Project Calculations*. The new WCH environmental requirements procedure, ENV-1-1.1, *Air Quality*, also requires project calculations to be documented and verified in accordance with ENG-1-4.5, *Project Calculations*. Personnel assigned to WCH are required to work to EDPI-4-37.01 until ENG-1-4.5 is released. The process established in project calculation procedures should ensure the accuracy of PTE determinations.

DOE/RL-2006-29
Revision O

Calculating Potential-to-Emit Radiological Releases and Doses

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

United States
Department of Energy
P.O. Box 550
Richland, Washington 99352

DOE/RL-2006-29
Revision O

Calculating Potential-to-Emit Radiological Releases and Doses

L. P. Diediker
D. J. Rokkan
Fluor Hanford, Inc.

K. Rhoads
L. H. Staven
Pacific Northwest National Laboratory

Date Published
May 2006

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

United States
Department of Energy
P.O. Box 550
Richland, Washington 99352

Release Approval   Date

Printed in the United States of America

CONTENTS

GLOSSARY v

1.0 INTRODUCTION 1-1

2.0 ESTIMATING POTENTIAL EMISSIONS 2-1
2.1 APPROVED METHODS 2-1
2.1.1 Method 1: Annual Possession Quantity 2-1
2.1.2 Method 2: Back-Calculating Emissions and In Situ Measurements 2-2
2.1.3 Method 3: Control Device and In Situ Measurements 2-2
2.1.4 Method 4: Measurement Upstream of Control Device 2-3
2.1.5 Method 5: Release Fractions 2-3
2.2 METHODS NOT APPROVED 2-4

3.0 CALCULATING DOSES TO THE MAXIUMUM PUBLIC RECEPTOR 3-1
3.1 CALCULATING RELEASES 3-1
3.2 SELECTING THE APPROPRIATE DOSE-PER-UNIT RELEASE FACTORS 3-2
3.2.1 Calculating Effective Release Height 3-2
3.2.2 Using Dose-Per-Unit Release Factor Tables 3-5
3.2.3 Handling Radioactive Decay Chains 3-5
3.3 RADIONUCLIDES WITHOUT DOSE-PER-UNIT RELEASE FACTORS 3-5
3.4 WHEN A SCENARIO-SPECIFIC CAP88-PC RUN IS WARRANTED 3-6
3.4.1 Emission Units Outside Emission Zones 3-6
3.4.2 Nonchronic Releases 3-6
3.4.3 Estimated Doses Near 0.1 mrem/yr 3-7
3.4.4 Default Lung-Retention Classes or Particle Sizes That Are Inappropriate 3-7
3.4.5 Releases Dominated by Volatile Radionuclides 3-8
3.4.6 Releases from Area Sources 3-8
3.4.7 Releases Dominated by Short-Lived Radionuclides 3-12
3.5 CALCULATING DOSES 3-13
3.6 REPORTING RELEASES AND DOSES IN AN NOC 3-16

4.0 DOSE-PER-UNIT RELEASE FACTORS FOR AIR EMISSIONS 4-1
4.1 OVERVIEW 4-1
4.2 USE OF HANFORD-SPECIFIC PARAMETERS AND DATA FOR DEMONSTRATING COMPLIANCE WITH AIR PATHWAY RADIATION DOSE STANDARDS 4-1
4.2.1 Regulatory Background 4-1
4.2.2 History of Data Used in Hanford Site Compliance Calculations 4-2
4.2.3 Hanford-Specific Parameters 4-2
4.2.4 Approval for Use of Hanford-Specific Parameters 4-3
4.2.5 Calculation of Worker Release-per-Unit Release Factors Using CAP88-PC and Regional Ingestion 4-3

5.0 QUALITY ASSURANCE: PTE DETERMINATION AND PEER REVIEW 5-1

6.0 PEER REVIEW DOCUMENTATION 6-1

7.0 REFERENCES 7-1

FIGURES

Figure 4-1. Hanford Site Map of Emission Zones.. 4-5
Figure 4-2. 300 Area Map of Emission Zones. 4-6

TABLES

Table 3-1. Default Lung-Clearance Classes and Particle Sizes in CAP88-PC.............................. 3-9
Table 3-2. Example 1: Decay-Corrected Radionuclide Inventory. 3-13
Table 3-3. Example 1: Potential-to-Emit Calculation for an Elevated Release from the Western Portion of the 300 Area. 3-14
Table 3-4. Example 2: Potential-to-Emit Calculation for a Ground-Level Release from the Eastern Portion of the 300 Area. 3-15
Table 3-5. Example 3: Original Assessed Potential-to-Emit for the Stack. 3-16
Table 3-6. Example 3: Original Assessed Potential-to-Emit for the Stack NOC. 3-17
Table 3-7. Example 3: Assessed Potential-to-Emit for the New Activity. 3-17
Table 3-8. Example 4: Assessed Potential-to-Emit for Stack, including New Activity. 3-18
Table 3-9. Example 3: Assessed Potential-to-Emit for the Stack NOC. 3-18
Table 3-10. Example 3: Detectability Check for Biweekly Sampling 3-19
Table 3-11. Example 3: Detectability Check for Monthly Sampling When Stack Operates at 2,500 cfm. 3-19
Table 3-12. Example 3: Detectability Check for Biweekly Sampling When Stack Operates at 1,900 cfm. 3-19
Table 4-1. Release Locations and Meteorological Stations Used. 4-7
Table 4-2. Direction and Distance to Each MPR Location from Respective Emission Zone. 4-8
Table 4-3. 100-B/C Area: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height. 4-9
Table 4-4. 100-D/DR Area: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height. 4-13
Table 4-5. 100-F Area: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height. 4-17
Table 4-6. 100-H Area: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height. 4-21
Table 4-7. 100-K Area: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height. 4-25
Table 4-8. 100-N Area: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height. 4-29

ABBREVIATIONS AND ACRONYMS

AED	aerodynamic equivalent diameter
AMAD	activity median aerodynamic diameter
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
DCG	Derived Concentration Guides
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
HEDOP	Hanford Environmental Dose Overview Panel
HEPA	high-efficiency particulate air [filter]
LIGO	Laser Interferometer Gravitational Wave Observatory
NDA	nondestructive assay
NOC	Notice of Construction
MEI	Maximally Exposed Individual
MPR	Maximum Public Receptor
PNNL	Pacific Northwest National Laboratory
PTRAEU	Portable Temporary Radioactive Air Emission Unit
WAC	Washington Administrative Code
WDOH	State of Washington Department of Health

DEFINITIONS

Acute Release — A short duration release with a significant emission rate.

Chronic Release — When emissions are nearly continuous and the emission rate is nearly constant for a period of at least 3 months.

Emission Zone — The Hanford Site has five major operating areas, the 100, 200 East, 200 West, 300, and 400 Areas, with the 100 Areas consisting of several distinct operating areas: 100-B/C, 100-D/DR, 100-F, 100-F, 100-KE/KW, and 100-N. Within those operating areas, 11 emission zones were established, based on differing receptor locations, atmospheric dispersion factors, and source locations. The emission zones are typically defined by the boundaries of each operating area, except for the 300 Area, which was divided into two emission zones (300-E and 300-W) representative of their distinctly different meteorology. For all facilities or outside activities located within an emission zone, the Dose-Per-Unit Release factors for that zone are to be used.

Maximum Public Receptor — The Maximum Public Receptor (MPR) is defined in greater detail below, along with a similarly detailed definition of the Maximally Exposed Individual (MEI). But first, a simplified "bulleted" listing of MPR and MEI attributes is given next to highlight their differences.

MPR attributes:

- a real or hypothetical member of the public at a location that is now occupied or could be occupied in the future
- may include a member of the public who is not employed by the Department of Energy or its contractors and who has unrestricted access to a work location on the Hanford Site
- a person or location that receives the maximum radiological dose from emissions emanating from a particular facility or emission zone
- determined by a prospective calculation using data reflecting future potential emissions
- use of meteorological data averaged over a long period; i.e., several years, at least
- hypothetical annual emission rates: either a potential-to-emit (i.e., unabated) emission rate or an abated emission rate estimate
- used to determine emission monitoring requirements for permitting new emission sources and for modifications to existing emission sources.

MEI attributes:

- an actual person who could occupy a qualifying school, business, or residence for a substantial fraction of a year
- a person who receives the maximum dose from all Hanford emission points
- can include a member of the public who is not employed by the Department of Energy or its contractors and who has unrestricted access to a work location on the Hanford Site
- determined by a retrospective calculation using data on actual emissions in a past calendar year
- meteorological data from the year analyzed are used for determining the dispersion factors
- emissions are measured or estimated "actual" annual emissions from Hanford facility operations, including diffuse and fugitive sources of emissions
- used for demonstrating compliance with emission standards

Maximum Public Receptor — MPRs are real or hypothetical members of the public at locations off the Hanford Site or on the Hanford Site at work locations with unrestricted access who incur the maximum radiological dose from a single source located within one of 11 established Hanford Site emissions zones. At least one MPR was established for each of the emission zones at the Hanford Site, whether those receptors are located onsite or offsite. Potential MPRs include employees working at facilities on the Hanford Site leased or owned by companies not affiliated with the Department of Energy or its contractors. Facilities at which MPRs work are further defined as affording unrestricted access to any member of the public. All MPRs are conservatively assumed to be at their locations 24 hours a day, every day of the year. Dispersion factors for particulate, volatile, and gaseous radionuclide emissions, based on multi-year meteorological data, are used to determine MPR locations. The geographic directions for the dispersion factors are identified within each emission zone. Distance from a central release point within an emission zone to potential MPRs is also a factor. MPRs locations, then, are those places at which the highest possible prospective (as opposed to actual historical) dose is calculated, using a combination of dispersion factors and distance to a potential MPR, along with other CAP88-PC parameters such as inhalation, exposure, and ingestion rates. Offsite MPR locations are always at the Hanford Site boundary where the potential exists for full occupancy by a member of the public. Onsite MPR locations are currently limited to two locations: the Energy Northwest Columbia Generating Station and the Laser Interferometer Gravitational

Wave Observatory (LIGO). Determining which MPR location is applicable to which emission zone depends on the combination of all parameters.

Three of the current 11 emission zones have dose-per-unit release factors for both an offsite and an onsite MPR. Those emission zone MPRs are determined by the radionuclides being modeled, which may vary according to the potential-to-emit source of radionuclides. This means the MPR for one activity may be onsite but another activity that emits a different mix of radionuclides may have an MPR located offsite. For the eight emissions zones (all six 100 Area zones and the two 300 Area zones) having each only a single MPR (offsite in every case), the offsite MPR dose factors for every radionuclide in the CAP88-PC library were greater than the respective onsite dose factors, which obviated the listing of onsite factors.

Maximally Exposed Individual — The Maximally Exposed Individual (MEI) is a member of the public who is located either off the Hanford Site or at on onsite location where access is unrestricted. The MEI incurs the maximum radiological dose from all measured and/or calculated radionuclide emissions from the Hanford Site during a past calendar year. Therefore, the MEI dose-model calculation is *retrospective* in nature and uses actual emission and meteorological data gathered from just the year evaluated. Emissions affecting the MEI 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. The meteorology is different in models for the Maximum Public Receptor (MPR) used to estimate potential-to-emit conditions for, say, Notices of Construction. The MPR meteorology reflected in this document encompasses as much as 14 years of data for most potential MPR locations. To that extent, the MEI and MPR differ. They also differ in that the MPR is hypothetically exposed for a prospective future year's worth of potential emissions from an individual source within a single emission zone, whereas the MEI is exposed to all actual emissions from the Hanford Site for a previous calendar year. Consequently, the dose-per-unit release factors for the MEI vary from those for the numerous MPRs. In a given year, an MPR location may be the same as the MEI location, yet even so the dose factors will not be the same, largely because of the differing meteorological data used. The MEI location, however, will not serve as the MPR location for every Hanford emission zone, nor should the term MEI be used interchangeably with MPR.

Stack Designation — Hanford Site stacks and vents that have or could potentially have emissions of radioactive material are classified as either "designated" (aka Category 1 or "major") or nondesignated (aka Category 2 or "minor"). A designated stack has the potential to discharge radionuclides into the air that could cause an effective dose equivalent (EDE) in excess of 0.1 mrem/year. A nondesignated stack has the potential to discharge radionuclides into the air that could cause no more than 0.1 mrem/year EDE. Potential-to-emit (PTE) calculations are performed to determine the classification of stacks and vents (PTE calculations are also done for activities involving non-point sources [i.e., not a stack or vent] that could potentially release radionuclides into the ambient air).

This page intentionally left blank.

1.0 INTRODUCTION

This document is essentially a handbook offered as a convenience to Hanford Site personnel when they need to estimate radionuclide emissions and subsequent radiological doses to both offsite and onsite members of the public (it supersedes a Fluor Hanford document, *Calculating Potential-to-Emit Releases and Dose for FEMPs and NOCs* [HNF-3602, Rev. 1, 2002]). Such potential doses are often needed for determining point source categorization (i.e., "stack designation") and Notices of Construction (NOC). Onsite members of the public are those who have unrestricted access to their workplace within Hanford Site boundaries but who are not employed by the U.S. Department of Energy (DOE) or its contractors. Within the context of this document, members of the public for whom radiological dose factors have been provided for estimating potential maximum doses they might receive are termed Maximum Public Receptors (MPRs). They vary in location according to their geographical relationship to radionuclide emission points, meteorological conditions, and levels and types of radionuclide emissions. Information and methods are given for estimating emissions from facilities or emission units and the resulting effective dose equivalent (EDE) to an MPR for use in regulatory NOCs, in accordance with requirements in 40 CFR Part 61, Subpart H, and with Washington Administrative Code (WAC) Chapters 246-247.

> Note: Care should be taken not to use the information in this document for applications other than those approved. A key example of an inappropriate application is using this document to estimate actual emissions for demonstration of compliance with annual dose limits. The Hanford Site effluent monitoring and reporting program annually demonstrates for both individual facilities and cumulatively for the Site the measure of compliance with DOE, state, and federal requirements imposed on actual radionuclide air emissions. The dose model that uses the measured emission data focuses on the Maximally Exposed Individual (MEI), who is not necessarily the same individual as any MPR identified herein. The dose factors used in the annual MEI model differ from MPR dose factors because the meteorology associated with the MEI is from only the year being evaluated for compliance.

Hanford-specific meteorological data from a 14-year period (1983 through 1996) were integrated into the dose-per-unit release factors (dose factors) presented in this document for determining the effective dose equivalent (EDE) to an MPR, whether located on or off the Hanford Site. Members of the public who work on the Hanford Site at locations to which access is unrestricted (i.e., no Hanford-specific security or radiological requirements imposed) are to be evaluated as potential MPRs. Only two of the meteorological stations, numbers 23 and 24, respectively, at Gable Mountain and the 100-F Area, had 10-year data sets, 1986 through 1996. Data sets from those locations are shorter because data collection there began later than at other locations.

The methods and information in this document have been reviewed and for technical validity as described in *Recommended Environmental Dose Calculation Methods and Hanford-Specific Parameters* (PNNL-3777). Although the by a Hanford Environmental Dose Overview Program, initiated by the DOE Richland Operations Office in the 1970s, is no longer active, the parameters and principles described in the document are still considered valid for preparing assessment involving the environmental transport of radioactive material that could be, or has been, released from a Hanford Site facility or operation. Thos Hanford-specific parameters have been approved by both EPA and WDOH for use in compliance, permitting, and reporting calculations.

This page intentionally left blank.

2.0 ESTIMATING POTENTIAL EMISSIONS

This document describes methods currently accepted by the State of Washington Department of Health (WDOH) and the United States Environmental Protection Agency (EPA) Region 10. Other acceptable methods are available for estimating potential emissions; however, methods that differ from those described herein may require a more extensive review and approval cycle.

2.1 APPROVED METHODS

Four methods for estimating potential unabated emissions are approved for use by WAC Chapter 246-247-30(21). The methods are:

1. multiply the annual possession quantity of each radionuclide by the release fractions provided in WAC Chapter 246-247-30(21)(a) and in 40 CFR Part 61, Appendix D
2. back-calculate using measured emission rates and in situ measurements of control device efficiencies, as approved by WDOH
3. measure the quantities of radionuclides captured in each control device, coupled with in situ measurements of control equipment efficiencies, as approved by WDOH
4. sample the effluent upstream from all control devices, as approved by WDOH.

Washington Administrative Code 246-247-30(21)(e) and 40 CFR Part 61, Subpart H, Section 61.96, allow alternative methods, but prior to use they must be approved by WDOH and EPA Region 10. They have previously approved the following alternative method, designated here as method 5, for estimating potential emissions:

5. multiply the annual possession quantity of each radionuclide by material-specific spill-release fractions, rather than using release fractions in WAC 246-247 and 40 CFR Part 61, Appendix D.

Method 1 above is authorized by 40 CFR Part 61, Subpart H, for calculating potential emissions. EPA Region 10 has also previously approved the use of Methods 2 through 5. The use of methods other than Methods 1 through 5 usually require a more extensive review and approval process.

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 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 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 Appendix D. For example, in an accident scenario for a spill of powder from a 1-meter height, a 4 E–05 release fraction (Sutter et al. 1981) would be used when the particle size is 10-micron aerodynamic-equivalent diameter (AED) and less. Likewise, a 4 E–05 release fraction (Sutter et al. 1981) would be used for a liquid spill from a 3-m height. The release fractions for both of these cases are more than two orders of magnitude lower than the Appendix D release fraction of 1 E–03 for particulate solids.

When the source-term properties are known and alternate release fractions are available, use of Method 5 should be considered.

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 unabated emissions.

Most of Hanford emission-control equipment includes a high-efficiency particulate air (HEPA) filter system. 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 utilizing 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 a measurement 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 unabated emissions. Several variations of performing this method are available. Each variation is described in sections 2.1.3.1 and 2.1.3.2.

2.1.3.1 Method 3.1: Control Device Inventory

Samples are taken of the collection media from a control device, which are representative of the radionuclide inventory contained within that control device. Isotopic analyses are performed on the samples. The 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 radionuclide inventory of the control device, its operating history, and its collection efficiency. The potential emissions are then calculated by dividing the annual release rate by the collection efficiency of the control device.

2.1.3.2 Method 3.2: Control Device NDA

A nondestructive assay measurement (NDA) is used to determine the radionuclide inventory of a control device. The radionuclide inventory in a control device is estimated 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 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* (WHC-SD-ER-TP-004, 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 unabated emissions.

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 unabated emissions are then calculated by multiplying the radionuclide concentrations by the annual discharge volume.

2.1.5 Method 5: Release Fractions

WAC Chapter 246-247-030(21)(a) states that with approval other release fractions may be used to estimate potential unabated emissions.

This method is identical to Method 1, except that it uses material-specific release fractions to calculate potential unabated emissions instead of the release fractions provided in WAC Chapter 246-247-030 or 40 CFR Part 61, Appendix D.

2.2 METHODS NOT APPROVED

Methods to determine potential emissions that have not been approved by WDOH and EPA may require additional time for their review and approval.

3.0 CALCULATING DOSES TO THE MAXIMUM PUBLIC RECEPTOR

The method presented here simplifies dose calculations for users by eliminating the need to run the CAP88-PC software (Chaki 2000). This method also incorporates Hanford Site-specific parameters, particularly a multi-year profile of meteorological data, which is viewed as superior over using default generic values in CAP88-PC. Successfully conducting a CAP88-PC run requires familiarity with modeling assumptions used at the Hanford Site as well as site-specific wind data and various pathway parameters needed as input to the CAP88-PC software.

Components of a dose calculation are discussed at length in the three sections that follow. The first section deals with the radionuclide source term. The second section deals with the selection of dose-per-unit release factors (dose factors). The third section describes how to combine the data derived in sections one and two into a dose and the meaning of that dose.

Variations in wind data over time are relatively minor compared with other uncertainties in dose calculations. The emphasis placed on using a particular set of meteorological data is unlikely to have a significant impact on the overall conclusions of these calculations. For potential-to-emit (PTE) calculations, using longer-term averaged meteorological data sets for the reporting period is more appropriate, whereas using annually averaged meteorological data is preferred for annual regulatory compliance reporting. Longer-term meteorological data predict more representatively the meteorological conditions for activities projected several years into the future.

When annual meteorological conditions change significantly, it is recommended that the dose factors be updated. The dispersion factors generated by CAP88-PC will be checked periodically using an updated meteorological data set. If the degree of variance exceeds a factor of two between the dispersion factors used for this document and those newly generated for the periodic comparison checks, the dose factors in this document should be updated.

3.1 CALCULATING RELEASES

Care should be taken to provide results with the correct number of significant digits. Significant digits should be handled in accordance with American Society for Testing and Material (ASTM) Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications (ASTM E 29). To minimize "rounding" errors, as many significant figures as possible should be carried through all calculations until the end of the calculation. Otherwise, rounding errors may occur. Using a computerized spreadsheet is recommended for all release calculations, since a computerized spreadsheet carries many significant digits but only displays the number of digits specified for the cells in the spreadsheet. Doses to an MPR should be reported using no more than two significant digits because the dose factors are at best only accurate to two significant digits, even though CAP88-PC uses three significant figures in reporting doses.

When potential emissions are estimated from an inventory of radioactive material, the activity of each radionuclide in the inventory should be corrected for radioactive decay, if applicable. That is, if the date of the inventory estimate is prior to the date of the emissions estimate, decay correction should be considered if short-lived nuclides are involved. Significant errors may arise in the calculations, and errors increase as half-lives of radionuclides decrease. Decay correction is particularly important when dealing with the ingrowth of long-lived progeny from short-lived parent nuclides (e.g., Am-241 from Pu-241). The following are the basic equations for radioactive decay.

Equation 3.1:

$$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$$

Equation 3.2:

$$A(t) = A(0)\, e^{-\lambda t}$$

λ	radioactive decay constant in s^{-1}, min^{-1}, hr^{-1}, day^{-1}, or yr^{-1}
$T_{1/2}$	half-life of radionuclide in s, min, hr, day, or yr
A(t)	current activity of a radionuclide at time t in Ci or Bq
A(0)	initial activity of a radionuclide in Ci or Bq
t	time in s, min, hr, day, or yr.

Miscellaneous radioactive decay data (e.g., half-lives, branching ratios, decay chains, and modes of decay) for most radionuclides can be found *Radioactive Decay Data Tables* (DOE/TIC-11026). Equations for decay chains can be found in many textbooks.

3.2 SELECTING THE APPROPRIATE DOSE-PER-UNIT RELEASE FACTORS

Selecting appropriate dose factors is extremely important. This section provides guidance for determining effective release height, using the tables of dose factors, and how to handle radioactive decay chains.

3.2.1 Calculating Effective Release Height

Knowing the effective release height is needed to use the tables of dose factors in Section 4.0. In most cases, this is the physical height of the point of release above grade. However, when dealing with stacks, several other parameters could be considered.

Plume rise can significantly increase the effective stack height, resulting in substantial differences in atmospheric dispersion estimates when not accurately accounted for. The plume rise attributed to momentum and buoyancy needs to be added to the physical stack height to obtain the effective release height, as shown in Equation 3.3.

Equation 3.3: $$H_{eff} = H + \Delta h_m + \Delta h_b$$

H_{eff}	effective release height for stacks in m
H	physical stack height (height above grade) in m
Δh_m	plume rise attributable to momentum in m
Δh_b	plume rise attributable to buoyancy in m.

The plume rise attributable to momentum can be determined using Equation 3.4 or Equation 3.5. Equation 3.5 is a simplified version of Equation 3.4 and thereby saves the user from calculating the velocity of stack emissions.

Equation 3.4: $$\Delta h_m = \frac{1.5\, v\, d}{\mu}$$

Δh_m	plume rise attributable to momentum in m
v	effluent stack gas velocity in m/s
d	inside stack diameter in m
μ	average wind velocity in m/s; use 3.4 m/s (7.6 mph) [PNNL-11794].

When the stack flow rate and the stack diameter are known in the specified units of measurement, use the following equation, which is a simplified equation for Δh_m. This equation includes all dose factors and uses 3.4 m/s (7.6 mph) for the average wind velocity (μ).

Equation 3.5: $$\Delta h_m = (2.65E-04) \frac{F_{STP}}{d}$$

Δh_m	plume rise attributable to momentum in m
d	inside stack diameter in m
F_{STP}	volumetric stack flow rate at STP in cfm.

Equations 3.6 through 3.9 can be used to calculate the plume rise attributable to plume buoyancy. Note that CAP88-PC uses several equations for buoyant plume rise. These equations apply to MPR locations at distances greater than 10 times the physical stack height and atmospheric stability classes A, B, C, and D. This is the only buoyant plume-rise equation provided in this document, since it is the most appropriate equation for virtually every application that may be encountered at the Hanford Site. Equation 3.9 is a simplified version of Equations 3.6 through 3.8, which will save the user several calculational steps.

Equation 3.6:

$$\Delta h_b = \frac{1.6\,(3.7E-05\,Q_H)^{\frac{1}{3}}\,(10\,H)^{\frac{2}{3}}}{\mu}$$

Δh_b	plume rise attributable to buoyancy in m
Q_H	heat emission from stack in cal/sec
H	physical stack height (height above grade) in m
μ	average wind velocity in m/s; use 3.4 m/s (7.6 mph) [PNNL-11794].

Equation 3.7:

$$Q_H = 8.48E+04\,F_a\left(\frac{T_o}{T_a}-1\right)$$

Q_H	heat emission from stack in cal/sec
T_a	ambient temperature in °K; use 285.2 °K (12.0 °C) [PNNL-11794]
T_o	exit temperature of the stack gas in °K
F_a	volumetric stack flow rate at T_a in m^3/s.

Equation 3.8:

$$F_a = F_{STP}\sqrt{\frac{T_a}{T_S}} = 0.9948\,F_{STP}$$

F_a	volumetric stack flow rate at T_a in m^3/s
F_{STP}	volumetric stack flow rate at STP in m^3/s
T_a	ambient temperature in °K; use 285.2 °K (12.0 °C) [PNNL-11794]
T_s	standard temperature in °K; use 288.2 °K (15.0 °C).

The following equation is a simplified equation for Δh_b when the physical stack height, stack flow rate, and stack temperature are known in the specified units of measurement. This equation includes all unit correction factors and uses 3.4 m/s (7.6 mph) for average wind velocity (μ).

Equation 3.9:

$$\Delta h_b = 2.50E-01\,H^{\frac{2}{3}}\left[F_{STP}\left(\frac{T_o}{285.2}-1\right)\right]^{\frac{1}{3}}$$

Δh_b	plume rise attributable to buoyancy in m
F_{STP}	volumetric stack flow rate at STP in cfm
H	physical stack height (height above grade) in m
T_o	exit temperature of the stack gas in °K.

3.2.2 Using Dose-Per-Unit Release Factor Tables

Dose factors have been calculated for each emission zone. Emission zones are associated with the major operating areas on the Hanford Site, which are the 100, 200 East, 200 West, 300, and 400 Areas. The emission zone in which an emission unit is located needs to be correctly identified to ensure accurate use of the corresponding set of dose factors. Hanford Site emission zones are shown in Figures 4-1 and 4-2. Figure 4-2 is of the 300 Area, consisting of two emission zones, the division of which is defined by a dashed line.

The dose factors in each table are organized by effective release height and radionuclide. Two effective release heights are used to represent both ranges of effective release heights. Ground-level releases were modeled using an effective release height of 10 m, yet conservatively include all release heights of less than 40 m. Elevated releases were modeled using an effective release height of 40 m, which includes all release heights of equal to or greater than 40 m. Section 3.2.1 provides guidance on calculating the effective release height.

After the emission zone and effective release height of an emission unit are identified, an individual can look up the dose factors for each nuclide in the tables of Section 4.0. Nuclides in the tables are arranged in order of atomic number and then atomic mass.

3.2.3 Handling Radioactive Decay Chains

Many radionuclides decay into other radionuclides, creating a radioactive decay chain consisting of a parent nuclide and its radioactive progeny (i.e., decay products, aka daughters). Except where noted (i.e., with a "+D"), the dose factors provided in Section 4.0 do not include any progeny for nuclides with decay chains. Each nuclide in a source term should be evaluated to determine if there are any decay products that could be significant to the calculations. If so, the source term should be adjusted to include significant decay products. The dose factors for each of the parent nuclides and each of the decay products would be used to calculate the total dose.

Progeny are often excluded from inventories, especially if considerable time is required for significant ingrowth of the progeny. Sometimes progeny are inadvertently excluded, even when the period for significant ingrowth is very short. An example of this is Y-90, the progeny of Sr-90, which is inadvertently overlooked in many inventories and calculations. A source term of pure Sr-90 only requires 19 days for Y-90 to reach secular equilibrium with Sr-90, such that there are equal quantities present, in terms of radioactivity. Secular equilibrium is possible when the half-life of the parent nuclide is much greater than that of the progeny. The time needed for an immediate decay product to reach secular equilibrium with its parent nuclide is approximately seven times the half-life of the decay product.

Branching ratios need accounting for as well. Nuclides that can decay into more than one decay product have branching ratios. Branching ratios are the percentages of radioactive decays that transform into particular decay products. An example of this is Cs-137, which decays to Ba-137m 94.6% of the time while the other 5.4% of the time decaying to stable Ba-137. Because of the 94.6 % branching ratio, the activity of Ba-137m will come within 94.6 % of the activity of Cs-137 within approximately seven half-lives (i.e., about 18 minutes).

Performing radioactive decay calculations is more difficult on more complex decay series because of branching ratios and different half-lives. Using a computer code such as RadDecay is recommended for most radioactive decay calculations, especially when a nuclide has multiple decay products.

3.3 RADIONUCLIDES WITHOUT DOSE-PER-UNIT RELEASE FACTORS

CAP88-PC calculates doses for only the 265 radionuclides contained in its library files. If no dose factors were computed for a particular nuclide, the dose factors for another nuclide may be substituted for the nuclide not included in the CAP88-PC Library. Selection of an appropriate substitute nuclide is very important to avoid either nonconservative errors or grossly conservative errors. For that reason, the substitute nuclide should have similar radiological and physical characteristics (i.e., particulate, volatile, or gaseous) to the missing nuclide to minimize differences attributable to atmospheric dispersion.

Three methods are recommended for selecting a substitute nuclide. The first method is to find a nuclide with the same physical characteristics and comparable Derived Concentration Guide (DCG) for air. The table of DCGs is in Chapter III of DOE Order 5400.5. The second method is to find a nuclide with the same physical characteristics and a comparable dose factor calculated using a generic run of the GENII (PNL-6584, 1988) environmental dose assessment code. The third method is to use both methods to select a suitable substitute radionuclide.

3.4 WHEN A SCENARIO-SPECIFIC CAP88-PC RUN IS WARRANTED

This section describes most of the scenarios in which it is inappropriate to use the dose factors in the tables of Section 4.0 and when dose factors for a specific scenario should be generated.

3.4.1 Emission Units Outside Emission Zones

When an emission unit is not located within or near a given emission zone, as shown in Figures 4-1 and 4-2, CAP88-PC will need to be run for the specific scenario. One exception to this would be emission units between the 200-E and 200-W emission zones. If an emission unit is located there, the dose factors for the zone to which the emission unit is closest should be used. In the event the emission unit is almost exactly between the 200-E and 200-W emission zones, the dose factors yielding the more conservative total dose should be used.

3.4.2 Nonchronic Releases

PTE calculations are usually performed for chronic release scenarios in which emissions are nearly continuous and the emission rate nearly constant for relatively long periods of time. For this document, a chronic release is defined as nearly continuous for a period of at least 3 months. However, some of the release scenarios at the Hanford Site are for relatively short periods of time (i.e., less than 3 months), can be intermittent, and/or have variable emission rates. These types of releases are not considered chronic releases, which makes use of the dose factors in Section 4.0 inappropriate.

The CAP88-PC model was designed to address only chronic releases. Currently, no regulatory-mandated, EPA-approved atmospheric-dispersion and dose-modeling codes are available to model nonchronic releases. Using CAP88-PC-generated dose factors for these scenarios can significantly underestimate doses to the MPR.

Another option is to use the GENII model to generate scenario-specific dose factors for short-term releases, even when the release has a duration of less than one month. GENII should be used to generate dose factors at the 95th percentile. The GENII model is the official Hanford Site model for demonstrating compliance with DOE requirements. However, using GENII or any other model for regulatory work requires appropriate agency approval.

3.4.3 Estimated Doses Near 0.1 mrem/yr

When estimated doses are within an order of magnitude of 0.1 mrem/yr (i.e., 1.0 to 0.01 mrem/yr), a scenario-specific CAP88-PC run may be warranted to eliminate additional conservatism from the dose calculation. The benefits of a scenario-specific run should be carefully weighed, since such a run can significantly increase the cost of performing and documenting the PTE; however, the potentially counter-balancing cost savings of avoiding major stack monitoring, maintenance, and inspection requirements should also be considered.

3.4.4 Default Lung-Retention Classes or Particle Sizes That Are Inappropriate

When the default lung-retention class or particle size for a nuclide is not appropriate and results in an unacceptably conservative or nonconservative dose factor, a scenario-specific CAP88-PC run should be considered. To conduct such a run, the lung-retention class and/or the particle size in relation to activity median aerodynamic diameter (AMAD) must be known. The lung-retention classes for many compounds can be found in Chapter III of DOE Order 5400.5.

CAP88-PC only allows the user to toggle between the valid choices for lung-clearance class and particle size. Particle-size options are extremely limited by CAP88-PC, resulting in the inability to change most nuclides from their default settings. The options for lung-clearance class are very limited, also. CAP88-PC limits the user to certain lung-clearance classes that it considers valid, even when other valid lung-clearance classes exist. The default lung-clearance class and particle size used by CAP88-PC for each nuclide are provided in Table 3-1. CAP88-PC does not specify the default lung-clearance class nor does it allow the user to specify a class for some nuclides. Also, CAP88-PC specifies a particle size of 0.0 for some nongaseous nuclides and does not allow the user to change the default parameter.

If a user encounters a scenario that may significantly underestimate or overestimate the dose because of CAP88-PC-imposed limitations for lung-clearance classes and particle sizes, the user may seek approval from the regulatory agencies to use a more appropriate computer model.

3.4.5 Releases Dominated by Volatile Radionuclides

When developing the dose factors in this document, an observation arose regarding the scenarios in which volatile nuclides (i.e., halogen nuclides) are involved. The distances and directions to respective MPRs are different for volatile nuclides in the 100-B/C, 100-D/DR, 100-H, 100-K, 100-N, and 200-W Area emission zones. A single MPR was chosen for each emission zone, resulting in an acceptably small error for most scenarios. However, the results may be nonconservative when releases are dominated by volatile nuclides.

A scenario-specific CAP88-PC run should be considered when an emission unit is located in one of the previously listed emission zones and the calculated unabated dose attributable to any specific volatile nuclide accounts for 5% or more of the total dose for that emission source, using the dose factors provided in Section 4.0. This does not apply to the 100-F, 200-E, 300-E, 300-W, and 400 Area emission zones, because the distances and directions to each respective MPR are the same for particulate, volatile, and gaseous nuclides.

3.4.6 Releases from Area Sources

When the ratio of receptor-distance versus source-diameter for an area source is 2.5 or greater, that area source is modeled as a point source by CAP88-PC. However, the differences in the dose factors are insignificant (i.e., within a factor of two) even when the ratio is as little as 0.22. (For clarification, the "receptor-distance/source-diameter" ratio applies to the distance between the receptor location and the center of the area source — or for a noncircular area, the "centroid" of the source — and the "effective" diameter of the source. This would only apply to onsite MPRs because none of the offsite MPRs are close enough for the source geometry to make a difference.) A scenario-specific CAP88-PC run is recommended when the receptor-distance/source-diameter ratio is less than 0.22.

Equation 3.10:

$$d_{eff} = \sqrt{\frac{4\,A}{\pi}}$$

d_{eff} effective diameter of an area source in m.

A area of the source in m^2.

Table 3-1. Default Lung-Clearance Classes and Particle Sizes in CAP88-PC.

Nuclide	Lung-clearance class[a]	Particle size (μm)	Nuclide	Lung-clearance class[a]	Particle size (μm)
H-3	N/A	0.00	Kr-85	N/A	0.00
Be-7	Y	1.00	Kr-85m	N/A	0.00
Be-10	—	0.00	Kr-87	N/A	0.00
C-11	D	1.00	Kr-88	N/A	0.00
C-14	N/A	0.00	Kr-89	N/A	0.00
C-15	D	1.00	Kr-90	N/A	0.00
N-13	D	1.00	Rb-86	D	1.00
O-15	D	1.00	Rb-87	D	1.00
F-18	D	1.00	Rb-88	D	1.00
Na-22	D	1.00	Rb-89	D	1.00
Na-24	D	1.00	Rb-90	—	0.00
P-32	D	1.00	Rb-90m	—	0.00
S-35	D	1.00	Sr-89	D	1.00
Ar-41	N/A	0.00	Sr-90	D	1.00
K-40	D	1.00	Sr-91	D	1.00
Ca-41	—	0.00	Sr-92	D	1.00
Sc-46	Y	1.00	Y-90	Y	1.00
Cr-51	Y	1.00	Y-90m	—	0.00
Mn-54	W	1.00	Y-91	Y	1.00
Mn-56	W	1.00	Y-91m	Y	1.00
Fe-55	W	1.00	Y-92	Y	1.00
Fe-59	W	1.00	Y-93	Y	1.00
Co-57	Y	1.00	Zr-93	W	1.00
Co-58	Y	1.00	Zr-95	W	1.00
Co-60	Y	1.00	Nb-93m	Y	1.00
Ni-59	W	1.00	Nb-94	Y	1.00
Ni-63	W	1.00	Nb-95	Y	1.00
Ni-65	W	1.00	Nb-95m	Y	1.00
Cu-64	Y	1.00	Nb-97	Y	1.00
Zn-65	Y	1.00	Nb-97m	Y	1.00
Zn-69m	Y	1.00	Mo-93	—	0.00
Zn-69	Y	1.00	Mo-99	Y	1.00
Ga-67	W	1.00	Tc-97	W	1.00
As-76	W	1.00	Tc-99	W	1.00
Se-79	—	0.00	Tc-99m	W	1.00
Br-82	D	1.00	Tc-101	—	0.00
Br-83	—	0.00	Ru-97	Y	1.00
Br-84	—	0.00	Ru-103	Y	1.00
Br-85	—	0.00	Ru-105	Y	1.00
Kr-83m	N/A	0.00	Ru-106	Y	1.00

Table 3-1. Default Lung-Clearance Classes and Particle Sizes in CAP88-PC.

Nuclide	Lung-clearance class[a]	Particle size (μm)	Nuclide	Lung-clearance class[a]	Particle size (μm)
Rh-103m	Y	1.00	I-129	D	1.00
Rh-105	Y	1.00	I-130	D	1.00
Rh-105m	Y	1.00	I-131	D	1.00
Rh-106	Y	1.00	I-132	D	1.00
Pd-107	Y	1.00	I-133	D	1.00
Pd-109	Y	1.00	I-134	D	1.00
Ag-109m	Y	1.00	I-135	D	1.00
Ag-110	Y	1.00	Xe-122	N/A	0.00
Ag-110m	Y	1.00	Xe-123	N/A	0.00
Ag-111	Y	1.00	Xe-125	N/A	0.00
Cd-113	—	0.00	Xe-127	N/A	0.00
Cd-113m	—	0.00	Xe-131m	N/A	0.00
Cd-115	Y	1.00	Xe-133	N/A	0.00
Cd-115m	Y	1.00	Xe-133m	N/A	0.00
In-113m	W	1.00	Xe-135	N/A	0.00
In-115	W	1.00	Xe-135m	N/A	0.00
In-115m	W	1.00	Xe-137	N/A	0.00
Sn-113	W	1.00	Xe-138	N/A	0.00
Sn-123	—	0.00	Cs-134	D	1.00
Sn-125	W	1.00	Cs-134m	D	1.00
Sn-126	W	1.00	Cs-135	D	1.00
Sb-124	W	1.00	Cs-136	D	1.00
Sb-125	W	1.00	Cs-137	D	1.00
Sb-126	W	1.00	Cs-138	D	1.00
Sb-126m	W	1.00	Cs-139	—	0.00
Sb-127	W	1.00	Ba-133	D	1.00
Te-125m	W	1.00	Ba-133m	D	1.00
Te-127	W	1.00	Ba-137m	D	1.00
Te-127m	W	1.00	Ba-139	D	1.00
Te-129	W	1.00	Ba-140	D	1.00
Te-129m	W	1.00	Ba-141	—	0.00
Te-131	W	1.00	Ba-142	—	0.00
Te-131m	W	1.00	La-140	W	1.00
Te-132	W	1.00	La-141	—	0.00
Te-133	—	0.00	La-142	—	0.00
Te-133m	—	0.00	Ce-141	Y	1.00
Te-134	—	0.00	Ce-143	Y	1.00
I-122	D	1.00	Ce-144	Y	1.00
I-123	D	1.00	Pr-143	Y	1.00
I-125	D	1.00	Pr-144	Y	1.00

Table 3-1. Default Lung-Clearance Classes and Particle Sizes in CAP88-PC.

Nuclide	Lung-clearance class[a]	Particle size (μm)	Nuclide	Lung-clearance class[a]	Particle size (μm)
Pr-144m	Y	1.00	Po-211	—	0.00
Nd-147	Y	1.00	Po-212	W	1.00
Pm-147	Y	1.00	Po-213	W	1.00
Pm-148	Y	1.00	Po-214	W	1.00
Pm-148m	Y	1.00	Po-215	W	1.00
Pm-149	Y	1.00	Po-216	W	1.00
Pm-151	—	0.00	Po-218	W	1.00
Sm-147	W	1.00	At-217	D	1.00
Sm-151	W	1.00	Rn-219	N/A	0.00
Sm-153	W	1.00	Rn-220	N/A	0.00
Eu-152	W	1.00	Rn-222	N/A	0.00
Eu-152m	—	0.00	Fr-221	D	1.00
Eu-154	W	1.00	Fr-223	D	1.00
Eu-155	W	1.00	Ra-223	W	1.00
Eu-156	W	1.00	Ra-224	W	1.00
Gd-152	—	0.00	Ra-225	W	1.00
Tb-160	W	1.00	Ra-226	W	1.00
Ho-166	W	1.00	Ra-228	W	1.00
Ho-166m	—	0.00	Ac-225	Y	1.00
Hf-181	W	1.00	Ac-227	Y	1.00
W-181	D	1.00	Ac-228	Y	1.00
W-185	D	1.00	Th-227	Y	1.00
W-187	D	1.00	Th-228	Y	1.00
Re-187	W	1.00	Th-229	Y	1.00
Ir-192	Y	1.00	Th-230	Y	1.00
Hg-203	W	1.00	Th-231	Y	1.00
Tl-207	D	1.00	Th-232	Y	1.00
Tl-208	D	1.00	Th-234	Y	1.00
Tl-209	D	1.00	Pa-231	Y	1.00
Pb-209	D	1.00	Pa-233	Y	1.00
Pb-210	D	1.00	Pa-234	Y	1.00
Pb-211	D	1.00	Pa-234m	Y	1.00
Pb-212	D	1.00	U-232	Y	1.00
Pb-214	D	1.00	U-233	Y	1.00
Bi-210	W	1.00	U-234	Y	1.00
Bi-211	W	1.00	U-235	Y	1.00
Bi-212	W	1.00	U-236	Y	1.00
Bi-213	W	1.00	U-237	Y	1.00
Bi-214	W	1.00	U-238	Y	1.00
Po-210	W	1.00	U-240	Y	1.00

Table 3-1. Default Lung-Clearance Classes and Particle Sizes in CAP88-PC.

Nuclide	Lung-clearance class[a]	Particle size (μm)	Nuclide	Lung-clearance class[a]	Particle size (μm)
Np-237	W	1.00	Am-241	W	1.00
Np-238	W	1.00	Am-242	W	1.00
Np-239	W	1.00	Am-242m	W	1.00
Np-240	W	1.00	Am-243	W	1.00
Np-240m	W	1.00	Cm-242	W	1.00
Pu-236	Y	1.00	Cm-243	W	1.00
Pu-238	Y	1.00	Cm-244	W	1.00
Pu-239	Y	1.00	Cm-245	W	1.00
Pu-240	Y	1.00	Cm-246	W	1.00
Pu-241	Y	1.00	Cm-247	W	1.00
Pu-242	Y	1.00	Cm-248	W	1.00
Pu-243	Y	1.00	Cf-252	Y	1.00
Pu-244	Y	1.00			

[a] N/A = not applicable; D = days; W = weeks; Y = years; "—" = no data provided by CAP88-PC.

3.4.7 Releases Dominated by Short-Lived Radionuclides

When developing the dose factors in this document, an observation was evaluated regarding scenarios involving nuclides with short half-lives. The distances and directions to respective MPRs are different for short-lived nuclides in the 100-D/DR, 100-F, 100-H, and 100-N Area emission zones. A single MPR was chosen for each emission zone, resulting in an acceptable amount of error for most scenarios. The error, however, may become unacceptable if releases are dominated by short-lived nuclides, now a highly unlikely scenario at the Hanford Site — other than those presented by ingrowth from longer-lived parents (e.g., Y-90 and Ba-137m, whose longer-lived parents are Sr-90 and Cs-137, respectively).

A scenario-specific CAP88-PC run should be considered when an emission unit is located in one of the previously listed emission zones and the calculated unabated dose attributable to any specific short-lived nuclide accounts for 5% or more of the total dose for that emission source when using the dose factors provided in Section 4.0. This does not apply to the 100-B/C, 100-K, 200-E, 300-E, 300-W, and 400 Area emission zones, because the distances and directions to respective MPRs are the same for both short-lived and long-lived nuclides.

3.5 CALCULATING DOSES

The dose factors in this document were calculated using CAP88-PC, a computer model for chronic release scenarios (i.e., nearly continuous for a period of at least 3 months). These dose factors are not appropriate for acute-release scenarios. The user should refer to Section 3.4.2 when a release is considered not chronic.

EXAMPLE 1

The PTE is calculated using Method 1 for a facility located in the western portion of the 300 Area and greater than 250 m away from the Columbia River. Emissions will be ventilated at an average stack flow rate of 2,000 cfm (0.944 m^3/s) from a 6-in.-diameter (0.1524-m-diameter) stack that is 82 ft (25 m) above grade. The stack abatement technology consists of a single bank of HEPA filters. The facility has an inventory of liquid radioactive material, last determined 10 years ago. The process used by the facility heats the source term to a temperature of 150 °C (423 °K), which produces emissions that exit the stack at an average temperature of 100 °C (373 °K). The boiling point for the entire source term is 100 °C (373 °K).

Table 3-2 gives the inventory from 10 years ago and the decay-corrected inventory as of today, using Equations 3.1 and 3.2. Note the increase in the inventory of Am-241 due to the decay of the parent nuclide, Pu-241.

Table 3-2. Example 1: Decay-Corrected Radionuclide Inventory.

Nuclide	Inventory determined 10 years ago, Ci	Decay-corrected inventory, Ci
H-3	2.0 E+01	1.1 E+01
Co-60	1.0 E–03	2.7 E–04
Sr-90	3.0 E–04	2.4 E–04
Y-90	3.0 E–04	2.4 E–04
Zr-95	2.0 E–04	0.0
Cs-137[3]	5.0 E–03	4.0 E–03
Ba-137m	5.0 E–03	3.8 E–03
Pu-239	9.0 E–06	9.0 E–06
Pu-241	8.5 E–04	5.3 E–04
Am-241	0.0	1.1 E–05

Using Appendix D from 40 CFR 61, the dose factor for this inventory is 1 because the source term is heated to over its boiling point, 100 °C. For gases, 1 is the appropriate HEPA filter adjustment factor. In addition, unabated PTE calculations assume no pollution control devices exist; therefore, the HEPA filter adjustment factor of 1 is used. Using the dose factor of 1 results in the annual release being equivalent to the radionuclide inventory.

Plume rise attributable to momentum and buoyancy is significant for this stack because of the small stack diameter and high temperature of the emissions. Using Equation 3.5, the plume rise attributable to momentum was calculated to be 3.5 m. Using Equation 3.9, the plume rise attributable to buoyancy was calculated to be 17.4 m. And using Equation 3.3., the effective stack height was calculated to be 45.9 m. As a result, the dose factors for elevated releases may be used because the H_{eff} is ≥40 m, even though the physical stack height is only 25 m.

Table 3-3 provides the PTE data and subsequent doses to the MPR for Example 1.

Table 3-3. Example 1: Potential-to-Emit Calculation for an Elevated Release from the Western Portion of the 300 Area.

Nuclide	Unabated annual releases, Ci/yr	Adjustment factor for HEPA filter	Abated annual release, Ci/yr	300 Area West dose-per-unit release factor, mrem/Ci	Unabated PTE to Offsite MPR, mrem/yr
H-3	1.1 E+01	1	1.1 E+01	1.2 E-04	1.3 E-03
Co-60	2.7 E-04	1	2.7 E-04	1.6 E+00	4.3 E-04
Sr-90	2.4 E-04	1	2.4 E-04	7.1 E-01	1.7 E-04
Y-90	2.4 E-04	1	2.4 E-04	2.2 E-03	5.3 E-07
Zr-95	0.0	1	0.0	0.0	0.0
Cs-137+D	4.0 E-03	1	4.0 E-03	1.5 E+00	6.0 E-03
Pu-239	9.0 E-06	1	9.0 E-06	5.0 E+01	4.5 E-04
Pu-241	5.3 E-04	1	5.3 E-04	7.9 E-01	4.2 E-04
Am-241	1.1 E-05	1	1.1 E-05	7.7 E+01	8.5 E-04
				Total dose ►	**9.6 E-03**

[a] The adjustment factor is 1 rather than 0.01 because the source term is heated to ≥100 °C and the temperature of the emissions is assumed to be ≥100 °C, making them behave as a gas.

EXAMPLE 2

The PTE is calculated using Method 1 for a contaminated burial ground located in the eastern portion of the 300 Area. All releases occur at ground level with no abatement technology used. The burial ground is a 1,000-m-by-500-m area (i.e., 5.0 E+05 m^2). The radioactive source term within the burial ground is contaminated soil, recently determined from the analysis of soil samples.

Using Appendix D of 40 CFR 61, the dose factor for this inventory is 1.0 E-03 because the source-term is a particulate solid. The effective diameter of the burial ground is 798 m, using Equation 3.10. The distance/diameter ratio is 1.50, which is well above the 0.22 minimum recommended in Section 3.4.6.

Table 3-4 provides the PTE data and subsequent doses to the MPR for Example 2.

Table 3-4. Example 2: Potential-to-Emit Calculation for a Ground-Level Release from the Eastern Portion of the 300 Area.

Nuclide	Inventory in soil, Ci	Appendix D release factor	Unabated and abated release rate, Ci/yr	300 Area East dose-per-unit release factor, mrem/Ci	Unabated and abated PTE to MPR, mrem/yr
U-234	2.5 E+00	1 E–03	2.5 E–03	7.4 E+01	1.9 E–01
U-235	1.2 E–01	1 E–03	1.2 E–04	7.1 E+01	8.5 E–03
U-238	2.5 E+00	1 E–03	2.5 E–03	6.6 E+01	1.7 E–01
				Total dose ►	**3.6 E–01**

3.6 REPORTING RELEASES AND DOSES IN AN NOC

Once the potential-to-emit is determined for an NOC, it is critical that the releases and doses be put into terms consistent with the measurement method. The potential-to-emit values generally become the emission limits for an NOC, making this conversion essential for purposes of demonstrating compliance to the emission limits.

If the NOC only addresses one activity associated with an existing emission unit, it is critical to establish the emission limits for the emission unit rather than for the activity. One would need to add the releases and doses associated with the activity to the releases and doses related to other activities affecting the emission unit. It is usually very difficult or impossible to demonstrate compliance to an NOC when the emission limits are for a specific activity and the compliance measurement is for the entire emission unit and all the activities ventilated by emission unit.

Emission limits should be checked for detectability prior to specifying the limits and measurement method in the NOC. Measurement methods specified in the NOC must be sufficiently sensitive to demonstrate that emission limits have not been exceeded. The method for determining whether or not a record sampling method is sensitive enough to verify emission limits of a stack is outlined in Equation 3.11. Equation 3.11 only applies to emission units using record sampling.

Equation 3.11:

$$MDL = 0.02832\,(MDC)(V_{stk})$$

MDL minimum detection level for an analyte on a specific stack in Ci/yr
MDC minimum detectable concentration for an analyte in μCi/mL
V_{stk} annual stack discharge volume in ft^3/yr.

Equation 3.12:

$$MDC = 3.531E\text{-}11\left(\frac{MDA}{V_s}\right)$$

MDC minimum detectable concentration for an analyte in μCi/mL
MDA minimum detectable activity for an analyte in pCi
V_s sample volume in ft^3.

When measurement methods other than record sampling are used, it is essential the measurement that demonstrates compliance with emission limits is specified in the NOC. As an example, the NOC for portable temporary radioactive air emission units (PTREAUs) uses handling limits to link the measurements to the emission limits. The PTRAEU NOC uses smear data to verify the handling limits specified in the NOC. The handling limits were established such that the emission limits cannot be exceeded unless the handling limits are first exceeded. Example 3 illustrates why these considerations are significant.

EXAMPLE 3

A hypothetical facility located in the 200 East Area contains contaminated equipment. The main building of the facility is ventilated by a single 30-m-high stack operating continuously at 2,500 cfm (1.18 m^3/s) and equipped with a single HEPA filter. The temperature of emissions leaving the stack is not more than 25 °C, which keeps the effective height of the stack below 40 m. The stack is a nondesignated (i.e., minor or Category 2) emission unit, the periodic confirmatory measurement method for which is record sampling. The facility is planning to sample the stack continuously and collect record samples biweekly. Only four of the 26 record samples expected annually will be analyzed and used to demonstrate compliance. Each of the samples used for the periodic confirmatory measurements will analyzed for gross alpha and gross beta activity. The stack has been assessed with the following potential-to-emit in Table 3-5.

Table 3-5. Example 3: Original Assessed Potential-to-Emit for the Stack.

Nuclide	Unabated release rate, Ci/yr	HEPA filter factor	Abated release rate, Ci/yr	200-E Area 10-m dose-per-unit release factor, mrem/Ci	Unabated dose to MPR, mrem/yr	Abated dose to MPR, mrem/yr
Sr-90	2.2 E–05	3,000	7.3 E–09	9.5 E–03	2.1 E–07	6.9 E–11
Y-90	2.2 E–05	3,000	7.3 E–09	2.6 E–04	5.7 E–09	1.9 E–12
Cs-137	5.3 E–05	3,000	1.8 E–08	2.0 E–03	1.1 E–07	3.6 E–11
Ba-137m	5.0 E–05	3,000	1.7 E–08	1.0 E–11	5.1 E–16	1.7 E–19
Pu-239	1.6 E–06	3,000	5.3 E–10	9.5 E+00	1.5 E–05	5.1 E–09
Pu-240	1.6 E–06	3,000	5.3 E–10	9.5 E+00	1.5 E–05	5.1 E–09
Pu-241	3.0 E–04	3,000	1.0 E–07	1.5 E–01	4.4 E–05	1.5 E–08
Am-241	1.5 E–04	3,000	5.8 E–08	1.5 E+01	2.3 E–03	8.8 E–07
				Total dose ►	**2.4 E–03**	**9.1 E–07**

The measurement method only includes total alpha and total beta analyses. It is essential that the nuclide-specific information in Table 3-5 be put into terms of total alpha activity and total beta activity. Table 3-6 contains the converted data. The unabated releases for all of the alpha-emitting nuclides were summed for Table 3-6. The unabated releases for all of the beta-emitting nuclides were also summed for Table 3-6. The most conservative dose factors for this example for the alpha- and beta-emitting nuclides were then used to calculate the doses. Note that Ba-137m was omitted from the table because it only emits gamma rays and its unabated potential-to-emit is not greater than 10% of the total potential-to-emit for the stack, not greater than 0.1 mrem/yr, and not greater than 25% of the abated potential-to-emit.

Table 3-6. Example 3: Original Assessed Potential-to-Emit for the Stack NOC.

Type of activity	Unabated release rate, Ci/yr	HEPA filter Factor	Abated release rate, Ci/yr	200-E Area 10-m dose-per-unit release factor, mrem/Ci	Unabated dose to MPR, mrem/yr	Abated dose to MPR, mrem/yr
Total alpha	1.5 E–04	3,000	5.1 E–08	1.5E+01	2.3 E–03	7.7 E–07
Total beta	4.0 E–04	3,000	1.3 E–07	1.5 E–01	5.8 E–05	1.9 E–08
				Total dose ►	**2.4 E–03**	**7.9 E–07**

A new activity is proposed for the facility would repackage material sent to it over the course of several months. The potential-to-emit releases and doses associated with the specific activity of the material have been assessed and included as Table 3-7.

Table 3-7. Example 3: Assessed Potential-to-Emit for the New Activity.

Nuclide	Unabated release rate, Ci/yr	HEPA filter factor	Abated release rate, Ci/yr	200-E Area 10-m dose-per-unit release factor, mrem/Ci	Unabated dose to MPR, mrem/yr	Abated dose to MPR, mrem/yr
H-3	1.0 E+00	1	1.0 E+00	7.1 E–06	7.1 E–06	7.1 E–06
Cs-137	4.3 E–04	3,000	1.4 E–07	2.0 E–03	8.6 E–07	2.8 E–10
Ba-137m	4.1 E–04	3,000	1.4 E–07	1.0 E–11	4.2 E–15	1.4 E–18
Eu-152	6.2 E–05	3,000	2.1 E–09	3.1 E–01	1.9 E–05	6.5 E–10
				Total dose ►	**3.8 E–05**	**7.1 E–06**

The potential-to-emit for this activity needs to be added into the potential-to-emit of the stack for determining its designation and emission limits. Table 3-8 provides the assessed potential-to-emit for all activities that will be ventilated by this stack.

Table 3-8. Example 4: Assessed Potential-to-Emit for Stack, including New Activity.

Nuclide	Unabated release rate, Ci/yr	HEPA filter factor	Abated release rate, Ci/yr	200-E Area 10-m dose-per-unit release factor, mrem/Ci	Unabated dose to MPR, mrem/yr	Abated dose to MPR, mrem/yr
H-3	1.0 E+00	1	1.0 E+00	7.1 E–06	7.1 E–06	7.1 E–06
Sr-90	2.2 E–05	3,000	7.3 E–09	9.5 E–03	2.1 E–07	6.9 E–11
Y-90	2.2 E–05	3,000	7.3 E–09	2.6 E–04	5.7 E–09	1.9 E–12
Cs-137+D	4.8 E–04	3,000	1.6 E–07	2.7 E–01	1.3 E–04	4.3 E–08
Ba-137m	4.6 E–04	3,000	1.5 E–07	1.0 E–11	4.7 E–15	1.5 E–18
Eu-152	6.2 E–06	3,000	2.1 E–09	3.1 E–01	1.9 E–06	6.5 E–10
Pu-239	1.6 E–06	3,000	5.3 E–10	9.5 E+00	1.5 E–05	5.1 E–09
Pu-240	1.6 E–06	3,000	5.3 E–10	9.5 E+00	1.5 E–05	5.1 E–09
Pu-241	3.0 E–04	3,000	1.0 E–07	1.5 E–01	4.4 E–05	1.5 E–08
Am-241	1.5 E–04	3,000	5.8 E–08	1.5 E+01	2.3 E–03	8.8 E–07
				Total dose ►	2.5 E–03	8.1 E–06

Again, the measurement method only includes gross alpha and gross beta analyses. It is essential that the nuclide-specific information in Table 3-8 be put in terms of gross alpha activity and gross beta activity. Table 3-9 contains the converted data. Note that H-3, a beta-emitting nuclide, was not included in the conversion to gross beta releases. H-3 is a vapor that cannot be sampled by the measurement method employed. H-3 does not need to be sampled, either, because its unabated potential-to-emit is not greater than 10% of the total potential-to-emit for the stack, greater than 0.1 mrem/yr, nor greater than 25% of the abated potential-to-emit. Also, Eu-152 only decays by beta emission 27.8% of the time; its activity was adjusted by a factor of 0.278 in the total beta release calculation. As before, Ba-137m was omitted from the table because it only emits gamma rays and did not require sampling.

Table 3-9. Example 3: Assessed Potential-to-Emit for the Stack NOC.

Type of activity	Unabated release rate, Ci/yr	HEPA filter factor	Abated release rate, Ci/yr	200-E Area dose-per-unit release factor, mrem/Ci	Unabated dose to MPR, mrem/yr	Abated dose to MPR, mrem/yr
Total alpha	1.5 E–04	3,000	5.1 E–08	1.5 E+01	2.3 E–03	7.7 E–07
Total beta	8.3 E–04	3,000	2.8 E–07	3.1 E–01	2.6 E–04	8.6 E–08
				Total dose ►	2.6 E–03	8.6 E–07

The final step is to check the detectability of the measurement method. A two-week stack emission sample typically has a volume of 40,000 ft^3 (1,133 m^3). The minimum detectable concentrations for a two week sample are 1.0 E–15 μCi/mL for gross alpha activity and 9.5 E–15 μCi/mL for gross beta activity. The stack operates continuously at 2,500 cfm (1.18 m^3/s). The dose factors for Am-241 and Eu-152 are used, respectively, to calculate the total alpha and total beta doses because they were the most conservative dose factors of all the nuclides included in the assessment. Table 3-10 displays the data and the results of the detectability calculations when the sampling frequency is biweekly and the stack operates at 2,500 cfm (1.18 m^3/s).

Table 3-10. Example 3: Detectability Check for Biweekly Sampling When the Stack Operates at 2,500 cfm.

Type of activity	Average stack flow rate, cfm	Annual operating time, hr	Analysis MDC, μCi/mL	Dose-per-unit release factor, mrem/Ci	Annual discharge volume, mL	MDL activity, Ci/yr	MDL dose, mrem/yr
Total alpha	2,500	8,760	1.0 E–15	1.5 E+01	3.7 E+13	3.7 E–08	5.6 E–07
Total beta	2,500	8,760	9.5 E–15	3.1 E–01	3.7 E+13	3.5 E–07	1.1 E–07

Note that the measurement method is not sensitive enough to detect the emission limits of total beta activity. As a result, the measurement method needs to be modified or the flow rate for the stack lowered. The easiest modification would be to lengthen the sampling period to four weeks (i.e., monthly sampling). This would double the sample volume and lower the MDCs by 50%. Table 3-11 displays the results based on a monthly sampling frequency.

Table 3-11. Example 3: Detectability Check for Monthly Sampling When Stack Operates at 2,500 cfm.

Type of activity	Average stack flow rate, cfm	Annual operating time, hr	Analysis MDC, μCi/mL	Dose-per-unit release factor, mrem/Ci	Annual discharge volume, mL	MDL activity, Ci/yr	MDL dose, mrem/yr
Total alpha	2,500	8,760	5.0 E–16	1.5 E+01	3.7 E+13	1.9 E–08	2.9 E–07
Total beta	2,500	8,760	4.8 E–15	3.1 E–01	3.7 E+13	1.8 E–07	5.5 E–08

Using a monthly sampling frequency ensures that the emission limits for both total alpha and total beta activity are detectable. Another alternative to improving the detectability would be to lower the stack flow rate. Table 3-12 display the results for the scenario in which lowering the stack flow rate by 600 cfm (0.283 m^3/s) was chosen over lengthening the sampling period. Note that a similar effect can be obtained by not operating the stack for planned time intervals.

Table 3-12. Example 3: Detectability Check for Biweekly Sampling When Stack Operates at 1,900 cfm.

Type of activity	Average stack flow rate, cfm	Annual operating time, hr	Analysis MDC, μCi/mL	Dose-per-unit release factor, mrem/Ci	Annual discharge volume, mL	MDL activity, Ci/yr	MDL dose, mrem/yr
Total alpha	1,900	8,760	1.0 E–15	1.5 E+01	2.8 E+13	2.8 E–08	4.2 E–07
Total beta	1,900	8,760	9.5 E–15	3.1 E–01	2.8 E+13	2.7 E–07	8.3 E–08

This page intentionally left blank.

4.0 DOSE-PER-UNIT RELEASE FACTORS FOR RADIONUCLIDE AIR EMISSIONS

4.1 OVERVIEW

The tables in this section present dose-per-unit release factors (dose factors) for both offsite and onsite MPRs, related to each emission zone and two release heights. Dose factors have been provided for each of the 265 radionuclides in the CAP88-PC library. The radionuclides in the tables are sorted first by atomic number and then by atomic weight.

Figure 4-1 displays the Hanford Site emission zones. The 300 Area, as shown in Figure 4-2, has been subdivided into two emission zones, 300-E and 300-W. This was done because receptor locations and dispersion factors were significantly different for emission releases at various locations within the 300 Area and because of the close proximity of the 300 Area to the Hanford Site eastern boundary. The dividing line between these two zones is marked by George Washington Way and the western boundary for the 300-FF-1 Operable Unit. This boundary can also be described as being approximately 320 ± 50 m from the western edge of the Columbia River.

The release locations and the meteorological stations used in calculating the dose factors for each emission zone are listed in Table 4-1. The distances and directions to the offsite and onsite MPRs for each emission zone are in Table 4-2. MPR locations are graphically depicted in Figures 4-1 and 4-2. The eleven offsite MPR locations are each designated with a solid dot, identified by a numeral, 1 through 11. The two onsite MPR locations are each designated with a solid star symbol, identified by the capital letter A or B. The numerals and capital letters are linked to respective distance and direction information in Table 4-2.

Tables 4-3 through 4-12 contain the dose factors for each of the eleven emission zones.

4.2 USE OF HANFORD-SPECIFIC PARAMETERS AND DATA FOR DEMONSTRATING COMPLIANCE WITH AIR PATHWAY RADIATION DOSE STANDARDS

The following information on methods used to calculate public doses from radionuclide air emissions at the Hanford Site was submitted to and approved by the U.S. Environmental Protection Agency (EPA) Region 10 and to the Washington State Department of Health (WDOH). This information gives the regulatory background for the standards, outlines the history of the site-specific data in question, and describes the justification for its use.

4.2.1 Regulatory Background

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 corresponding Washington State regulations appear in Washington Administrative Code (WAC) 246-247, "Radiation Protection — Air Emissions," and WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides."

Both WAC 246-247 and WAC 173-480 incorporate by reference any more restrictive standards in other federal and state regulations.

Regulatory requirements for determining compliance with the radionuclide air emissions standards are specified 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, Subparts H and I. WAC 173-480 refers to methods specified in WAC 402-80, which was subsequently recodified as WAC 246-247, or to "other methods that department of social and health services has determined to be suitable."

4.2.2 History of Data Used in Hanford Site Compliance Calculations

Since the 1970s, DOE-RL has maintained a program for developing and recommending 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 (e.g., PNNL-6584, 1988) have been developed to implement regulatory requirements, based on recommendations of national and international standards organizations for radiological protection. In association with that effort, publications that described the recommended input parameters for various types of dose calculations were issued and periodically updated (PNL-3509, 1981; PNL-3777, Rev. 0, 1982; PNL-3777, Rev. 1, 1984; PNL-3777, Rev. 2, 1993). These recommendations were based on data collected at the Hanford Site or on information obtained in surveys of the area and nearby communities.

Site-specific parameters historically have been used at Hanford for calculating dose to the maximally exposed individual (MEI) in demonstrating compliance with radionuclide air emission standards in 40 CFR 61, Subpart H, and in WAC 246-247. These parameters have also been used for calculating dose to the maximum public receptor (MPR) in "applications to construct or modify" and "Notices of Construction" (NOCs) for new or modified emission units at Hanford (for example, HNF-3602, 1999). In addition, they have been used routinely for other types of Hanford Site assessments, such as the annually published *Radionuclide Air Emissions Report* (e.g., DOE/RL-2005-06, 2005) and the *Hanford Site Annual Environmental Report* (e.g., PNNL-15222, 2005) and environmental evaluations for site activities prepared under the National Environmental Policy Act.

4.2.3 Hanford-Specific Parameters

Site-specific data developed for use at Hanford include:

- onsite meteorological data (data collection methods, annual and historical summaries may be found in PNNL-15160, 2005; data used with specific software are re-formatted as required)

- population within 50 miles (80 kilometers) of major operating areas PNNL-14428, 1991, or updated census data as it becomes available
- food production and consumption parameters
- other exposure parameters.

"Average" individual parameters are used for collective dose assessments and for evaluating doses to individuals whose exposure is more representative of the population as a whole. Hanford-specific values are used in CAP-88-PC calculations and are generally consistent with the most recent recommendations in PNL-3777, Rev. 2, 1993, as approved by WDOH for use in Hanford Site analyses. Other bases for the recommended parameters are presented as appropriate.

4.2.4 Approval for Use of Hanford-Specific Parameters

Hanford-specific parameters have been approved by both EPA and WDOH for use in compliance, permitting, and reporting calculations. The dose factors in this document were calculated using Hanford-specific parameters.

4.2.5 Calculation of Worker Dose-per-Unit Release Factors Using CAP88-PC and Regional Ingestion

CAP88-PC was used to estimate the dose factors in this document for radionuclides for the member of the public who works within the Hanford boundary. Traditionally, the dose to the worker has been evaluated exclusively for inhalation and external pathways since food is not produced at the work location. However, to more fully evaluate public worker doses, ingestion doses were included in assessments for the onsite public worker. The food that the public worker ingests was not grown at the business location of the worker. In order to evaluate ingestion for a worker whose business location is known, but whose residence is not known, regional ingestion was estimated by a method not available in CAP88-PC. Regional ingestion is defined here as the consumption of produce and animal products grown outside the Hanford exclusion area, but within 80 km (50 mi) of the source facility.

Several limitations of CAP88-PC make this calculation less than straightforward. First, CAP88-PC was not designed to model ingestion of food stuffs grown in a location different from the full-time location of the individual. Second, although it is possible to turn the ingestion pathway on and off, CAP88-PC does not have the option of exclusively evaluating the ingestion pathway. And, third, what is offered as a regional food-production option in CAP88-PC does not apply because it assumes that food is grown uniformly around the source term out to 80 km. The local food-production option takes into account the Hanford exclusion zone by assuming that food is produced only where the population is located.

To calculate the public worker dose, three runs were made. The first run evaluated the public worker scenario with inhalation and external pathways only. Then two population runs were made with and without ingestion. By subtracting the dose without ingestion from the dose with ingestion it is possible to assess the ingestion-only population dose. These were run with average individual parameters, so by dividing the ingestion-only population dose by the number of individuals in the population, it is possible to assess the average individual ingestion dose. This was then added to the onsite public total inhalation and external dose estimate.

Another adjustment to the ingestion was made to more realistically reflect local food consumption patterns. It must also be recognized that much of an individual's food comes from sources imported into the region. Thus the fraction of locally grown produce and leafy vegetables coming from a local garden is adjusted to be 25% of consumption, with 75% being imported and assumed uncontaminated. This assumption is one of the "average" individual parameters incorporated into the population dose.

The formula describing the worker dose with regional ingestion is as follows:

$$\text{Total Worker dose} = \text{Worker}_{ext+inh} + ([\text{Pop}_{ext+inh+ing} - \text{Pop}_{ext+inh}]/N) * 1{,}000$$

Where:

Worker Dose (mrem/yr per Ci/yr released) is the total EDE

$\text{Worker}_{ext+inh}$ (person-rem/yr per Ci/yr released) is the individual EDE from the external and inhalation pathways only at onsite non-DOE business having unrestricted access

$\text{Pop}_{ext+inh+ing}$ (person-rem/yr per Ci/yr released) is the population collective EDE from external, inhalation, and ingestion pathways with the ingestion pathway calculated using Hanford-specific "average individual" parameters

$\text{Pop}_{ext+inh}$ (mrem/y per Ci/y released) is the population collective EDE from external and inhalation pathways only

N is the number of people within 80 km (50 mi) of the source

1,000 is a conversion factor that converts rem to mrem.

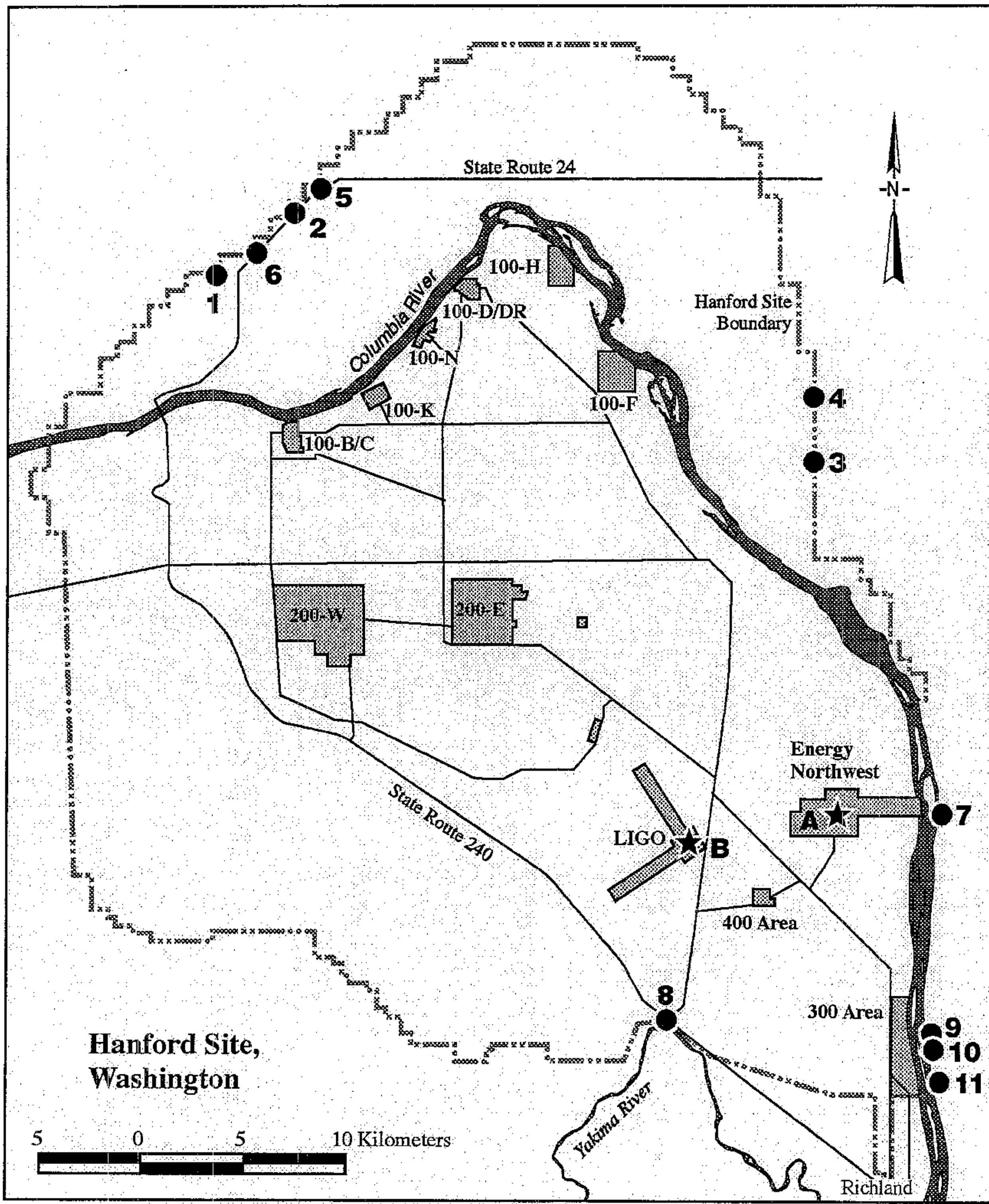

Figure 4-1. Hanford Site Map of Emission Zones.
(See Table 4-2 for geographical information on MPR locations, symbolized on this figure by the solid circles and stars, with identifying numerals and letters alongside them, respectively.)

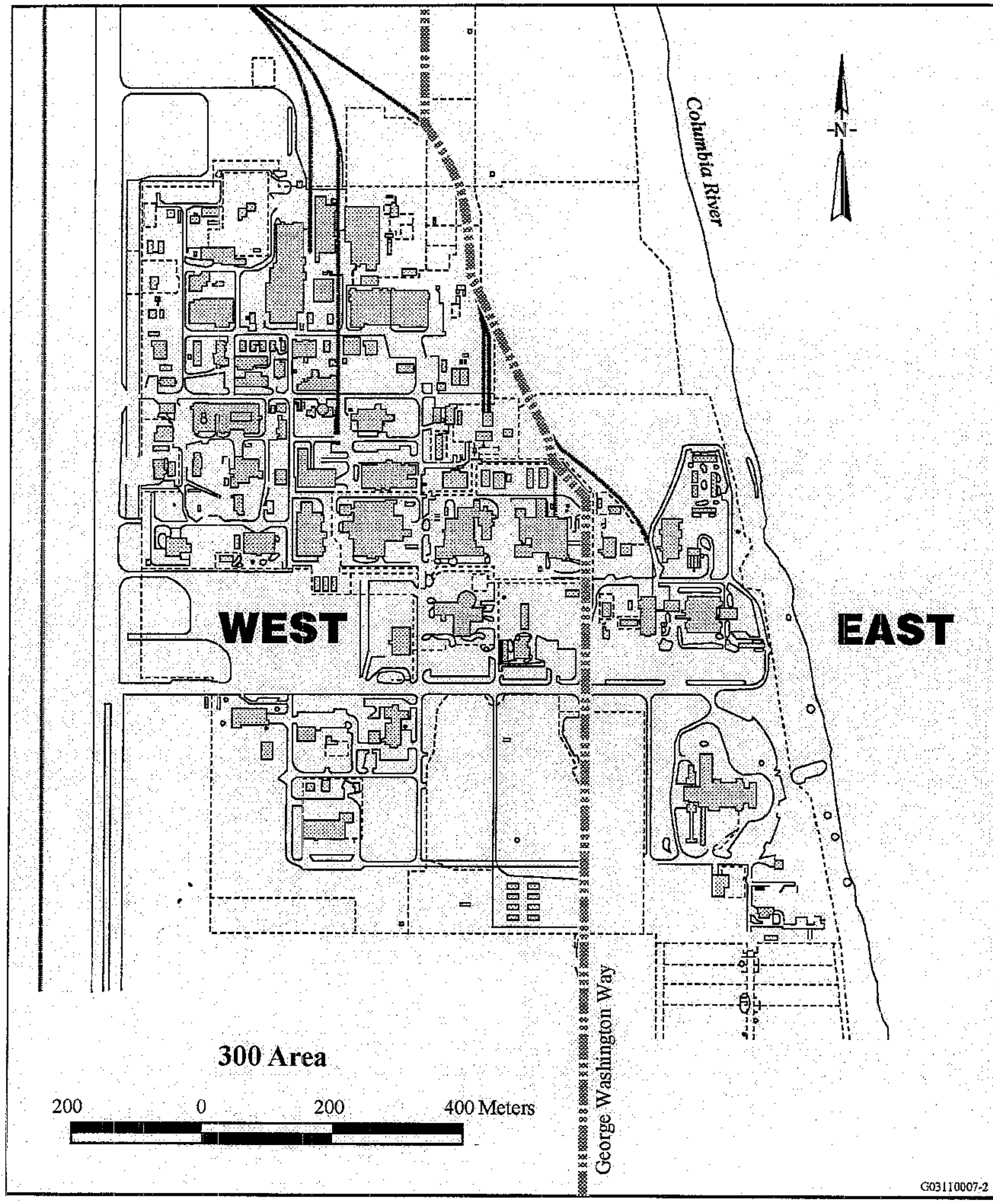

Figure 4-2. 300 Area Map of Emission Zones.

Table 4-1. Release Locations and Meteorological Stations Used.

Release locations[a]			Meteorological station[b]
Emission zone (building/facility)	Geographic coordinates	Washington State plane coordinates	
100-B/C (105-B Building)	46° 37' 49.2" longitude 119° 38' 51.1" latitude	565,275 m E 144,515 m N	GABW (#23) 1986-1996
100-D/DR (105-D Building)	46° 41' 35.2" longitude 119° 32' 8.4" latitude	573,755 m E 151,590 m N	100N (#13) 1983-1996
100-F (105-F Building)	46° 39' 23.2" longitude 119° 26' 56.2" latitude	580,440 m E 147,600 m N	100F (#24) 1986-1996
100-H (105-H Building)	46° 42' 4.0" longitude 119° 28' 58.4" latitude	577,780 m E 152,530 m N	100F (#24) 1986-1996
100-K (105-KW Building)	46° 38' 50.4" longitude 119° 36' 11.9" latitude	568,640 m E 146,440 m N	GABW (#23) 1986-1996
100-N (105-N Building)	46° 40' 29.0" longitude 119° 34' 8.8" latitude	571,220 m E 149,515 m N	100N (#13) 1983-1996
200-W (REDOX)	46° 32' 5.5" longitude 119° 37' 16.7" latitude	567,400 m E 133,925 m N	200W (#7) 1983-1996
200-E (PUREX)	46° 32' 58.1" longitude 119° 31' 14.4" latitude	575,100 m E 135,640 m N	200E (#6) 1983-1996
300-E (331 Building)	46° 21' 53.7" longitude 119° 16' 17.3" latitude	594,528 m E 115,396 m N	300 (#11) 1983-1996
300-W (324 Building)	46° 22' 7.8" longitude 119° 16' 28.3" latitude	594,285 m E 115,828 m N	300 (#11) 1983-1996
400 Area (FFTF)	46° 26' 7.0" longitude 119° 21' 35.9" latitude	587,605 m E 123,115 m N	400 (#9) 1983-1996

Table 4-2. Direction and Distance to Each MPR Location from Respective Emission Zone.

Emission Zone	Offsite MPR			Onsite MPR[a]		
Building/facility	Map ID from Figures 4-1 and 4-2	Direction	Distance, m[b]	Map ID from Figures 4-1 and 4-2	Direction	Distance, m[b]
100-B/C (105-B Building)	1	NNW	8,600	N/A	N/A	N/A
100-D/DR (105-D Building)	2	WNW	8,900	N/A	N/A	N/A
100-F (105-F Building)	3	ESE	9,700	N/A	N/A	N/A
100-H (105-H Building)	4	ESE	11,600	N/A	N/A	N/A
100-K (105-KW Building)	5	NNW	8,900	N/A	N/A	N/A
100-N (105-N Building)	6	WNW	8,500	N/A	N/A	N/A
200-E (PUREX)	7	ESE	20,200	A	ESE	16,630
200-W (REDOX)	8	SE	22,000	B	ESE	18,310
300-E (331 Building)	9	NE	1,100	N/A	N/A	N/A
300-W (324 Building)	10	NE	1,400	N/A	N/A	N/A
400 Area (FFTF)	11	SE	9,100	A	NNE	4,390

N/A = not applicable.

[a] The dose factors of offsite MPRs for emission zones 100-B/C, 100-D/DR, 100-F, 100-H, 100-K, 100-N, 300-E, and 300-W were always greater than the factors of current potential onsite MPRs.

[b] These values represent the shortest distance from the respective point of release to the Hanford Site boundary in a given sector of the wind rose.

Table 4-3. 100-B/C Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
H-3	5.1 E–05	2.6 E–05	Kr-85	1.1 E–07	5.8 E–08
Be–7	4.1 E–04	2.5 E–04	Kr-85m	4.5 E–06	2.3 E–06
Be–10[a]	(Sr–90)	(Sr–90)	Kr-87	1.6 E–05	7.8 E–06
C-11	4.1 E–06	2.3 E–06	Kr-88	5.6 E–05	2.8 E–05
C-14	4.0 E–03	2.0 E–03	Kr-89	4.6 E–08	2.4 E–08
C-15[b]	0.0	0.0	Kr-90[b]	0.0	0.0
N-13	9.5 E–07	5.5 E–07	Rb-86	6.0 E–03	3.7 E–03
O-15	1.0 E–09	6.1 E–10	Rb-87	2.0 E–02	1.2 E–02
F-18	2.5 E–05	1.5 E–05	Rb-88	2.7 E–06	1.5 E–06
Na-22	2.7 E–01	1.7 E–01	Rb-89	5.4 E–06	3.1 E–06
Na-24	4.6 E–04	2.8 E–04	Rb-90	1.6 E–08	9.3 E–09
P-32	6.0 E–03	3.8 E–03	Rb-90m	2.7 E–07	1.6 E–07
S-35	8.5 E–04	5.3 E–04	Sr-89	3.6 E–03	2.2 E–03
Ar-41	2.8 E–05	1.4 E–05	*Sr-90*	*2.3 E–01*	*1.5 E–01*
K-40	2.6 E–01	1.6 E–01	Sr-90+D[c]	2.4 E–01	1.5 E–01
Ca-41	2.1 E–05	1.3 E–05	Sr-91	9.5 E–05	5.7 E–05
Sc-46	2.5 E–02	1.6 E–02	Sr-92	6.1 E–05	3.6 E–05
Cr-51	1.8 E–04	1.1 E–04	Y-90	7.2 E–04	4.4 E–04
Mn-54	3.4 E–02	2.1 E–02	Y-90m	2.1 E–05	1.3 E–05
Mn-56	6.8 E–05	4.0 E–05	Y-91	5.3 E–03	3.2 E–03
Fe–55	4.8 E–04	3.0 E–04	Y-91m	7.0 E–06	4.1 E–06
Fe–59	9.8 E–03	6.1 E–03	Y-92	5.2 E–05	3.1 E–05
Co-57	5.9 E–03	3.7 E–03	Y-93	1.3 E–04	7.5 E–05
Co-58	1.1 E–02	7.1 E–03	Zr-93	2.7 E–03	1.6 E–03
Co-60	5.1 E–01	3.2 E–01	*Zr-95*	*8.1 E–03*	*5.1 E–03*
Ni-59	6.4 E–04	4.0 E–04	Zr-95+D[c]	1.5 E–02	9.1 E–03
Ni-63	5.5 E–04	3.4 E–04	Nb-93m	4.3 E–03	2.7 E–03
Ni-65	2.7 E–05	1.6 E–05	Nb-94	1.7 E+00	1.1 E+00
Cu-64	3.3 E–05	2.0 E–05	Nb-95	1.0 E–02	6.2 E–03
Zn-65	5.1 E–02	3.2 E–02	Nb-95m	6.3 E–04	3.9 E–04
Zn-69m	8.7 E–05	5.3 E–05	Nb-97	1.4 E–05	8.5 E–06
Zn-69	1.3 E–06	7.5 E–07	Nb-97m[b]	0.0	0.0
Ga-67	1.3 E–04	7.9 E–05	Mo-93	5.8 E–03	3.7 E–03
As-76	2.9 E–04	1.7 E–04	*Mo-99*	*3.7 E–04*	*2.2 E–04*
Se–79[a]	(Pu–241)	(Pu–241)	Mo-99+D[c]	4.2 E–04	2.5 E–04
Br-82	6.7 E–04	4.2 E–04	Tc-97	1.2 E–02	7.5 E–03
Br-83	2.0 E–07	1.2 E–07	Tc-99	4.7 E–02	2.9 E–02
Br-84	1.4 E–05	8.2 E–06	Tc-99m	8.4 E–06	5.1 E–06
Br-85	7.3 E–10	4.4 E–10	Tc-101	6.7 E–07	3.9 E–07
Kr-83m	5.0 E–09	2.5 E–09	Ru-97	1.4 E–04	8.6 E–05

Table 4-3. 100-B/C Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Ru-103	*3.8 E–03*	*2.4 E–03*	Te–133m	3.0 E–05	1.8 E–05
Ru-103+D[c]	3.8 E–03	2.4 E–03	Te–134	8.7 E–06	5.0 E–06
Ru-105[b]	5.7 E–05	3.4 E–05	I-122	1.7 E–09	6.6 E–09
Ru-106	*3.3 E–02*	*2.0 E–02*	I-123	9.1 E–06	3.9 E–05
Ru-106+D[c]	4.2 E–02	2.6 E–02	I-125	1.6 E–02	6.9 E–02
Rh-103m	1.7 E–07	9.5 E–08	I-129	2.7 E–01	1.2 E+00
Rh-105	1.0 E–04	6.2 E–05	I-130	9.9 E–05	4.3 E–04
Rh-105m	0.0	0.0	I-131	8.9 E–03	3.8 E–02
Rh-106[b]	0.0	0.0	I-132	1.4 E–05	6.2 E–05
Pd-107[b]	7.8 E–04	4.7 E–04	I-133	1.0 E–04	4.4 E–04
Pd-109[b]	7.6 E–05	4.5 E–05	I-134	4.1 E–06	1.8 E–05
Ag-109m[b]	0.0	0.0	I-135	3.3 E–05	1.4 E–04
Ag-110[b]	0.0	0.0	Xe–122	2.2 E–06	1.1 E–06
Ag-110m	1.0 E–01	6.2 E–02	Xe–123	1.4 E–05	7.2 E–06
Ag-111	2.1 E–03	1.3 E–03	Xe–125	8.0 E–06	4.1 E–06
Cd-113[a]	(Pu–241)	(Pu–241)	Xe–127	8.9 E–06	4.5 E–06
Cd-113m[a]	(Pu–241)	(Pu–241)	Xe–131m	3.2 E–07	1.7 E–07
Cd-115[b]	4.1 E–04	2.5 E–04	Xe–133	1.2 E–06	6.1 E–07
Cd-115m	7.5 E–03	4.6 E–03	Xe–133m	1.0 E–06	5.2 E–07
In-113m	6.9 E–06	4.1 E–06	Xe–135	7.6 E–06	3.9 E–06
In-115	1.3 E–01	7.7 E–02	Xe–135m	1.2 E–06	5.8 E–07
In-115m	1.3 E–05	8.0 E–06	Xe–137	1.1 E–08	5.7 E–09
Sn-113	4.6 E–03	2.9 E–03	Xe–138	3.0 E–06	1.5 E–06
Sn-123	1.1 E–04	6.7 E–05	Cs-134	2.1 E–01	1.3 E–01
Sn-125	5.0 E–03	3.1 E–03	Cs-134m	2.3 E–06	1.4 E–06
Sn-126	9.8 E–02	6.1 E–02	Cs-135	9.2 E–03	5.7 E–03
Sb-124	1.8 E–02	1.1 E–02	Cs-136	7.7 E–03	4.8 E–03
Sb-125	5.5 E–02	3.4 E–02	*Cs-137*	*5.5 E–02*	*3.5 E–02*
Sb-126	6.8 E–03	4.3 E–03	Cs-137+D[c]	5.0 E–1	3.1 E–01
Sb-126m	5.7 E–06	3.2 E–06	Cs-138	2.0 E–05	1.1 E–05
Sb-127	9.8 E–04	6.0 E–04	Cs-139	2.6 E–07	1.5 E–07
Te–125m	2.2 E–03	1.3 E–03	Ba-133	1.6 E–01	9.7 E–02
Te–127	1.8 E–05	1.1 E–05	Ba-133m	6.6 E–05	4.0 E–05
Te–127m	5.3 E–03	3.3 E–03	Ba-137m	3.1 E–09	1.9 E–09
Te–129	3.9 E–06	2.3 E–06	Ba-139	5.5 E–06	3.2 E–06
Te–129m	5.2 E–03	3.2 E–03	*Ba-140*	*2.2 E–03*	*1.4 E–03*
Te–131	3.2 E–06	1.8 E–06	Ba-140+D[c]	5.7 E–03	3.5 E–03
Te–131m	5.0 E–04	3.0 E–04	Ba-141	2.9 E–06	1.6 E–06
Te–132	8.6 E–04	5.3 E–04	Ba-142	1.0 E–06	5.8 E–07
Te–133	1.4 E–06	8.2 E–07	La-140	8.4 E–04	5.2 E–04

Table 4-3. 100-B/C Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
La-141	1.6 E–06	9.5 E–07	Pb-211	1.2 E–04	7.1 E–05
La-142	6.1 E–05	3.6 E–05	Pb-212	7.2 E–03	4.2 E–03
Ce-141	1.6 E–03	9.7 E–04	Pb-214	1.0 E–05	5.7 E–06
Ce-143	2.5 E–04	1.5 E–04	Bi-210	9.5 E–03	5.6 E–03
Ce-144	*2.6 E–02*	*1.6 E–02*	Bi-211	2.7 E–09	1.6 E–09
Ce-144+D[c]	2.7 E–02	1.6 E–02	Bi-212	6.9 E–04	4.0 E–04
Pr-143	1.2 E–03	7.6 E–04	Bi-213	2.2 E–05	1.3 E–05
Pr-144	4.8 E–07	2.7 E–07	Bi-214	8.2 E–06	4.7 E–06
Pr-144m	2.5 E–08	1.5 E–08	Po-210	1.1 E+00	6.7 E–01
Nd-147	1.2 E–03	7.5 E–04	Po-211[b]	0.0	0.0
Pm-147	2.3 E–03	1.4 E–03	Po-212[b]	0.0	0.0
Pm-148	1.8 E–03	1.1 E–03	Po-213[b]	0.0	0.0
Pm-148m	1.6 E–02	1.0 E–02	Po-214[b]	0.0	0.0
Pm-149	2.3 E–04	1.4 E–04	Po-215[b]	0.0	0.0
Pm-151	6.1 E–05	3.8 E–05	Po-216[b]	0.0	0.0
Sm-147	3.5 E+00	2.1 E+00	Po-218	1.4 E–09	8.1 E–10
Sm-151	1.6 E–03	9.3 E–04	At-217[b]	0.0	0.0
Sm-153	1.6 E–04	9.8 E–05	Rn-219[d]	5.4 E–03	3.2 E–03
Eu-152	5.0 E–01	3.1 E–01	Rn-220[d]	1.0 E–05	5.9 E–06
Eu-152m	2.2 E–05	1.3 E–05	Rn-222	1.4 E–04	7.3 E–05
Eu-154	4.1 E–01	2.6 E–01	Fr-221	8.4 E–07	5.0 E–07
Eu-155	1.7 E–02	1.0 E–02	Fr-223	1.9 E–05	1.1 E–05
Eu-156	5.1 E–03	3.1 E–03	Ra-223	5.0 E–01	3.0 E–01
Gd-152[a]	(Pu–239)	(Pu–239)	Ra-224	1.8 E–01	1.1 E–01
Tb-160	1.3 E–02	8.3 E–03	Ra-225	3.1 E–01	1.9 E–01
Ho-166	1.9 E–04	1.1 E–04	Ra-226	9.6 E–01	5.9 E–01
Ho-166m	1.7 E+00	1.0 E+00	Ra-228	4.0 E–01	2.4 E–01
Hf-181	5.1 E–03	3.2 E–03	Ac-225	3.0 E–01	1.8 E–01
W-181	9.4 E–04	5.9 E–04	Ac-227	3.1 E+01	1.8 E+01
W-185	1.3 E–03	7.8 E–04	Ac-228	3.5 E–03	2.0 E–03
W-187	1.1 E–04	6.6 E–05	Th-227	5.5 E–01	3.3 E–01
Re–187	3.6 E–05	2.2 E–05	Th-228	1.2 E+01	6.9 E+00
Ir-192	1.1 E–02	7.1 E–03	Th-229	3.3 E+01	1.9 E+01
Hg-203	7.1 E–03	4.4 E–03	Th-230	1.2 E+01	6.9 E+00
Tl-207	1.8 E–09	1.1 E–09	Th-231	5.1 E–05	3.0 E–05
Tl-208	5.9 E–08	3.5 E–08	*Th-232*	*1.7 E+01*	*9.9 E+00*
Tl-209	4.0 E–09	2.4 E–09	Th-232+D[c]	1.9 E+01	1.2 E+01
Pb-209	3.5 E–06	2.1 E–06	Th-234	5.0 E–03	3.1 E–03
Pb-210	*3.0 E+00*	*1.8 E+00*	Pa-231	2.4 E+01	1.4 E+01
Pb-210+D[c]	3.0 E+00	1.8 E+00	Pa-233	2.2 E–03	1.3 E–03

Table 4-3. 100-B/C Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Pa-234	1.5 E–04	9.2 E–05	Pu-240	1.7 E+01	1.0 E+01
Pa-234m[b]	0.0	0.0	*Pu-241*	*2.7 E–0*	*1.6 E–01*
U-232	2.3 E+01	1.4 E+01	Pu-241+D[c]	2.7 E–01	1.6 E–01
U-233	6.6 E+00	3.9 E+00	Pu-242	1.6 E+01	9.8 E+00
U-234	6.5 E+00	3.9 E+00	Pu-243	1.0 E–05	5.9 E–06
U-235	6.2 E+00	3.7 E+00	Pu-244	1.6 E+01	9.7 E+00
U-236	6.2 E+00	3.7 E+00	Am-241	2.7 E+01	1.6 E+01
U-237	6.4 E–04	4.0 E–04	Am-242	2.6 E–03	1.5 E–03
U-238	5.8 E+00	3.4 E+00	Am-242m	2.6 E+01	1.5 E+01
U-240	1.1 E–04	6.6 E–05	Am-243	2.7 E+01	1.6 E+01
Np-237	2.4 E+01	1.4 E+01	Cm-242	8.6 E–01	5.1 E–01
Np-238	1.7 E–03	1.0 E–03	Cm-243	1.8 E+01	1.1 E+01
Np-239	2.5 E–04	1.5 E–04	Cm-244	1.4 E+01	8.3 E+00
Np-240	2.1 E–05	1.2 E–05	Cm-245	2.8 E+01	1.6 E+01
Np-240m	1.6 E–07	9.3 E–08	Cm-246	2.7 E+01	1.6 E+01
Pu-236	4.2 E+00	2.5 E+00	Cm-247	2.5 E+01	1.5 E+01
Pu-238	1.6 E+01	9.5 E+00	Cm-248	1.0 E+02	5.9 E+01
Pu-239	1.7 E+01	1.0 E+01	Cf-252	7.5 E+00	4.4 E+00

[a] Dose factors for this nuclide not included in the CAP88-PC library; thus, substituting the dose factors of the radionuclide in parentheses is recommended.

[b] Factor is ≤1.0 E–11, or effectively zero, considering also the scarcity and short half-life of the nuclide.

[c] "+D" indicates factors from in-grown progeny are also included.

[d] Short-lived Rn isotopes modeled on dose from their longer-lived progeny. Yet, 1 Ci of Rn does not equal 1Ci of Pb. Each Ci of Rn-219 released generates 0.0018 Ci of Pb-210, and each Ci of Rn-220, 0.0014 Ci of Pb-212. Dose based on Pb progeny multiplied by appropriate equilibrium factor (HNF-3602 1999).

Table 4-4. 100-D/DR Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
H-3	3.8 E–05	2.2 E–05	Kr-85	8.4 E–08	4.9 E–08
Be–7	2.8 E–04	2.1 E–04	Kr-85m	3.0 E–06	1.8 E–06
Be–10[a]	(Sr–90)	(Sr–90)	Kr-87	8.5 E–06	5.1 E–06
C-11	1.5 E–06	1.1 E–06	Kr-88	3.6 E–05	2.1 E–05
C-14	2.9 E–03	1.7 E–03	Kr-89	2.5 E–08	1.5 E–08
C-15[b]	0.0	0.0	Kr-90[b]	0.0	0.0
N-13	4.2 E–07	3.1 E–07	Rb-86	4.1 E–03	3.1 E–03
O-15	4.7 E–10	3.5 E–10	Rb-87	1.4 E–02	1.0 E–02
F-18	1.4 E–05	1.0 E–05	Rb-88	9.8 E–07	7.3 E–07
Na-22	1.8 E–01	1.4 E–01	Rb-89	2.0 E–06	1.5 E–06
Na-24	3.1 E–04	2.3 E–04	Rb-90	7.5 E–09	5.6 E–09
P-32	4.2 E–03	3.1 E–03	Rb-90m	1.4 E–07	1.1 E–07
S-35	5.9 E–04	4.4 E–04	Sr-89	2.5 E–03	1.8 E–03
Ar-41	1.7 E–05	9.9 E–06	*Sr-90*	*1.6 E–01*	*1.2 E–01*
K-40	1.8 E–01	1.3 E–01	Sr-90+D[c]	1.6 E–01	1.2 E–01
Ca-41	1.5 E–05	1.1 E–05	Sr-91	6.2 E–05	4.6 E–05
Sc-46	1.7 E–02	1.3 E–02	Sr-92	3.6 E–05	2.6 E–05
Cr-51	1.3 E–04	9.4 E–05	Y-90	4.9 E–04	3.6 E–04
Mn-54	2.4 E–02	1.8 E–02	Y-90m	1.3 E–05	9.5 E–06
Mn-56	4.0 E–05	2.9 E–05	Y-91	3.6 E–03	2.7 E–03
Fe–55	3.3 E–04	2.5 E–04	Y-91m	3.1 E–06	2.3 E–06
Fe–59	6.8 E–03	5.1 E–03	Y-92	3.2 E–05	2.3 E–05
Co-57	4.1 E–03	3.1 E–03	Y-93	8.3 E–05	6.0 E–05
Co-58	7.8 E–03	5.9 E–03	Zr-93	1.8 E–03	1.3 E–03
Co-60	3.6 E–01	2.7 E–01	*Zr-95*	*5.6 E–03*	*4.2 E–03*
Ni-59	4.4 E–04	3.3 E–04	Zr-95+D[c]	1.0 E–2	7.5 E–03
Ni-63	3.8 E–04	2.8 E–04	Nb-93m	3.0 E–03	2.2 E–03
Ni-65	1.6 E–05	1.2 E–05	Nb-94	1.2 E+00	8.7 E–01
Cu-64	2.2 E–05	1.6 E–05	Nb-95	6.9 E–03	5.2 E–03
Zn-65	3.6 E–02	2.7 E–02	Nb-95m	4.3 E–04	3.2 E–04
Zn-69m	5.8 E–05	4.3 E–05	Nb-97	7.3 E–06	5.3 E–06
Zn-69	6.0 E–07	4.4 E–07	Nb-97m[b]	0.0	0.0
Ga-67	8.8 E–05	6.5 E–05	Mo-93	4.0 E–03	3.0 E–03
As-76	2.0 E–04	1.4 E–04	*Mo-99*	*2.5 E–04*	*1.8 E–04*
Se–79[a]	(Pu–241)	(Pu–241)	Mo-99+D[c]	2.8 E–04	2.1 E–04
Br-82	4.6 E–04	3.4 E–04	Tc-97	8.3 E–03	6.2 E–03
Br-83	1.2 E–07	8.7 E–08	Tc-99	3.2 E–02	2.4 E–02
Br-84	5.6 E–06	4.1 E–06	Tc-99m	5.4 E–06	4.0 E–06
Br-85	3.6 E–10	2.7 E–10	Tc-101	2.6 E–07	1.9 E–07
Kr-83m	3.0 E–09	1.8 E–09	Ru-97	9.5 E–05	7.1 E–05

Table 4-4. 100-D/DR Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Ru-103	*2.7 E–03*	*2.0 E–03*	Te–133m	1.4 E–05	1.0 E–05
Ru-103+D[c]	2.7 E–03	2.0 E–03	Te–134	3.7 E–06	2.7 E–06
Ru-105	3.6 E–05	2.6 E–05	I-122	7.4 E–10	2.7 E–09
Ru-106	*2.2 E–02*	*1.6 E–02*	I-123	5.0 E–06	2.0 E–05
Ru-106+D[c]	2.9 E–02	2.1 E–02	I-125	9.0 E–03	3.6 E–02
Rh-103m	7.7 E–08	5.6 E–08	I-129	1.5 E–01	6.1 E–01
Rh-105	6.9 E–05	5.1 E–05	I-130	5.4 E–05	2.2 E–04
Rh-105m[b]	0.0	0.0	I-131	5.0 E–03	2.0 E–02
Rh-106[b]	0.0	0.0	I-132	7.2 E–06	2.8 E–05
Pd-107	5.4 E–04	3.9 E–04	I-133	5.6 E–05	2.3 E–04
Pd-109	5.0 E–05	3.6 E–05	I-134	1.8 E–06	6.7 E–06
Ag-109m[b]	0.0	0.0	I-135	1.8 E–05	7.1 E–05
Ag-110[b]	0.0	0.0	Xe–122	1.6 E–06	9.3 E–07
Ag-110m	6.9 E–02	5.2 E–02	Xe–123	8.7 E–06	5.2 E–06
Ag-111	1.5 E–03	1.1 E–03	Xe–125	5.7 E–06	3.4 E–06
Cd-113[b]	(Pu–241)	(Pu–241)	Xe–127	6.5 E–06	3.8 E–06
Cd-113m[b]	(Pu–241)	(Pu–241)	Xe–131m	2.4 E–07	1.4 E–07
Cd-115	2.8 E–04	2.0 E–04	Xe–133	8.7 E–07	5.2 E–07
Cd-115m	5.1 E–03	3.8 E–03	Xe–133m	7.4 E–07	4.4 E–07
In-113m	3.8 E–06	2.8 E–06	Xe–135	5.3 E–06	3.2 E–06
In-115	8.7 E–02	6.4 E–02	Xe–135m	4.7 E–07	2.9 E–07
In-115m	8.4 E–06	6.1 E–06	Xe–137	6.0 E–09	3.8 E–09
Sn-113	3.2 E–03	2.4 E–03	Xe–138	1.2 E–06	7.4 E–07
Sn-123	7.4 E–05	5.6 E–05	Cs-134	1.4 E–01	1.1 E–01
Sn-125	3.4 E–03	2.5 E–03	Cs-134m	1.4 E–06	9.9 E–07
Sn-126	6.8 E–02	5.1 E–02	Cs-135	6.4 E–03	4.8 E–03
Sb-124	1.2 E–02	9.3 E–03	Cs-136	5.3 E–03	4.0 E–03
Sb-125	3.8 E–02	2.8 E–02	*Cs-137*	*3.8 E–02*	*2.9 E–02*
Sb-126	4.7 E–03	3.5 E–03	Cs-137+D[c]	3.4 E–01	2.6 E–01
Sb-126m	2.1 E–06	1.5 E–06	Cs-138	7.7 E–06	5.7 E–06
Sb-127	6.7 E–04	5.0 E–04	Cs-139	1.2 E–07	8.8 E–08
Te–125m	1.5 E–03	1.1 E–03	Ba-133	1.1 E–01	8.1 E–02
Te–127	1.2 E–05	8.6 E–06	Ba-133m	4.5 E–05	3.3 E–05
Te–127m	3.7 E–03	2.7 E–03	Ba-137m	1.5 E–09	1.1 E–09
Te–129	1.9 E–06	1.4 E–06	Ba-139	2.9 E–06	2.1 E–06
Te–129m	3.6 E–03	2.7 E–03	*Ba-140*	*1.5 E–03*	*1.1 E–03*
Te–131	1.2 E–06	8.8 E–07	Ba-140+D[c]	3.9 E–03	2.9 E–03
Te–131m	3.4 E–04	2.5 E–04	Ba-141	1.0 E–06	7.8 E–07
Te–132	5.9 E–04	4.3 E–04	Ba-142	4.2 E–07	3.2 E–07
Te–133	5.7 E–07	4.3 E–07	La-140	5.8 E–04	4.2 E–04

Table 4-4. 100-D/DR Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
La-141	9.8 E–07	7.2 E–07	Pb-211	5.0 E–05	3.7 E–05
La-142	3.3 E–05	2.4 E–05	Pb-212	4.7 E–03	3.4 E–03
Ce–141	1.1 E–03	8.0 E–04	Pb-214	3.7 E–06	2.8 E–06
Ce–143	1.7 E–04	1.2 E–04	Bi-210	6.4 E–03	4.6 E–03
Ce–144	*1.8 E–02*	*1.3 E–02*	Bi-211	1.3 E–09	9.4 E–10
Ce-144+D[c]	1.8 E–02	1.3 E–02	Bi-212	3.3 E–04	2.4 E–04
Pr-143	8.5 E–04	6.3 E–04	Bi-213	9.4 E–06	6.9 E–06
Pr-144	1.7 E–07	1.3 E–07	Bi-214	3.0 E–06	2.2 E–06
Pr-144m	1.3 E–08	9.4 E–09	Po-210	7.5 E–01	5.5 E–01
Nd-147	8.3 E–04	6.2 E–04	Po-211[b]	0.0	0.0
Pm-147	1.5 E–03	1.1 E–03	Po-212[b]	0.0	0.0
Pm-148	1.2 E–03	9.2 E–04	Po-213[b]	0.0	0.0
Pm-148m	1.1 E–02	8.3 E–03	Po-214[b]	0.0	0.0
Pm-149	1.6 E–04	1.1 E–04	Po-215[b]	0.0	0.0
Pm-151	4.1 E–05	3.1 E–05	Po-216[b]	0.0	0.0
Sm-147	2.4 E+00	1.7 E+00	Po-218	6.8 E–10	5.1 E–10
Sm-151	1.1 E–03	7.7 E–04	At-217[b]	0.0	0.0
Sm-153	1.1 E–04	8.0 E–05	Rn-219[d]	3.6 E–03	2.7 E–03
Eu-152	3.5 E–01	2.6 E–01	Rn-220[d]	6.6 E–06	4.8 E–06
Eu-152m	1.5 E–05	1.1 E–05	Rn-222	1.1 E–04	6.2 E–05
Eu-154	2.8 E–01	2.1 E–01	Fr-221	4.4 E–07	3.3 E–07
Eu-155	1.1 E–02	8.5 E–03	Fr-223	6.7 E–06	5.0 E–06
Eu-156	3.5 E–03	2.6 E–03	Ra-223	3.4 E–01	2.5 E–01
Gd-152[a]	(Pu–239)	(Pu–239)	Ra-224	1.2 E–01	8.8 E–02
Tb-160	9.2 E–03	6.9 E–03	Ra-225	2.1 E–01	1.6 E–01
Ho-166	1.3 E–04	9.2 E–05	Ra-226	6.6 E–01	4.8 E–01
Ho-166m	1.1 E+00	8.6 E–01	Ra-228	2.7 E–01	2.0 E–01
Hf-181	3.5 E–03	2.6 E–03	Ac-225	2.0 E–01	1.5 E–01
W-181	6.5 E–04	4.9 E–04	Ac-227	2.1 E+01	1.5 E+01
W-185	8.6 E–04	6.4 E–04	Ac-228	2.2 E–03	1.6 E–03
W-187	7.3 E–05	5.4 E–05	Th-227	3.7 E–01	2.7 E–01
Re–187	2.5 E–05	1.9 E–05	Th-228	8.0 E+00	5.7 E+00
Ir-192	7.8 E–03	5.8 E–03	Th-229	2.2 E+01	1.6 E+01
Hg-203	4.9 E–03	3.6 E–03	Th-230	8.0 E+00	5.7 E+00
Tl-207	9.4 E–10	7.0 E–10	Th-231	3.4 E–05	2.5 E–05
Tl-208	3.0 E–08	2.2 E–08	*Th-232*	*1.1 E+01*	*8.2 E+00*
Tl-209	1.9 E–09	1.4 E–09	Th-232+D[c]	1.3 E+01	9.6 E+00
Pb-209	2.1 E–06	1.5 E–06	Th-234	3.4 E–03	2.5 E–03
Pb-210	*2.0 E+00*	*1.5 E+00*	Pa-231	1.6 E+01	1.2 E+01
Pb-210+D[c]	2.0 E+00	1.5 E+00	Pa-233	1.5 E–03	1.1 E–03

Table 4-4. 100-D/DR Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Pa-234	9.9 E–05	7.2 E–05	Pu-240	1.2 E+01	8.5 E+00
Pa-234m[b]	0.0	0.0	*Pu-241*	*1.9 E–01*	*1.3 E–01*
U-232	1.6 E+01	1.1 E+01	Pu-241+D[c]	1.9 E–01	1.3 E–01
U-233	4.5 E+00	3.2 E+00	Pu-242	1.1 E+01	8.1 E+00
U-234	4.4 E+00	3.2 E+00	Pu-243	6.3 E–06	4.5 E–06
U-235	4.2 E+00	3.1 E+00	Pu-244	1.1 E+01	8.0 E+00
U-236	4.2 E+00	3.0 E+00	Am-241	1.8 E+01	1.3 E+01
U-237	4.4 E–04	3.3 E–04	Am-242	1.7 E–03	1.2 E–03
U-238	3.9 E+00	2.8 E+00	Am-242m	1.7 E+01	1.3 E+01
U-240	7.3 E–05	5.3 E–05	Am-243	1.8 E+01	1.3 E+01
Np-237	1.7 E+01	1.2 E+01	Cm-242	5.9 E–01	4.2 E–01
Np-238	1.1 E–03	8.2 E–04	Cm-243	1.2 E+01	8.7 E+00
Np-239	1.7 E–04	1.3 E–04	Cm-244	9.5 E+00	6.9 E+00
Np-240	1.0 E–05	7.4 E–06	Cm-245	1.9 E+01	1.4 E+01
Np-240m	7.7 E–08	5.8 E–08	Cm-246	1.9 E+01	1.3 E+01
Pu-236	2.9 E+00	2.1 E+00	Cm-247	1.7 E+01	1.2 E+01
Pu-238	1.1 E+01	7.9 E+00	Cm-248	6.8 E+01	4.9 E+01
Pu-239	1.2 E+01	8.5 E+00	Cf-252	5.1 E+00	3.7 E+00

[a] Dose factors for this nuclide not included in the CAP88-PC library; thus, substituting the dose factors of the radionuclide in parentheses is recommended.

[b] Factor is ≤1.0 E–11, or effectively zero, considering also the scarcity and short half-life of the nuclide.

[c] "+D" indicates factors from in-grown progeny are also included.

[d] Short-lived Rn isotopes modeled on dose from their longer-lived progeny. Yet, 1 Ci of Rn does not equal 1Ci of Pb. Each Ci of Rn-219 released generates 0.0018 Ci of Pb-210, and each Ci of Rn-220, 0.0014 Ci of Pb-212. Dose based on Pb progeny multiplied by appropriate equilibrium factor (HNF-3602 1999).

Table 4-5. 100-F Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
H-3	6.5 E–05	3.2 E–05	Kr-85	1.5 E–07	7.1 E–08
Be–7	4.5 E–04	3.0 E–04	Kr-85m	5.2 E–06	2.6 E–06
Be–10[a]	(Sr–90)	(Sr–90)	Kr-87	1.5 E–05	8.6 E–06
C-11	3.9 E–06	3.2 E–06	Kr-88	6.2 E–05	3.2 E–05
C-14	5.1 E–03	2.5 E–03	Kr-89	4.6 E–08	3.4 E–08
C-15[b]	0.0	0.0	Kr-90[b]	0.0	0.0
N-13	1.2 E–06	1.0 E–06	Rb-86	6.6 E–03	4.4 E–03
O-15	7.2 E–10	6.1 E–10	Rb-87	2.2 E–02	1.5 E–02
F-18	2.4 E–05	1.6 E–05	Rb-88	2.7 E–06	2.3 E–06
Na-22	3.0 E–01	2.0 E–01	Rb-89	5.8 E–06	4.9 E–06
Na-24	4.9 E–04	3.3 E–04	Rb-90	1.4 E–08	1.2 E–08
P-32	6.7 E–03	4.5 E–03	Rb-90m	3.3 E–07	2.8 E–07
S-35	9.5 E–04	6.4 E–04	Sr-89	4.0 E–03	2.7 E–03
Ar-41	2.9 E–05	1.6 E–05	*Sr-90*	*2.6 E–01*	*1.7 E–01*
K-40	2.9 E–01	1.9 E–01	Sr-90+D[c]	2.6 E–01	1.8 E–01
Ca-41	2.4 E–05	1.6 E–05	Sr-91	1.0 E–04	6.7 E–05
Sc-46	2.8 E–02	1.9 E–02	Sr-92	6.0 E–05	4.1 E–05
Cr-51	2.0 E–04	1.4 E–04	Y-90	8.0 E–04	5.2 E–04
Mn-54	3.8 E–02	2.6 E–02	Y-90m	2.1 E–05	1.4 E–05
Mn-56	6.6 E–05	4.5 E–05	Y-91	5.9 E–03	3.9 E–03
Fe-55	5.3 E–04	3.5 E–04	Y-91m	5.9 E–06	4.5 E–06
Fe-59	1.1 E–02	7.3 E–03	Y-92	5.2 E–05	3.5 E–05
Co-57	6.6 E–03	4.4 E–03	Y-93	1.4 E–04	8.7 E–05
Co-58	1.3 E–02	8.4 E–03	Zr-93	3.0 E–03	1.9 E–03
Co-60	5.7 E–01	3.8 E–01	*Zr-95*	*9.0 E–03*	*6.0 E–03*
Ni-59	7.1 E–04	4.8 E–04	Zr-95+D[c]	1.6 E–02	1.1 E–02
Ni-63	6.1 E–04	4.0 E–04	Nb-93m	4.8 E–03	3.2 E–03
Ni-65	2.6 E–05	1.8 E–05	Nb-94	1.9 E+00	1.3 E+00
Cu-64	3.5 E–05	2.3 E–05	Nb-95	1.1 E–02	7.4 E–03
Zn-65	5.7 E–02	3.8 E–02	Nb-95m	6.9 E–04	4.6 E–04
Zn-69m	9.4 E–05	6.2 E–05	Nb-97	1.3 E–05	9.2 E–06
Zn-69	1.1 E–06	8.2 E–07	Nb-97m[b]	0.0	0.0
Ga-67	1.4 E–04	9.4 E–05	Mo-93	6.5 E–03	4.4 E–03
As-76	3.2 E–04	2.1 E–04	*Mo-99*	*4.0 E–04*	*2.6 E–04*
Se-79[a]	(Pu–241)	(Pu–241)	Mo-99+D[c]	4.6 E–04	3.0 E–04
Br-82	7.4 E–04	4.9 E–04	Tc-97	1.3 E–02	8.9 E–03
Br-83	2.0 E–07	1.4 E–07	Tc-99	5.2 E–02	3.5 E–02
Br-84	1.2 E–05	9.8 E–06	Tc-99m	8.8 E–06	5.9 E–06
Br-85	7.0 E–10	5.9 E–10	Tc-101	7.5 E–07	6.3 E–07
Kr-83m	5.2 E–09	2.8 E–09	Ru-97	1.5 E–04	1.0 E–04

Table 4-5. 100-F Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Ru-103	*4.3 E-03*	*2.8 E-03*	Te-133m	2.6 E-05	1.9 E-05
Ru-103+D	4.3 E-03	2.8 E-03	Te-134	7.3 E-06	5.7 E-06
Ru-105	5.9 E-05	3.9 E-05	I-122	5.5 E-09	1.1 E-08
Ru-106	*3.6 E-02*	*2.4 E-02*	I-123	1.3 E-05	3.9 E-05
Ru-106+D	4.7 E-02	3.1 E-02	I-125	2.4 E-02	7.0 E-02
Rh-103m	1.4 E-07	1.1 E-07	I-129	4.0 E-01	1.2 E+00
Rh-105	1.1 E-04	7.4 E-05	I-130	1.5 E-04	4.3 E-04
Rh-105m[b]	0.0	0.0	I-131	1.3 E-02	3.9 E-02
Rh-106[b]	0.0	0.0	I-132	2.3 E-05	6.1 E-05
Pd-107	8.7 E-04	5.6 E-04	I-133	1.5 E-04	4.4 E-04
Pd-109	8.2 E-05	5.3 E-05	I-134	7.8 E-06	1.9 E-05
Ag-109m[b]	0.0	0.0	I-135	4.9 E-05	1.4 E-04
Ag-110[b]	0.0	0.0	Xe-122	2.7 E-06	1.3 E-06
Ag-110m	1.1 E-01	7.5 E-02	Xe-123	1.5 E-05	8.1 E-06
Ag-111	2.3 E-03	1.6 E-03	Xe-125	9.9 E-06	4.9 E-06
Cd-113[a]	(Pu-241)	(Pu-241)	Xe-127	1.1 E-05	5.5 E-06
Cd-113m[a]	(Pu-241)	(Pu-241)	Xe-131m	4.1 E-07	2.0 E-07
Cd-115	4.5 E-04	2.9 E-04	Xe-133	1.5 E-06	7.3 E-07
Cd-115m	8.3 E-03	5.5 E-03	Xe-133m	1.3 E-06	6.3 E-07
In-113m	6.4 E-06	4.5 E-06	Xe-135	9.3 E-06	4.6 E-06
In-115	1.4 E-01	9.2 E-02	Xe-135m	1.3 E-06	9.2 E-07
In-115m	1.4 E-05	9.1 E-06	Xe-137	1.3 E-08	9.1 E-09
Sn-113	5.1 E-03	3.4 E-03	Xe-138	3.2 E-06	2.4 E-06
Sn-123	1.2 E-04	8.0 E-05	Cs-134	2.3 E-01	1.6 E-01
Sn-125	5.5 E-03	3.7 E-03	Cs-134m	2.3 E-06	1.5 E-06
Sn-126	1.1 E-01	7.3 E-02	Cs-135	1.0 E-02	6.8 E-03
Sb-124	2.0 E-02	1.3 E-02	Cs-136	8.6 E-03	5.7 E-03
Sb-125	6.1 E-02	4.1 E-02	*Cs-137*	*6.1 E-02*	*4.1 E-02*
Sb-126	7.6 E-03	5.1 E-03	Cs-137+D[c]	5.5 E-01	3.7 E-01
Sb-126m	5.5 E-06	4.7 E-06	Cs-138	1.7 E-05	1.3 E-05
Sb-127	1.1 E-03	7.2 E-04	Cs-139	3.4 E-07	2.9 E-07
Te-125m	2.4 E-03	1.6 E-03	Ba-133	1.7 E-01	1.2 E-01
Te-127	2.0 E-05	1.3 E-05	Ba-133m	7.3 E-05	4.8 E-05
Te-127m	5.9 E-03	3.9 E-03	Ba-137m	2.7 E-09	2.3 E-09
Te-129	3.4 E-06	2.5 E-06	Ba-139	4.9 E-06	3.5 E-06
Te-129m	5.8 E-03	3.8 E-03	*Ba-140*	*2.5 E-03*	*1.6 E-03*
Te-131	2.9 E-06	2.4 E-06	Ba-140+D[c]	6.3 E-03	4.2 E-03
Te-131m	5.5 E-04	3.6 E-04	Ba-141	2.8 E-06	2.4 E-06
Te-132	9.5 E-04	6.3 E-04	Ba-142	1.2 E-06	1.1 E-06
Te-133	1.7 E-06	1.4 E-06	La-140	9.3 E-04	6.1 E-04

Table 4-5. 100-F Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
La-141	1.6 E–06	1.1 E–06	Pb-211	1.0 E–04	8.2 E–05
La-142	5.6 E–05	3.9 E–05	Pb-212	7.7 E–03	5.0 E–03
Ce-141	1.8 E–03	1.2 E–03	Pb-214	8.7 E–06	7.2 E–06
Ce-143	2.8 E–04	1.8 E–04	Bi-210	1.0 E–02	6.6 E–03
Ce-144	*2.9 E–02*	*1.9 E–02*	Bi-211	2.0 E–09	1.7 E–09
Ce-144+D[c]	3.0 E–02	1.9 E–02	Bi-212	6.0 E–04	4.4 E–04
Pr-143	1.4 E–03	9.1 E–04	Bi-213	1.8 E–05	1.4 E–05
Pr-144	4.8 E–07	4.1 E–07	Bi-214	7.9 E–06	6.6 E–06
Pr-144m	3.5 E–08	2.9 E–08	Po-210	1.2 E+00	8.0 E–01
Nd-147	1.3 E–03	8.9 E–04	Po-211[b]	0.0	0.0
Pm-147	2.5 E–03	1.6 E–03	Po-212[b]	0.0	0.0
Pm-148	2.0 E–03	1.3 E–03	Po-213[b]	0.0	0.0
Pm-148m	1.8 E–02	1.2 E–02	Po-214[b]	0.0	0.0
Pm-149	2.5 E–04	1.6 E–04	Po-215[b]	0.0	0.0
Pm-151	6.7 E–05	4.5 E–05	Po-216[b]	0.0	0.0
Sm-147	3.9 E+00	2.5 E+00	Po-218	1.4 E–09	1.1 E–09
Sm-151	1.7 E–03	1.1 E–03	At-217[b]	0.0	0.0
Sm-153	1.8 E–04	1.2 E–04	Rn-219[d]	5.9 E–03	4.0 E–03
Eu-152	5.6 E–01	3.8 E–01	Rn-220[d]	1.1 E–05	7.0 E–06
Eu-152m	2.4 E–05	1.6 E–05	Rn-222	1.8 E–04	8.9 E–05
Eu-154	4.5 E–01	3.0 E–01	Fr-221	1.1 E–06	9.0 E–07
Eu-155	1.8 E–02	1.2 E–02	Fr-223	1.7 E–05	1.4 E–05
Eu-156	5.6 E–03	3.7 E–03	Ra-223	5.6 E–01	3.6 E–01
Gd-152[a]	(Pu–239)	(Pu–239)	Ra-224	2.0 E–01	1.3 E–01
Tb-160	1.5 E–02	9.9 E–03	Ra-225	3.5 E–01	2.2 E–01
Ho-166	2.1 E–04	1.3 E–04	Ra-226	1.1 E+00	7.0 E–01
Ho-166m	1.8 E+00	1.2 E+00	Ra-228	4.4 E–01	2.9 E–01
Hf-181	5.7 E–03	3.8 E–03	Ac-225	3.3 E–01	2.1 E–01
W-181	1.0 E–03	7.0 E–04	Ac-227	3.4 E+01	2.2 E+01
W-185	1.4 E–03	9.3 E–04	Ac-228	3.6 E–03	2.4 E–03
W-187	1.2 E–04	7.8 E–05	Th-227	6.1 E–01	3.9 E–01
Re-187	4.0 E–05	2.7 E–05	Th-228	1.3 E+01	8.3 E+00
Ir-192	1.3 E–02	8.4 E–03	Th-229	3.6 E+01	2.3 E+01
Hg-203	7.8 E–03	5.2 E–03	Th-230	1.3 E+01	8.3 E+00
Tl-207	2.3 E–09	1.9 E–09	Th-231	5.6 E–05	3.6 E–05
Tl-208	5.9 E–08	5.0 E–08	*Th-232*	*1.9 E+01*	*1.2 E+01*
Tl-209	3.1 E–09	2.6 E–09	Th-232+D[c]	2.2 E+01	1.4 E+01
Pb-209	3.5 E–06	2.4 E–06	Th-234	5.5 E–03	3.7 E–03
Pb-210	*3.3 E+00*	*2.2 E+00*	Pa-231	2.7 E+01	1.7 E+01
Pb-210+D[c]	3.3 E+00	2.2 E+00	Pa-233	2.4 E–03	1.6 E–03

Table 4-5. 100-F Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Pa-234	1.6 E–04	1.1 E–04	Pu-240	1.9 E+01	1.2 E+01
Pa-234m[b]	0.0	0.0	*Pu-241*	*3.0 E–01*	*1.9 E–01*
U-232	2.6 E+01	1.6 E+01	Pu-241+D[c]	3.0 E–01	1.9 E–01
U-233	7.3 E+00	4.7 E+00	Pu-242	1.8 E+01	1.2 E+01
U-234	7.2 E+00	4.6 E+00	Pu-243	1.0 E–05	6.8 E–06
U-235	6.9 E+00	4.4 E+00	Pu-244	1.8 E+01	1.2 E+01
U-236	6.8 E+00	4.4 E+00	Am-241	2.9 E+01	1.9 E+01
U-237	7.1 E–04	4.7 E–04	Am-242	2.8 E–03	1.8 E–03
U-238	6.4 E+00	4.1 E+00	Am-242m	2.8 E+01	1.8 E+01
U-240	1.2 E–04	7.7 E–05	Am-243	2.9 E+01	1.9 E+01
Np-237	2.7 E+01	1.7 E+01	Cm-242	9.6 E–01	6.1 E–01
Np-238	1.8 E–03	1.2 E–03	Cm-243	2.0 E+01	1.3 E+01
Np-239	2.8 E–04	1.8 E–04	Cm-244	1.6 E+01	9.9 E+00
Np-240	1.8 E–05	1.3 E–05	Cm-245	3.0 E+01	1.9 E+01
Np-240m	2.2 E–07	1.8 E–07	Cm-246	3.0 E+01	1.9 E+01
Pu-236	4.7 E+00	3.0 E+00	Cm-247	2.8 E+01	1.8 E+01
Pu-238	1.8 E+01	1.1 E+01	Cm-248	1.1 E+02	7.1 E+01
Pu-239	1.9 E+01	1.2 E+01	Cf-252	8.3 E+00	5.3 E+00

[a] Dose factors for this nuclide not included in the CAP88-PC library; thus, substituting the dose factors of the radionuclide in parentheses is recommended.

[b] Factor is ≤1.0 E–11, or effectively zero, considering also the scarcity and short half-life of the nuclide.

[c] "+D" indicates factors from in-grown progeny are also included.

[d] Short-lived Rn isotopes modeled on dose from their longer-lived progeny. Yet, 1 Ci of Rn does not equal 1Ci of Pb. Each Ci of Rn-219 released generates 0.0018 Ci of Pb-210, and each Ci of Rn-220, 0.0014 Ci of Pb-212. Dose based on Pb progeny multiplied by appropriate equilibrium factor (HNF-3602 1999).

Table 4-6. 100-H Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
H-3	5.3 E–05	2.6 E–05	Kr-85	1.2 E–07	5.8 E–08
Be-7	3.6 E–04	2.5 E–04	Kr-85m	4.0 E–06	2.1 E–06
B-10[a]	(Sr–90)	(Sr–90)	Kr-87	1.1 E–05	6.2 E–06
C-11	2.4 E–06	2.1 E–06	Kr-88	4.6 E–05	2.5 E–05
C-14	4.2 E–03	2.0 E–03	Kr-89	1.2 E–08	8.5 E–09
C-15[b]	0.0	0.0	Kr-90[b]	0.0	0.0
N-13	6.5 E–07	5.6 E–07	Rb-86	5.2 E–03	3.6 E–03
O-15[b]	0.0	0.0	Rb-87	1.7 E–02	1.2 E–02
F-18	1.7 E–05	1.2 E–05	Rb-88	1.7 E–06	1.4 E–06
Na-22	2.3 E–01	1.6 E–01	Rb-89	3.5 E–06	3.0 E–06
Na-24	3.8 E–04	2.6 E–04	Rb-90	2.7 E–09	2.3 E–09
P-32	5.3 E–03	3.6 E–03	Rb-90m	1.1 E–07	9.4 E–08
S-35	7.5 E–04	5.2 E–04	Sr-89	3.1 E–03	2.2 E–03
Ar-41	2.1 E–05	1.2 E–05	*Sr-90*	*2.1 E–01*	*1.4 E–01*
K-40	2.2 E–01	1.6 E–01	Sr-90+D[c]	2.1 E–01	1.4 E–01
Ca-41	1.9 E–05	1.3 E–05	Sr-91	7.8 E–05	5.3 E–05
Sc-46	2.2 E–02	1.5 E–02	Sr-92	4.3 E–05	3.1 E–05
Cr-51	1.6 E–04	1.1 E–04	Y-90	6.2 E–04	4.2 E–04
Mn-54	3.0 E–02	2.1 E–02	Y-90m	1.6 E–05	1.1 E–05
Mn-56	4.8 E–05	3.4 E–05	Y-91	4.6 E–03	3.1 E–03
Fe-55	4.2 E–04	2.9 E–04	Y-91m	4.0 E–06	3.1 E–06
Fe-59	8.6 E–03	5.9 E–03	Y-92	3.9 E–05	2.7 E–05
Co-57	5.2 E–03	3.6 E–03	Y-93	1.0 E–04	6.9 E–05
Co-58	9.9 E–03	6.9 E–03	Zr-93	2.3 E–03	1.6 E–03
Co-60	4.5 E–01	3.1 E–01	*Zr-95*	*7.1 E–03*	*4.9 E–03*
Ni-59	5.6 E–04	3.9 E–04	Zr-95+D[c]	1.3 E–02	8.8 E–03
Ni-63	4.8 E–04	3.3 E–04	Nb-93m	3.8 E–03	2.6 E–03
Ni-65	1.9 E–05	1.3 E–05	Nb-94	1.5 E+00	1.0 E+00
Cu-64	2.7 E–05	1.8 E–05	Nb-95	8.7 E–03	6.0 E–03
Zn-65	4.5 E–02	3.1 E–02	Nb-95m	5.4 E–04	3.7 E–04
Zn-69m	7.3 E–05	4.9 E–05	Nb-97	8.7 E–06	6.6 E–06
Zn-69	7.4 E–07	5.8 E–07	Nb-97m[b]	0.0	0.0
Ga-67	1.1 E–04	7.6 E–05	Mo-93	5.1 E–03	3.5 E–03
As-76	2.5 E–04	1.7 E–04	*Mo-99*	*3.2 E–04*	*2.1 E–04*
Se-79[a]	(Pu–241)	(Pu–241)	Mo-99+D[c]	3.6 E–04	2.4 E–04
Br-82	5.8 E–04	4.0 E–04	Tc-97	1.0 E–02	7.2 E–03
Br-83	1.4 E–07	1.0 E–07	Tc-99	4.1 E–02	2.8 E–02
Br-84	7.9 E–06	6.6 E–06	Tc-99m	6.7 E–06	4.6 E–06
Br-85	1.5 E–10	1.3 E–10	Tc-101	4.4 E–07	3.8 E–07
Kr-83m	3.7 E–09	2.1 E–09	Ru-97	1.2 E–04	8.3 E–05

Table 4-6. 100-H Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Ru-103	*3.4 E–03*	*2.3 E–03*	Te-133m	1.7 E–05	1.4 E–05
Ru-103+D	3.4 E–03	2.3 E–03	Te-134	4.8 E–06	3.9 E–06
Ru-105	4.4 E–05	3.0 E–05	I-122	1.4 E–09	2.8 E–09
Ru-106	*2.9 E–02*	*1.9 E–02*	I-123	9.1 E–06	2.7 E–05
Ru-106+D	4.7 E–02	3.1 E–02	I-125	1.6 E–02	4.9 E–02
Rh-103m	9.4 E–08	7.3 E–08	I-129	2.7 E–01	8.2 E–01
Rh-105	8.8 E–05	5.9 E–05	I-130	9.9 E–05	2.9 E–04
Rh-105m	1.8 E–20	1.6 E–20	I-131	8.9 E–03	2.7 E–02
Rh-106	4.1 E–26	3.5 E–26	I-132	1.5 E–05	3.9 E–05
Pd-107	6.8 E–04	4.6 E–04	I-133	1.0 E–04	3.0 E–04
Pd-109	6.3 E–05	4.2 E–05	I-134	4.9 E–06	1.1 E–05
Ag-109m	5.1 E–23	4.4 E–23	I-135	3.3 E–05	9.5 E–05
Ag-110	3.6 E–32	3.1 E–32	Xe-122	2.2 E–06	1.1 E–06
Ag-110m	8.8 E–02	6.1 E–02	Xe-123	1.1 E–05	6.1 E–06
Ag-111	1.8 E–03	1.3 E–03	Xe-25	8.0 E–06	4.0 E–06
Cd-113[a]	(Pu–241)	(Pu–241)	Xe-127	9.2 E–06	4.5 E–06
Cd-113m[a]	(Pu–241)	(Pu–241)	Xe-131m	3.4 E–07	1.7 E–07
Cd-115	3.5 E–04	2.4 E–04	Xe-133	1.2 E–06	6.0 E–07
Cd-115m	6.5 E–03	4.5 E–03	Xe-133m	1.0 E–06	5.2 E–07
In-113m	4.5 E–06	3.3 E–06	Xe-135	7.3 E–06	3.7 E–06
In-115	1.1 E–01	7.5 E–02	Xe-135m	7.6 E–07	5.7 E–07
In-115m	1.0 E–05	7.0 E–06	Xe-137	3.8 E–09	2.8 E–09
Sn-113	4.0 E–03	2.8 E–03	Xe-138	1.9 E–06	1.4 E–06
Sn-123	9.4 E–05	6.5 E–05	Cs-134	1.8 E–01	1.3 E–01
Sn-125	4.3 E–03	3.0 E–03	Cs-134m	1.6 E–06	1.2 E–06
Sn-126	8.6 E–02	5.9 E–02	Cs-135	8.0 E–03	5.6 E–03
Sb-124	1.6 E–02	1.1 E–02	Cs-136	6.8 E–03	4.7 E–03
Sb-125	4.8 E–02	3.3 E–02	*Cs-137*	*4.8 E–02*	*3.3 E–02*
Sb-126	6.0 E–03	4.1 E–03	Cs-137+D[c]	4.4 E–01	3.0 E–01
Sb-126m	3.5 E–06	3.0 E–06	Cs-138	1.1 E–05	9.1 E–06
Sb-127	8.5 E–04	5.8 E–04	Cs-139	1.8 E–07	1.5 E–07
Te-125m	1.9 E–03	1.3 E–03	Ba-133	1.4 E–01	9.4 E–02
Te-127	1.5 E–05	1.0 E–05	Ba-133m	5.7 E–05	3.9 E–05
Te-127m	4.6 E–03	3.2 E–03	Ba-137m	5.1 E–10	4.4 E–10
Te-129	2.3 E–06	1.8 E–06	Ba-139	3.4 E–06	2.5 E–06
Te-129m	4.6 E–03	3.1 E–03	*Ba-140*	*1.9 E–03*	*1.3 E–03*
Te-131	1.8 E–06	1.6 E–06	Ba-140+D[c]	5.0 E–03	3.4 E–03
Te-131m	4.3 E–04	2.9 E–04	Ba-141	1.8 E–06	1.5 E–06
Te-132	7.5 E–04	5.1 E–04	Ba-142	6.8 E–07	5.8 E–07
Te-133	9.6 E–07	8.3 E–07	La-140	7.3 E–04	5.0 E–04

Table 4-6. 100-H Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
La-141	1.2 E–06	8.3 E–07	Pb-211	6.8 E–05	5.6 E–05
La-142	3.9 E–05	2.9 E–05	Pb-212	5.9 E–03	3.9 E–03
Ce-141	1.4 E–03	9.4 E–04	Pb-214	5.6 E–06	4.8 E–06
Ce-143	2.2 E–04	1.4 E–04	Bi-210	8.1 E–03	5.4 E–03
Ce-144	*2.3 E–02*	*1.5 E–02*	Bi-211	2.8 E–10	2.4 E–10
Ce-144+D[c]	2.4 E–02	1.6 E–02	Bi-212	4.0 E–04	3.1 E–04
Pr-143	1.1 E–03	7.3 E–04	Bi-213	1.2 E–05	9.6 E–06
Pr-144	3.0 E–07	2.6 E–07	Bi-214	4.9 E–06	4.2 E–06
Pr-144m	1.6 E–08	1.4 E–08	Po-210	9.5 E–01	6.5 E–01
Nd-147	1.1 E–03	7.2 E–04	Po-211[b]	0.0	0.0
Pm-147	2.0 E–03	1.3 E–03	Po-212[b]	0.0	0.0
Pm-148	1.6 E–03	1.1 E–03	Po-213[b]	0.0	0.0
Pm-148m	1.4 E–02	9.7 E–03	Po-214[b]	0.0	0.0
Pm-149	2.0 E–04	1.3 E–04	Po-215[b]	0.0	0.0
Pm-151	5.2 E–05	3.6 E–05	Po-216[b]	0.0	0.0
Sm-147	3.1 E+00	2.0 E+00	Po-218	3.2 E–10	2.7 E–10
Sm-151	1.4 E–03	9.0 E–04	At-217[b]	0.0	0.0
Sm-153	1.4 E–04	9.4 E–05	Rn-219[d]	4.7 E–03	3.2 E–03
Eu-152	4.4 E–01	3.0 E–01	Rn-220[d]	8.3 E–06	5.5 E–06
Eu-152m	1.8 E–05	1.2 E–05	Rn-222	1.5 E–04	7.3 E–05
Eu-154	3.6 E–01	2.5 E–01	Fr-221	3.9 E–07	3.3 E–07
Eu-155	1.5 E–02	1.0 E–02	Fr-223	1.1 E–05	9.4 E–06
Eu-156	4.4 E–03	3.0 E–03	Ra-223	4.4 E–01	2.9 E–01
Gd-152[a]	(Pu–239)	(Pu–239)	Ra-224	1.6 E–01	1.0 E–01
Tb-160	1.2 E–02	8.0 E–03	Ra-225	2.7 E–01	1.8 E–01
Ho-166	1.6 E–04	1.1 E–04	Ra-226	8.4 E–01	5.7 E–01
Ho-166m	1.4 E+00	1.0 E+00	Ra-228	3.5 E–01	2.4 E–01
Hf-181	4.5 E–03	3.1 E–03	Ac-225	2.6 E–01	1.7 E–01
W-181	8.2 E–04	5.7 E–04	Ac-227	2.7 E+01	1.8 E+01
W-185	1.1 E–03	7.5 E–04	Ac-228	2.7 E–03	1.8 E–03
W-187	9.2 E–05	6.3 E–05	Th-227	4.8 E–01	3.1 E–01
Re-187	3.1 E–05	2.2 E–05	Th-228	1.0 E+01	6.7 E+00
Ir-192	9.9 E–03	6.8 E–03	Th-229	2.8 E+01	1.9 E+01
Hg-203	6.2 E–03	4.3 E–03	Th-230	1.0 E+01	6.7 E+00
Tl-207	8.2 E–10	7.0 E–10	Th-231	4.3 E–05	2.9 E–05
Tl-208	1.4 E–08	1.2 E–08	*Th-232*	*1.5 E+01*	*9.6 E+00*
Tl-209	4.6 E–10	3.9 E–10	Th-232+D[c]	1.7 E+01	1.1 E+01
Pb-209	2.6 E–06	1.8 E–06	Th-234	4.4 E–03	3.0 E–03
Pb-210	*2.6 E+00*	*1.8 E+00*	Pa-231	2.1 E+01	1.4 E+01
Pb-210+D[c]	2.6 E+00	1.8 E+00	Pa-233	1.9 E–03	1.3 E–03

Table 4-6. 100-H Area: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Pa-234	1.2 E–04	8.3 E–05	Pu-240	1.5 E+01	9.9 E+00
Pa-234m[b]	0.0	0.0	*Pu-241*	*2.4 E–01*	*1.6 E–01*
U-232	2.0 E+01	1.3 E+01	Pu-241+D[c]	2.4 E–01	1.6 E–01
U-233	5.7 E+00	3.8 E+00	Pu-242	1.4 E+01	9.5 E+00
U-234	5.7 E+00	3.7 E+00	Pu-243	7.7 E–06	5.2 E–06
U-235	5.4 E+00	3.6 E+00	Pu-244	1.4 E+01	9.4 E+00
U-236	5.4 E+00	3.5 E+00	Am-241	2.3 E+01	1.5 E+01
U-237	5.6 E–04	3.8 E–04	Am-242	2.2 E–03	1.5 E–03
U-238	5.0 E+00	3.3 E+00	Am-242m	2.2 E+01	1.5 E+01
U-240	9.2 E–05	6.2 E–05	Am-243	2.3 E+01	1.5 E+01
Np-237	2.1 E+01	1.4 E+01	Cm-242	7.5 E–01	5.0 E–01
Np-238	1.4 E–03	9.5 E–04	Cm-243	1.6 E+01	1.0 E+01
Np-239	2.2 E–04	1.5 E–04	Cm-244	1.2 E+01	8.0 E+00
Np-240	1.2 E–05	9.3 E–06	Cm-245	2.4 E+01	1.6 E+01
Np-240m	1.0 E–07	8.7 E–08	Cm-246	2.4 E+01	1.6 E+01
Pu-236	3.7 E+00	2.4 E+00	Cm-247	2.2 E+01	1.5 E+01
Pu-238	1.4 E+01	9.2 E+00	Cm-248	8.7 E+01	5.7 E+01
Pu-239	1.5 E+01	9.9 E+00	Cf-252	6.5 E+00	4.3 E+00

[a] Dose factors for this nuclide not included in the CAP88-PC library; thus, substituting the dose factors of the radionuclide in parentheses is recommended.

[b] Factor is ≤1.0 E–11, or effectively zero, considering also the scarcity and short half-life of the nuclide.

[c] "+D" indicates factors from in-grown progeny are also included.

[d] Short-lived Rn isotopes modeled on dose from their longer-lived progeny. Yet, 1 Ci of Rn does not equal 1Ci of Pb. Each Ci of Rn-219 released generates 0.0018 Ci of Pb-210, and each Ci of Rn-220, 0.0014 Ci of Pb-212. Dose based on Pb progeny multiplied by appropriate equilibrium factor (HNF-3602 1999).

Table 4-7. 100-K Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
H-3	4.9 E–05	2.5 E–05	Kr-85	1.1 E–07	5.6 E–08
Be-7	3.9 E–04	2.4 E–04	Kr-85m	4.2 E–06	2.2 E–06
Be-10[a]	(Sr–90)	(Sr–90)	Kr-87	1.5 E–05	7.3 E–06
C-11	3.6 E–06	2.1 E–06	Kr-88	5.3 E–05	2.7 E–05
C-14	3.8 E–03	2.0 E–03	Kr-89	3.6 E–08	1.9 E–08
C-15[b]	0.0	0.0	Kr-90[b]	0.0	0.0
N-13	8.3 E–07	4.9 E–07	Rb-86	5.7 E–03	3.6 E–03
O-15	7.3 E–10	4.4 E–10	Rb-87	1.9 E–02	1.2 E–02
F-18	2.3 E–05	1.4 E–05	Rb-88	2.4 E–06	1.4 E–06
Na-22	2.5 E–01	1.6 E–01	Rb-89	4.8 E–06	2.8 E–06
Na-24	4.3 E–04	2.7 E–04	Rb-90	1.2 E–08	7.1 E–09
P-32	5.7 E–03	3.6 E–03	Rb-90m	2.3 E–07	1.4 E–07
S-35	8.1 E–04	5.1 E–04	Sr-89	3.4 E–03	2.1 E–03
Ar-41	2.6 E–05	1.3 E–05	*Sr-90*	*2.2 E–01*	*1.4 E–01*
K-40	2.4 E–01	1.5 E–01	Sr-90+D[c]	2.2 E–01	1.4 E–01
Ca-41	2.0 E–05	1.3 E–05	Sr-91	9.0 E–05	5.5 E–05
Sc-46	2.4 E–02	1.5 E–02	Sr-92	5.7 E–05	3.4 E–05
Cr-51	1.7 E–04	1.1 E–04	Y-90	6.8 E–04	4.2 E–04
Mn-54	3.3 E–02	2.1 E–02	Y-90m	2.0 E–05	1.2 E–05
Mn-56	6.4 E–05	3.8 E–05	Y-91	5.0 E–03	3.1 E–03
Fe-55	4.5 E–04	2.9 E–04	Y-91m	6.4 E–06	3.8 E–06
Fe-59	9.3 E–03	5.9 E–03	Y-92	4.9 E–05	2.9 E–05
Co-57	5.6 E–03	3.5 E–03	Y-93	1.2 E–04	7.2 E–05
Co-58	1.1 E–02	6.8 E–03	Zr-93	2.6 E–03	1.6 E–03
Co-60	4.9 E–01	3.1 E–01	*Zr-95*	*7.7 E–03*	*4.8 E–03*
Ni-59	6.1 E–04	3.8 E–04	Zr-95+D[c]	1.4 E–02	8.7 E–03
Ni-63	5.2 E–04	3.2 E–04	Nb-93m	4.1 E–03	2.5 E–03
Ni-65	2.5 E–05	1.5 E–05	Nb-94	1.6 E+00	1.0 E+00
Cu-64	3.1 E–05	1.9 E–05	Nb-95	9.5 E–03	6.0 E–03
Zn-65	4.9 E–02	3.1 E–02	Nb-95m	5.9 E–04	3.7 E–04
Zn-69m	8.3 E–05	5.1 E–05	Nb-97	1.3 E–05	7.9 E–06
Zn-69	1.2 E–06	7.0 E–07	Nb-97m[b]	0.0	0.0
Ga-67	1.2 E–04	7.6 E–05	Mo-93	5.6 E–03	3.5 E–03
As-76	2.7 E–04	1.7 E–04	*Mo-99*	*3.5 E–04*	*2.1 E–04*
Se-79[a]	(Pu–241)	(Pu–241)	Mo-99+D[c]	3.9 E–04	2.4 E–04
Br-82	6.4 E–04	4.0 E–04	Tc-97	1.1 E–02	7.2 E–03
Br-83	1.9 E–07	1.2 E–07	Tc-99	4.5 E–02	2.8 E–02
Br-84	1.3 E–05	7.6 E–06	Tc-99m	7.9 E–06	4.9 E–06
Br-85	5.7 E–10	3.4 E–10	Tc-101	6.0 E–07	3.5 E–07
Kr-83m	4.7 E–09	2.4 E–09	Ru-97	1.3 E–04	8.2 E–05

Table 4-7. 100-K Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Ru-103	*3.6 E–03*	*2.3 E–03*	Te-133m	2.8 E–05	1.6 E–05
Ru-103+D	3.6 E–03	2.3 E–03	Te-134	8.0 E–06	4.7 E–06
Ru-105	5.4 E–05	3.3 E–05	I-122	1.3 E–09	5.2 E–09
Ru-106	*3.1 E–02*	*1.9 E–02*	I-123	8.1 E–06	3.6 E–05
Ru-106+D	4.0 E–02	2.5 E–02	I-125	1.5 E–02	6.4 E–02
Rh-103m	1.5 E–07	8.9 E–08	I-129	2.4 E–01	1.1 E+00
Rh-105	9.7 E–05	5.9 E–05	I-130	8.9 E–05	3.9 E–04
Rh-105m	1.1 E–17	6.8 E–18	I-131	8.0 E–03	3.5 E–02
Rh-106[b]	0.0	0.0	I-132	1.3 E–05	5.7 E–05
Pd-107[b]	0.0	0.0	I-133	9.2 E–05	4.0 E–04
Pd-109	7.2 E–05	4.3 E–05	I-134	3.6 E–06	1.6 E–05
Ag-109m[b]	0.0	0.0	I-135	2.9 E–05	1.3 E–04
Ag-110[b]	0.0	0.0	Xe-122	2.1 E–06	1.1 E–06
Ag-110m	9.5 E–02	6.0 E–02	Xe-123	1.3 E–05	6.8 E–06
Ag-111	2.0 E–03	1.3 E–03	Xe-125	7.6 E–06	3.9 E–06
Cd-113[a]	(Pu–241)	(Pu–241)	Xe-127	8.5 E–06	4.4 E–06
Cd-113m[a]	(Pu–241)	(Pu–241)	Xe-131m	3.1 E–07	1.6 E–07
Cd-115	3.8 E–04	2.4 E–04	Xe-133	1.1 E–06	5.8 E–07
Cd-115m	7.1 E–03	4.4 E–03	Xe-133m	9.7 E–07	5.0 E–07
In-113m	6.5 E–06	3.9 E–06	Xe-135	7.2 E–06	3.7 E–06
In-115	1.2 E–01	7.4 E–02	Xe-135m	1.1 E–06	5.2 E–07
In-115m	1.3 E–05	7.6 E–06	Xe-137	9.0 E–09	4.7 E–09
Sn-113	4.4 E–03	2.8 E–03	Xe-138	2.6 E–06	1.3 E–06
Sn-123	1.0 E–04	6.4 E–05	Cs-134	2.0 E–01	1.3 E–01
Sn-125	4.7 E–03	3.0 E–03	Cs-134m	2.1 E–06	1.3 E–06
Sn-126	9.3 E–02	5.9 E–02	Cs-135	8.7 E–03	5.5 E–03
Sb-124	1.7 E–02	1.1 E–02	Cs-136	7.3 E–03	4.6 E–03
Sb-125	5.2 E–02	3.3 E–02	*Cs-137*	*5.3 E–02*	*3.3 E–02*
Sb-126	6.5 E–03	4.1 E–03	Cs-137+D[c]	4.7 E–01	3.0 E–01
Sb-126m	5.1 E–06	2.9 E–06	Cs-138	1.8 E–05	1.0 E–05
Sb-127	9.3 E–04	5.8 E–04	Cs-139	2.3 E–07	1.3 E–07
Te-125m	2.0 E–03	1.3 E–03	Ba-133	1.5 E–01	9.3 E–02
Te-127	1.7 E–05	1.0 E–05	Ba-133m	6.3 E–05	3.9 E–05
Te-127m	5.0 E–03	3.1 E–03	Ba-137m	2.4 E–09	1.4 E–09
Te-129	3.6 E–06	2.1 E–06	Ba-139	5.1 E–06	3.0 E–06
Te-129m	4.9 E–03	3.1 E–03	*Ba-140*	*2.1 E–03*	*1.3 E–03*
Te-131	2.9 E–06	1.7 E–06	Ba-140+D[c]	5.4 E–03	3.4 E–03
Te-131m	4.7 E–04	2.9 E–04	Ba-141	2.6 E–06	1.5 E–06
Te-132	8.2 E–04	5.1 E–04	Ba-142	8.7 E–07	5.1 E–07
Te-133	1.3 E–06	7.4 E–07	La-140	8.0 E–04	5.0 E–04

Table 4-7. 100-K Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
La-141	1.5 E–06	9.0 E–07	Pb-211	1.1 E–04	6.5 E–05
La-142	5.6 E–05	3.4 E–05	Pb-212	6.8 E–03	4.1 E–03
Ce-141	1.5 E–03	9.3 E–04	Pb-214	9.1 E–06	5.2 E–06
Ce-143	2.4 E–04	1.5 E–04	Bi-210	8.9 E–03	5.4 E–03
Ce-144	*2.5 E–02*	*1.5 E–02*	Bi-211	2.0 E–09	1.2 E–09
Ce-144+D[c]	2.6 E–02	1.6 E–02	Bi-212	6.4 E–04	3.8 E–04
Pr-143	1.2 E–03	7.3 E–04	Bi-213	2.0 E–05	1.2 E–05
Pr-144	4.3 E–07	2.5 E–07	Bi-214	7.4 E–06	4.3 E–06
Pr-144m	2.2 E–08	1.3 E–08	Po-210	1.0 E+00	6.4 E–01
Nd-147	1.2 E–03	7.2 E–04	Po-211[b]	0.0	0.0
Pm-147	2.1 E–03	1.3 E–03	Po-212[b]	0.0	0.0
Pm-148	1.7 E–03	1.1 E–03	Po-213[b]	0.0	0.0
Pm-148m	1.5 E–02	9.7 E–03	Po-214[b]	0.0	0.0
Pm-149	2.2 E–04	1.3 E–04	Po-215[b]	0.0	0.0
Pm-151	5.8 E–05	3.6 E–05	Po-216[b]	0.0	0.0
Sm-147	3.3 E+00	2.0 E+00	Po-218	1.1 E–09	6.5 E–10
Sm-151	1.5 E–03	9.0 E–04	At-217[b]	0.0	0.0
Sm-153	1.5 E–04	9.4 E–05	Rn-219[d]	5.0 E–03	3.2 E–03
Eu-152	4.8 E–01	3.0 E–01	Rn-220[d]	9.5 E–06	5.7 E–06
Eu-152m	2.1 E–05	1.3 E–05	Rn-222	1.4 E–04	7.1 E–05
Eu-154	3.9 E–01	2.5 E–01	Fr-221	7.1 E–07	4.3 E–07
Eu-155	1.6 E–02	9.9 E–03	Fr-223	1.7 E–05	9.7 E–06
Eu-156	4.8 E–03	3.0 E–03	Ra-223	4.8 E–01	2.9 E–01
Gd-152[b]	(Pu–239)	(Pu–239)	Ra-224	1.7 E–01	1.0 E–01
Tb-160	1.3 E–02	8.0 E–03	Ra-225	3.0 E–01	1.8 E–01
Ho-166	1.8 E–04	1.1 E–04	Ra-226	9.1 E–01	5.6 E–01
Ho-166m	1.6 E+00	9.9 E–01	Ra-228	3.8 E–01	2.3 E–01
Hf-181	4.8 E–03	3.0 E–03	Ac-225	2.8 E–01	1.7 E–01
W-181	8.9 E–04	5.6 E–04	Ac-227	2.9 E+01	1.8 E+01
W-185	1.2 E–03	7.5 E–04	Ac-228	3.3 E–03	2.0 E–03
W-187	1.0 E–04	6.3 E–05	Th-227	5.2 E–01	3.1 E–01
Re-187	3.4 E–05	2.1 E–05	Th-228	1.1 E+01	6.7 E+00
Ir-192	1.1 E–02	6.8 E–03	Th-229	3.1 E+01	1.9 E+01
Hg-203	6.7 E–03	4.2 E–03	Th-230	1.1 E+01	6.7 E+00
Tl-207	1.5 E–09	9.1 E–10	Th-231	4.8 E–05	2.9 E–05
Tl-208	4.6 E–08	2.8 E–08	*Th-232*	*1.6 E+01*	*9.5 E+00*
Tl-209	2.9 E–09	1.8 E–09	Th-232+D[c]	1.8 E+01	1.1 E+01
Pb-209	3.3 E–06	2.0 E–06	Th-234	4.7 E–03	2.9 E–03
Pb-210	*2.8 E+00*	*1.8 E+00*	Pa-231	2.3 E+01	1.4 E+01
Pb-210+D[c]	2.8 E+00	1.8 E+00	Pa-233	2.1 E–03	1.3 E–03

Table 4-7. 100-K Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Pa-234	1.4 E–04	8.8 E–05	Pu-240	1.6 E+01	9.9 E+00
Pa-234m[b]	0.0	0.0	*Pu-241*	*2.6 E–01*	*1.6 E–01*
U-232	2.2 E+01	1.3 E+01	Pu-241+D[c]	2.6 E–01	1.6 E–01
U-233	6.2 E+00	3.8 E+00	Pu-242	1.6 E+01	9.4 E+00
U-234	6.2 E+00	3.7 E+00	Pu-243	9.4 E–06	5.6 E–06
U-235	5.9 E+00	3.5 E+00	Pu-244	1.6 E+01	9.3 E+00
U-236	5.8 E+00	3.5 E+00	Am-241	2.5 E+01	1.5 E+01
U-237	6.1 E–04	3.8 E–04	Am-242	2.5 E–03	1.5 E–03
U-238	5.5 E+00	3.3 E+00	Am-242m	2.4 E+01	1.5 E+01
U-240	1.1 E–04	6.3 E–05	Am-243	2.5 E+01	1.5 E+01
Np-237	2.3 E+01	1.4 E+01	Cm-242	8.2 E–01	4.9 E–01
Np-238	1.6 E–03	9.6 E–04	Cm-243	1.7 E+01	1.0 E+01
Np-239	2.4 E–04	1.5 E–04	Cm-244	1.3 E+01	8.0 E+00
Np-240	1.9 E–05	1.1 E–05	Cm-245	2.6 E+01	1.6 E+01
Np-240m	1.4 E–07	8.1 E–08	Cm-246	2.6 E+01	1.6 E+01
Pu-236	4.0 E+00	2.4 E+00	Cm-247	2.4 E+01	1.4 E+01
Pu-238	1.5 E+01	9.2 E+00	Cm-248	9.5 E+01	5.7 E+01
Pu-239	1.6 E+01	9.9 E+00	Cf-252	7.1 E+00	4.3 E+00

[a] Dose factors for this nuclide not included in the CAP88-PC library; thus, substituting the dose factors of the radionuclide in parentheses is recommended.

[b] Factor is ≤1.0 E–11, or effectively zero, considering also the scarcity and short half-life of the nuclide.

[c] "+D" indicates factors from in-grown progeny are also included.

[d] Short-lived Rn isotopes modeled on dose from their longer-lived progeny. Yet, 1 Ci of Rn does not equal 1Ci of Pb. Each Ci of Rn-219 released generates 0.0018 Ci of Pb-210, and each Ci of Rn-220, 0.0014 Ci of Pb-212. Dose based on Pb progeny multiplied by appropriate equilibrium factor (HNF-3602 1999).

Table 4-8. 100-N Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
H-3	4.0 E–05	2.3 E–05	Kr-85	8.9 E–08	5.2 E–08
Be-7	3.0 E–04	2.2 E–04	Kr-85m	3.2 E–06	1.9 E–06
Be-10[b]	(Sr–90)	(Sr–90)	Kr-87	9.4 E–06	5.6 E–06
C-11	1.7 E–06	1.3 E–06	Kr-88	3.9 E–05	2.3 E–05
C-14	3.1 E–03	1.8 E–03	Kr-89	3.3 E–08	2.1 E–08
C-15[b]	0.0	0.0	Kr-90[b]	0.0	0.0
N-13	4.9 E–07	3.6 E–07	Rb-86	4.4 E–03	3.3 E–03
O-15	7.4 E–10	5.4 E–10	Rb-87	1.5 E–02	1.1 E–02
F-18	1.6 E–05	1.1 E–05	Rb-88	1.1 E–06	8.4 E–07
Na-22	2.0 E–01	1.5 E–01	Rb-89	2.4 E–06	1.7 E–06
Na-24	3.3 E–04	2.4 E–04	Rb-90	1.1 E–08	8.0 E–09
P-32	4.5 E–03	3.3 E–03	Rb-90m	1.8 E–07	1.4 E–07
S-35	6.3 E–04	4.7 E–04	Sr-89	2.7 E–03	2.0 E–03
Ar-41	1.8 E–05	1.1 E–05	*Sr-90*	*1.7 E–01*	*1.3 E–01*
K-40	1.9 E–01	1.4 E–01	Sr-90+D[c]	1.8 E–01	1.3 E–01
Ca-41	1.6 E–05	1.2 E–05	Sr-91	6.8 E–05	4.9 E–05
Sc-46	1.9 E–02	1.4 E–02	Sr-92	4.0 E–05	2.9 E–05
Cr-51	1.4 E–04	1.0 E–04	Y-90	5.3 E–04	3.8 E–04
Mn-54	2.5 E–02	1.9 E–02	Y-90m	1.4 E–05	1.0 E–05
Mn-56	4.4 E–05	3.2 E–05	Y-91	3.9 E–03	2.8 E–03
Fe-55	3.6 E–04	2.6 E–04	Y-91m	3.6 E–06	2.6 E–06
Fe-59	7.3 E–03	5.4 E–03	Y-92	3.5 E–05	2.5 E–05
Co-57	4.4 E–03	3.2 E–03	Y-93	9.0 E–05	6.4 E–05
Co-58	8.4 E–03	6.2 E–03	Zr-93	2.0 E–03	1.4 E–03
Co-60	3.8 E–01	2.8 E–01	*Zr-95*	*6.0 E–03*	*4.4 E–03*
Ni-59	4.8 E–04	3.5 E–04	Zr-95+D[c]	1.1 E–02	8.0 E–03
Ni-63	4.0 E–04	3.0 E–04	Nb-93m	3.2 E–03	2.3 E–03
Ni-65	1.7 E–05	1.3 E–05	Nb-94	1.3 E+00	9.2 E–01
Cu-64	2.3 E–05	1.7 E–05	Nb-95	7.4 E–03	5.5 E–03
Zn-65	3.8 E–02	2.8 E–02	Nb-95m	4.6 E–04	3.4 E–04
Zn-69m	6.3 E–05	4.5 E–05	Nb-97	8.1 E–06	5.9 E–06
Zn-69	6.8 E–07	4.9 E–07	Nb-97m[b]	0.0	0.0
Ga-67	9.5 E–05	6.9 E–05	Mo-93	4.3 E–03	3.2 E–03
As-76	2.1 E–04	1.5 E–04	*Mo-99*	*2.7 E–04*	*1.9 E–04*
S E–79[a]	(Pu–241)	(Pu–241)	Mo-99+D[c]	3.1 E–04	2.2 E–04
Br-82	5.0 E–04	3.6 E–04	Tc-97	8.9 E–03	6.6 E–03
Br-83	1.3 E–07	9.5 E–08	Tc-99	3.5 E–02	2.6 E–02
Br-84	6.4 E–06	4.7 E–06	Tc-99m	5.9 E–06	4.3 E–06
Br-85	5.1 E–10	3.8 E–10	Tc-101	3.0 E–07	2.2 E–07
Kr-83m	3.3 E–09	1.9 E–09	Ru-97	1.0 E–04	7.5 E–05

Table 4-8. 100-N Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Ru-103	*2.9 E–03*	*2.1 E–03*	Te-133m	1.6 E–05	1.1 E–05
Ru-103+D	2.9 E–03	2.1 E–03	Te-134	4.2 E–06	3.1 E–06
Ru-105	3.9 E–05	2.8 E–05	I-122	1.0 E–09	3.9 E–09
Ru-106	*2.4 E–02*	*1.7 E–02*	I-123	5.7 E–06	2.3 E–05
Ru-106+D	3.1 E–02	2.3 E–02	I-125	1.0 E–02	4.2 E–02
Rh-103m	8.7 E–08	6.3 E–08	I-129	1.7 E–01	7.0 E–01
Rh-105	7.5 E–05	5.4 E–05	I-130	6.2 E–05	2.5 E–04
Rh-105m[b]	0.0	0.0	I-131	5.6 E–03	2.3 E–02
Rh-106[b]	0.0	0.0	I-132	8.4 E–06	3.3 E–05
Pd-107	5.8 E–04	4.1 E–04	I-133	6.4 E–05	2.6 E–04
Pd-109	5.4 E–05	3.9 E–05	I-134	2.1 E–06	8.1 E–06
Ag-109m[b]	0.0	0.0	I-135	2.0 E–05	8.1 E–05
Ag-110[b]	0.0	0.0	Xe-122	1.7 E–06	9.9 E–07
Ag-110m	7.4 E–02	5.5 E–02	Xe-123	9.5 E–06	5.6 E–06
Ag-111	1.6 E–03	1.2 E–03	Xe-125	6.1 E–06	3.6 E–06
Cd-113[a]	(Pu–241)	(Pu–241)	Xe-127	6.9 E–06	4.1 E–06
Cd-113m[a]	(Pu–241)	(Pu–241)	Xe-131m	2.5 E–07	1.5 E–07
Cd-115	3.0 E–04	2.1 E–04	Xe-133	9.3 E–07	5.4 E–07
Cd-115m	5.5 E–03	4.0 E–03	Xe-133m	7.9 E–07	4.6 E–07
In-113m	4.2 E–06	3.0 E–06	Xe-135	5.7 E–06	3.4 E–06
In-115	9.3 E–02	6.8 E–02	Xe-135m	5.3 E–07	3.3 E–07
In-115m	9.1 E–06	6.5 E–06	Xe-137	7.9 E–09	4.9 E–09
Sn-113	3.4 E–03	2.5 E–03	Xe-138	1.4 E–06	8.5 E–07
Sn-123	8.0 E–05	5.9 E–05	Cs-134	1.6 E–01	1.1 E–01
Sn-125	3.7 E–03	2.7 E–03	Cs-134m	1.5 E–06	1.1 E–06
Sn-126	7.3 E–02	5.4 E–02	Cs-135	6.8 E–03	5.0 E–03
Sb-124	1.3 E–02	9.8 E–03	Cs-136	5.7 E–03	4.2 E–03
Sb-125	4.1 E–02	3.0 E–02	*Cs-137*	*4.1 E–02*	*3.0 E–02*
Sb-126	5.1 E–03	3.7 E–03	Cs-137+D[c]	3.7 E–01	2.7 E–01
Sb-126m	2.4 E–06	1.8 E–06	Cs-138	8.8 E–06	6.4 E–06
Sb-127	7.2 E–04	5.3 E–04	Cs-139	1.4 E–07	1.0 E–07
Te-125m	1.6 E–03	1.2 E–03	Ba-133	1.2 E–01	8.5 E–02
Te-127	1.3 E–05	9.2 E–06	Ba-133m	4.9 E–05	3.5 E–05
Te-127m	3.9 E–03	2.9 E–03	Ba-137m	2.2 E–09	1.6 E–09
Te-129	2.2 E–06	1.6 E–06	Ba-139	3.2 E–06	2.3 E–06
Te-129m	3.9 E–03	2.8 E–03	*Ba-140*	*1.6 E–03*	*1.2 E–03*
Te-131	1.4 E–06	1.0 E–06	Ba-140+D[c]	4.2 E–03	3.1 E–03
Te-131m	3.7 E–04	2.6 E–04	Ba-141	1.2 E–06	8.9 E–07
Te-132	6.4 E–04	4.6 E–04	Ba-142	4.9 E–07	3.6 E–07
Te-133	6.6 E–07	4.9 E–07	La-140	6.2 E–04	4.5 E–04

Table 4-8. 100-N Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
La-141	1.1 E–06	7.7 E–07	Pb-211	5.7 E–05	4.1 E–05
La-142	3.6 E–05	2.6 E–05	Pb-212	5.1 E–03	3.6 E–03
Ce-141	1.2 E–03	8.5 E–04	Pb-214	4.3 E–06	3.1 E–06
Ce-143	1.8 E–04	1.3 E–04	Bi-210	6.9 E–03	4.9 E–03
Ce-144	*1.9 E–02*	*1.4 E–02*	Bi-211	2.0 E–09	1.4 E–09
Ce-144+D[c]	2.0 E–02	1.4 E–02	Bi-212	3.7 E–04	2.7 E–04
Pr-143	9.1 E–04	6.7 E–04	Bi-213	1.1 E–05	7.8 E–06
Pr-144	2.0 E–07	1.5 E–07	Bi-214	3.4 E–06	2.5 E–06
Pr-144m	1.5 E–08	1.1 E–08	Po-210	8.1 E–01	5.9 E–01
Nd-147	9.0 E–04	6.5 E–04	Po-211[b]	0.0	0.0
Pm-147	1.7 E–03	1.2 E–03	Po-212[b]	0.0	0.0
Pm-148	1.3 E–03	9.7 E–04	Po-213[b]	0.0	0.0
Pm-148m	1.2 E–02	8.8 E–03	Po-214[b]	0.0	0.0
Pm-149	1.7 E–04	1.2 E–04	Po-215[b]	0.0	0.0
Pm-151	4.5 E–05	3.3 E–05	Po-216[b]	0.0	0.0
Sm-147	2.6 E+00	1.8 E+00	Po-218	9.4 E–10	7.0 E–10
Sm-151	1.2 E–03	8.2 E–04	At-217[b]	0.0	0.0
Sm-153	1.2 E–04	8.5 E–05	Rn-219[d]	4.0 E–03	2.9 E–03
Eu-152	3.7 E–01	2.8 E–01	Rn-220[d]	7.1 E–06	5.0 E–06
Eu-152m	1.6 E–05	1.1 E–05	Rn-222	1.1 E–04	6.6 E–05
Eu-154	3.0 E–01	2.2 E–01	Fr-221	5.6 E–07	4.1 E–07
Eu-155	1.2 E–02	9.0 E–03	Fr-223	7.8 E–06	5.7 E–06
Eu-156	3.7 E–03	2.8 E–03	Ra-223	3.7 E–01	2.6 E–01
Gd-152[a]	(Pu–239)	(Pu–239)	Ra-224	1.3 E–01	9.4 E–02
Tb-160	9.9 E–03	7.3 E–03	Ra-225	2.3 E–01	1.7 E–01
Ho-166	1.4 E–04	9.8 E–05	Ra-226	7.1 E–01	5.1 E–01
Ho-166m	1.2 E+00	9.1 E–01	Ra-228	2.9 E–01	2.1 E–01
Hf-181	3.8 E–03	2.8 E–03	Ac-225	2.2 E–01	1.5 E–01
W-181	7.0 E–04	5.2 E–04	Ac-227	2.3 E+01	1.6 E+01
W-185	9.3 E–04	6.8 E–04	Ac-228	2.4 E–03	1.7 E–03
W-187	7.9 E–05	5.7 E–05	Th-227	4.0 E–01	2.8 E–01
Re-187	2.7 E–05	2.0 E–05	Th-228	8.6 E+00	6.1 E+00
Ir-192	8.4 E–03	6.2 E–03	Th-229	2.4 E+01	1.7 E+01
Hg-203	5.2 E–03	3.9 E–03	Th-230	8.6 E+00	6.1 E+00
Tl-207	1.2 E–09	8.8 E–10	Th-231	3.7 E–05	2.6 E–05
Tl-208	4.1 E–08	3.0 E–08	*Th-232*	*1.2 E+01*	*8.7 E+00*
Tl-209	2.9 E–09	2.1 E–09	Th-232+D[c]	1.4 E+01	1.0 E+01
Pb-209	2.4 E–06	1.7 E–06	Th-234	3.7 E–03	2.7 E–03
Pb-210	*2.2 E+00*	*1.6 E+00*	Pa-231	1.8 E+01	1.3 E+01
Pb-210+D[c]	2.2 E+00	1.6 E+00	Pa-233	1.6 E–03	1.2 E–03

Table 4-8. 100-N Area: Offsite MPR CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height		Nuclide	Effective release height	
	<40 m	≥40 m		<40 m	≥40 m
Pa-234	1.1 E–04	7.7 E–05	Pu-240	1.3 E+01	9.0 E+00
Pa-234m[b]	0.0	0.0	*Pu-241*	*2.0 E–01*	*1.4 E–01*
U-232	1.7 E+01	1.2 E+01	Pu-241+D[c]	2.0 E–01	1.4 E–01
U-233	4.8 E+00	3.4 E+00	Pu-242	1.2 E+01	8.6 E+00
U-234	4.8 E+00	3.4 E+00	Pu-243	6.8 E–06	4.9 E–06
U-235	4.6 E+00	3.2 E+00	Pu-244	1.2 E+01	8.5 E+00
U-236	4.5 E+00	3.2 E+00	Am-241	2.0 E+01	1.4 E+01
U-237	4.8 E–04	3.5 E–04	Am-242	1.9 E–03	1.3 E–03
U-238	4.2 E+00	3.0 E+00	Am-242m	1.9 E+01	1.3 E+01
U-240	7.9 E–05	5.6 E–05	Am-243	2.0 E+01	1.4 E+01
Np-237	1.8 E+01	1.3 E+01	Cm-242	6.3 E–01	4.5 E–01
Np-238	1.2 E–03	8.7 E–04	Cm-243	1.3 E+01	9.3 E+00
Np-239	1.9 E–04	1.3 E–04	Cm-244	1.0 E+01	7.3 E+00
Np-240	1.1 E–05	8.2 E–06	Cm-245	2.0 E+01	1.4 E+01
Np-240m	9.2 E–08	6.8 E–08	Cm-246	2.0 E+01	1.4 E+01
Pu-236	3.1 E+00	2.2 E+00	Cm-247	1.9 E+01	1.3 E+01
Pu-238	1.2 E+01	8.4 E+00	Cm-248	7.3 E+01	5.2 E+01
Pu-239	1.3 E+01	9.0 E+00	Cf-252	5.5 E+00	3.9 E+00

[a] Dose factors for this nuclide not included in the CAP88-PC library; thus, substituting the dose factors of the radionuclide in parentheses is recommended.

[b] Factor is ≤1.0 E–11, or effectively zero, considering also the scarcity and short half-life of the nuclide.

[c] "+D" indicates factors from in-grown progeny are also included.

[d] Short-lived Rn isotopes modeled on dose from their longer-lived progeny. Yet, 1 Ci of Rn does not equal 1Ci of Pb. Each Ci of Rn-219 released generates 0.0018 Ci of Pb-210, and each Ci of Rn-220, 0.0014 Ci of Pb-212. Dose based on Pb progeny multiplied by appropriate equilibrium factor (HNF-3602 1999).

Table 4-9. 200-E Area: Offsite and Onsite MPRs CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
H-3	2.5 E–05	7.1 E–06	1.4 E–05	4.2 E–06
Be-7	2.0 E–04	2.3 E–04	1.3 E–04	1.5 E–04
Be-10[b]	(Sr–90)	(Sr–90)	(Sr–90)	(Sr–90)
C-11	1.0 E–06	2.0 E–06	7.7 E–07	1.4 E–06
C-14	1.9 E–03	1.8 E–04	1.1 E–03	1.1 E–04
C-15[c]	0.0	0.0	0.0	0.0
N-13	9.9 E–08	2.7 E–07	7.9 E–08	2.1 E–07
O-15[c]	0.0	0.0	0.0	0.0
F-18	1.0 E–05	1.5 E–05	7.0 E–06	9.7 E–06
Na-22	1.3 E–01	1.5 E–01	8.7 E–02	9.8 E–02
Na-24	2.1 E–04	2.7 E–04	1.4 E–04	1.8 E–04
P-32	2.9 E–03	2.7 E–04	2.0 E–03	2.0 E–04
S-35	4.1 E–04	2.8 E–05	2.8 E–04	2.4 E–05
Ar-41	1.2 E–05	1.6 E–05	6.7 E–06	9.1 E–06
K-40	1.2 E–01	8.9 E–02	8.4 E–02	6.0 E–02
Ca-41	1.0 E–05	1.3 E–05	6.9 E–06	8.7 E–06
Sc-46	1.2 E–02	1.4 E–02	8.2 E–03	9.0 E–03
Cr-51	8.7 E–05	8.4 E–05	5.9 E–05	5.6 E–05
Mn-54	1.6 E–02	2.0 E–02	1.1 E–02	1.4 E–02
Mn-56	2.9 E–05	4.0 E–05	1.9 E–05	2.6 E–05
Fe-55	2.3 E–04	6.0 E–05	1.6 E–04	4.0 E–05
Fe-59	4.7 E–03	4.2 E–03	3.2 E–03	2.8 E–03
Co-57	2.8 E–03	3.2 E–03	1.9 E–03	2.1 E–03
Co-58	5.5 E–03	5.8 E–03	3.7 E–03	3.9 E–03
Co-60	2.5 E–01	3.0 E–01	1.7 E–01	2.0 E–01
Ni-59	3.1 E–04	2.9 E–04	2.1 E–04	1.9 E–04
Ni-63	2.6 E–04	6.9 E–05	1.8 E–04	4.5 E–05
Ni-65	1.2 E–05	1.6 E–05	7.7 E–06	1.0 E–05
Cu-64	1.5 E–05	2.0 E–05	1.0 E–05	1.3 E–05
Zn-65	2.5 E–02	1.2 E–02	1.7 E–02	8.0 E–03
Zn-69m	4.1 E–05	7.5 E–07	2.7 E–05	5.0 E–07
Zn-69	4.9 E–07	5.1 E–05	3.4 E–07	3.3 E–05
Ga-67	6.1 E–05	6.0 E–05	4.1 E–05	3.9 E–05
As-76	1.4 E–04	1.6 E–04	8.9 E–05	1.1 E–04
Se-79[b]	(Pu–241)	(Pu–241)	(Pu–241)	(Pu–241)
Br-82	3.2 E–04	3.7 E–04	2.2 E–04	2.4 E–04
Br-83	8.7 E–08	1.2 E–07	5.8 E–08	7.9 E–08
Br-84	4.6 E–06	7.9 E–06	3.3 E–06	5.5 E–06
Br-85[c]	0.0	0.0	0.0	0.0
Kr-83m	2.1 E–09	2.8 E–09	1.2 E–09	1.6 E–09
Kr-85	5.5 E–08	6.8 E–08	3.1 E–08	3.8 E–08
Kr-85m	2.0 E–06	2.6 E–06	1.1 E–06	1.5 E–06
Kr-87	6.1 E–06	8.8 E–06	3.7 E–06	5.1 E–06

Table 4-9. 200-E Area: Offsite and Onsite MPRs CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Kr-88	2.4 E–05	3.2 E–05	1.4 E–05	1.8 E–05
Kr-89[c]	0.0	4.5 E–10	0.0	3.3 E–10
Kr-90[c]	0.0	0.0	0.0	4.2 E–37
Rb-86	2.9 E–03	4.6 E–04	1.9 E–03	3.2 E–04
Rb-87	9.4 E–03	6.2 E–04	6.4 E–03	5.1 E–04
Rb-88	6.1 E–07	1.2 E–06	4.6 E–07	9.1 E–07
Rb-89	1.1 E–06	2.3 E–06	8.2 E–07	1.7 E–06
Rb-90[c]	0.0	0.0	0.0	0.0
Rb-90m	1.7 E–09	1.1 E–08	1.3 E–09	8.7 E–09
Sr-89	1.7 E–03	2.1 E–04	1.2 E–03	1.4 E–04
Sr-90	*1.1 E–01*	*9.5 E–03*	*7.6 E–02*	*7.0 E–03*
Sr-90+D[d]	1.1 E–01	9.5 E–03	7.6 E–02	7.0 E–03
Sr-91	4.4 E–05	5.7 E–05	2.9 E–05	3.7 E–05
Sr-92	2.6 E–05	3.6 E–05	1.8 E–05	2.4 E–05
Y-90	3.4 E–04	2.6 E–04	2.3 E–04	1.6 E–04
Y-90m	9.3 E–06	1.3 E–05	6.2 E–06	8.3 E–06
Y-91	2.5 E–03	1.4 E–03	1.7 E–03	9.0 E–04
Y-91m	2.6 E–06	4.0 E–06	1.8 E–06	2.7 E–06
Y-92	2.3 E–05	3.1 E–05	1.5 E–05	2.0 E–05
Y-93	5.8 E–05	7.5 E–05	3.8 E–05	4.8 E–05
Zr-93	1.3 E–03	1.3–03	8.4 E–04	8.6 E–04
Zr-95	*3.9 E–03*	*4.2 E–03*	*2.6 E–03*	*2.8 E–03*
Zr-95+D[d]	7.0 E–03	8.1 E–03	4.7 E–03	5.4 E–03
Nb-93m	2.1 E–03	1.2 E–03	1.4 E–03	7.8 E–04
Nb-94	8.1 E–01	1.0 E+00	5.5 E–01	6.7 E–01
Nb-95	4.8 E–03	2.4 E–03	3.2 E–03	1.7 E–03
Nb-95m	3.0 E–04	9.7 E–05	2.0 E–04	6.5 E–05
Nb-97	5.7 E–06	8.4 E–06	3.9 E–06	5.6 E–06
Nb-97m[c]	0.0	0.0	0.0	0.0
Mo-93	2.8 E–03	3.6 E–03	1.9 E–03	2.4 E–03
Mo-99	*1.7 E–04*	*1.6 E–04*	*1.2 E–04*	*1.0 E–04*
Mo-99+D[d]	2.0 E–04	1.9 E–04	1.3 E–04	1.2 E–04
Tc-97	5.7 E–03	4.2 E–03	3.9 E–03	2.8 E–03
Tc-99	2.3 E–02	1.4 E–03	1.5 E–02	1.3 E–03
Tc-99m	3.8 E–06	3.2 E–05	2.5 E–06	2.1 E–05
Tc-101	1.2 E–07	2.7 E–07	9.3 E–08	2.0 E–07
Ru-97	6.6 E–05	7.2 E–05	4.5 E–05	4.8 E–05
Ru-103	*1.8 E–03*	1.8 E–03	*1.2 E–03*	*1.2 E–03*
Ru-103+D[d]	1.8 E–03	1.8 E–03	1.2 E–03	1.2 E–03
Ru-105	2.5 E–05	3.4 E–05	1.7 E–05	2.2 E–05
Ru-106	1.6 E–02	1.3 E–02	1.0 E–02	8.5 E–03
Ru-106+D[d]	2.0 E–02	1.9 E–02	1.3 E–02	1.2 E–02
Rh-103m	6.3 E–08	9.5 E–08	4.3 E–08	6.4 E–08
Rh-105	4.8 E–05	4.1 E–05	3.2 E–05	2.7 E–05

Table 4-9. 200-E Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Rh-105m[c]	0.0	0.0	0.0	0.0
Rh-106[c]	0.0	2.9 E–36	0.0	0.0
Pd-107	3.7 E–04	3.6 E–04	2.5 E–04	2.3 E–04
Pd-109	3.5 E–05	4.2 E–05	2.3 E–05	2.7 E–05
Ag-109m[c]	0.0	0.0	0.0	0.0
Ag-110[c]	0.0	0.0	0.0	0.0
Ag-110m	4.8 E–02	5.4 E–02	3.3 E–02	3.6 E–02
Ag-111	1.0 E–03	2.4 E–04	6.8 E–04	1.6 E–04
Cd-113[b]	(Pu–241)	(Pu–241)	(Pu–241)	(Pu–241)
Cd-113m[b]	(Pu–241)	(Pu–241)	(Pu–241)	(Pu–241)
Cd-115	1.9 E–04	1.7 E–04	1.3 E–04	1.1 E–04
Cd-115m	3.6 E–03	1.3 E–03	2.4 E–03	8.6 E–04
In-113m	2.9 E–06	4.1 E–06	1.9 E–06	2.7 E–06
In-115	6.0 E–02	3.0 E–02	4.0 E–02	1.9 E–02
In-115m	5.9 E–06	7.9 E–06	3.9 E–06	5.2 E–06
Sn-113	2.2 E–03	5.3 E–04	1.5 E–03	3.7 E–04
Sn-123	5.1 E–05	6.6 E–05	3.5 E–05	4.4 E–05
Sn-125	2.4 E–03	7.0 E–04	1.6 E–03	4.6 E–04
Sn-126	4.7 E–02	4.1 E–02	3.2 E–02	2.8 E–02
Sb-124	8.6 E–03	9.1 E–03	5.8 E–03	6.0 E–03
Sb-125	2.6 E–02	3.3 E–02	1.8 E–02	2.2 E–02
Sb-126	3.3 E–03	3.1 E–03	2.2 E–03	2.1 E–03
Sb-126m	1.4 E–06	2.7 E–06	1.0 E–06	2.0 E–06
Sb-127	4.7 E–04	3.9 E–04	3.1 E–04	2.6 E–04
Te-125m	1.0 E–03	3.2 E–04	6.9 E–04	2.1 E–04
Te-127	8.4 E–06	1.1 E–05	5.5 E–06	7.0 E–06
Te-127m	2.5 E–03	7.1 E–04	1.7 E–03	4.7 E–04
Te-129	1.5 E–06	2.3 E–06	1.0 E–06	1.5 E–06
Te-129m	2.5 E–03	8.0 E–04	1.7 E–03	5.3 E–04
Te-131	9.3 E–07	1.7 E–06	6.8 E–07	1.2 E–06
Te-131m	2.4 E–04	2.9 E–04	1.6 E–04	1.9 E–04
Te-132	4.1 E–04	2.9 E–04	2.7 E–04	1.9 E–04
Te-133	2.2 E–07	5.2 E–07	1.7 E–07	4.0 E–07
Te-133m	1.1 E–05	1.7 E–05	7.9 E–06	1.2 E–05
Te-134	3.1 E–06	5.0 E–06	2.2 E–06	3.4 E–06
I-122[c]	0.0	1.1 E–10	0.0	2.0 E–10
I-123	6.5 E–06	1.0 E–05	1.6 E–05	2.5 E–05
I-125	1.2 E–02	4.1 E–04	2.9 E–02	8.1 E–04
I-129	2.0 E–01	2.2 E–02	4.8 E–01	5.0 E–02
I-130	7.1 E–05	1.2 E–04	1.7 E–04	2.7 E–04
I-131	6.4 E–03	5.0 E–04	1.6 E–02	1.1 E–03
I-132	1.0 E–05	1.8 E–05	2.4 E–05	4.2 E–05
I-133	7.3 E–05	6.6 E–05	1.8 E–04	1.6 E–04

Table 4-9. 200-E Area: Offsite and Onsite MPRs CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
I-134	3.0 E–06	5.8 E–06	6.6 E–06	1.3 E–05
I-135	2.3 E–05	4.0 E–05	5.6 E–05	9.5 E–05
Xe-122	1.0 E–06	1.3 E–06	5.8 E–07	7.3 E–07
Xe-123	6.0 E–06	8.1 E–06	3.5 E–06	4.7 E–06
Xe-125	3.7 E–06	4.7 E–06	2.1 E–06	2.7 E–06
Xe-127	4.2 E–06	5.3 E–06	2.4 E–06	3.0 E–06
Xe-131m	1.5 E–07	1.9 E–07	8.7 E–08	1.1 E–07
Xe-133	5.6 E–07	7.0 E–07	3.2 E–07	3.9 E–07
Xe-133m	4.8 E–07	6.1 E–07	2.7 E–07	3.4 E–07
Xe-135	3.5 E–06	4.5 E–06	2.0 E–06	2.5 E–06
Xe-135m	2.2 E–07	4.7 E–07	1.5 E–07	3.2 E–07
Xe-137[c]	0.0	2.6 E–10	0.0	1.9 E–10
Xe-138	5.0 E–07	1.1 E–06	3.5 E–07	7.6 E–07
Cs-134	1.0 E–01	4.7 E–02	6.8 E–02	6.1 E–02
Cs-134m	9.8 E–07	1.3 E–06	6.5 E–07	8.8 E–07
Cs-135	4.4 E–03	3.2 E–04	3.0 E–03	2.6 E–04
Cs-136	3.7 E–03	1.4 E–03	2.5 E–03	1.7 E–03
Cs-137	*2.7 E–02*	2.0 E–03	*1.8 E–02*	1.6 E–03
Cs-137+D[d]	2.4 E–01	2.7 E–01	1.6 E–01	1.8 E–01
Cs-138	6.4 E–06	1.0 E–05	4.6 E–06	7.5 E–06
Cs-139	2.4 E–08	6.8 E–08	1.9 E–08	5.4 E–08
Ba-133	7.5 E–02	4.8 E–02	5.1 E–02	6.3 E–02
Ba-133m	3.1 E–05	2.3 E–05	2.1 E–05	1.7 E–05
Ba-137m[c]	0.0	0.0	0.0	0.0
Ba-139	2.2 E–06	3.1 E–06	1.5 E–06	2.1 E–06
Ba-140	*1.1 E–03*	3.3 E–04	*7.2 E–04*	*2.2 E–04*
Ba-140+D[d]	2.7 E–03	2.5 E–03	1.9 E–03	1.6 E–03
Ba-141	6.6 E–07	1.3 E–06	5.0 E–07	9.8 E–07
Ba-142	1.2 E–07	3.1 E–07	9.4 E–08	2.4 E–07
La-140	4.0 E–04	3.2 E–04	2.7 E–04	3.0 E–04
La-141	6.9 E–07	7.5 E–07	4.6 E–07	6.1 E–07
La-142	2.5 E–05	3.2 E–05	1.7 E–05	2.3 E–05
Ce-141	7.5 E–04	3.7 E–04	5.1 E–04	3.1 E–04
Ce-143	1.2 E–04	1.2 E–04	7.8 E–05	8.6 E–05
Ce-144	*1.2 E–02*	*1.1 E–02*	*8.1 E–03*	*7.0 E–03*
Ce-144+D[d]	1.3 E–02	1.2 E–02	8.5 E–03	7.4 E–03
Pr-143	5.9 E–04	2.4 E–04	4.0 E–04	1.5 E–04
Pr-144	1.1 E–07	2.2 E–07	7.9 E–08	1.6 E–07
Pr-144m	1.2 E–09	4.3 E–09	9.9 E–10	3.4 E–09
Nd-147	5.8 E–04	3.3 E–04	3.9 E–04	2.1 E–04
Pm-147	1.1 E–03	1.1 E–03	7.0 E–04	6.9 E–04
Pm-148	8.6 E–04	5.6 E–04	5.7 E–04	3.6 E–04
Pm-148m	7.8 E–03	8.1 E–03	5.3 E–03	5.3 E–03
Pm-149	1.1 E–04	9.2 E–05	7.2 E–05	5.9 E–05

Table 4-9. 200-E Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Pm-151	2.9 E–05	3.7 E–05	1.9 E–05	2.5 E–05
Sm-147	1.7 E+00	2.1 E+00	1.1 E+00	1.3 E+00
Sm-151	7.5 E–04	8.4 E–04	4.9 E–04	5.4 E–04
Sm-153	7.7 E–05	7.2 E–05	5.1 E–05	4.6 E–05
Eu-152	2.4 E–01	3.1 E–01	1.7 E–01	2.1 E–01
Eu-152m	1.0 E–05	1.3 E–05	6.8 E–06	8.7 E–06
Eu-154	2.0 E–01	2.5 E–01	1.3 E–01	1.7 E–01
Eu-155	8.0 E–03	9.8 E–03	5.4 E–03	6.5 E–03
Eu-156	2.4 E–03	1.9 E–03	1.6 E–03	1.3 E–03
Gd-152[b]	(Pu–239)	(Pu–239)	(Pu–239)	(Pu–239)
Tb-160	6.4 E–03	6.7 E–03	4.3 E–03	4.4 E–03
Ho-166	8.9 E–05	1.0 E–04	5.8 E–05	6.5 E–05
Ho-166m	8.0 E–01	1.0 E+00	5.4 E–01	6.8 E–01
Hf-181	2.5 E–03	2.3 E–03	1.7 E–03	1.5 E–03
W-181	4.5 E–04	4.3 E–04	3.1 E–04	2.9 E–04
W-185	6.0 E–04	4.3 E–05	4.1 E–04	3.3 E–05
W-187	5.1 E–05	6.2 E–05	3.4 E–05	4.1 E–05
Re-187	1.7 E–05	2.1 E–06	1.2 E–05	1.5 E–06
Ir-192	5.5 E–03	5.8 E–03	3.7 E–03	3.9 E–03
Hg-203	3.4 E–03	1.2 E–03	2.3 E–03	8.1 E–04
Tl-207[c]	0.0	1.0 E–10	0.0	0.0
Tl-208[c]	0.0	5.3 E–10	0.0	4.2 E–10
Tl-209[c]	0.0	0.0	0.0	0.0
Pb-209	1.5 E–06	2.1 E–06	1.0 E–06	1.4 E–06
Pb-210	*1.4 E+00*	*4.0 E–01*	*9.5 E–01*	*2.6 E–01*
Pb-210+D[c]	1.4 E+00	4.0 E–01	9.5 E–01	2.6 E–01
Pb-211	4.2 E–05	6.9 E–05	3.0 E–05	4.8 E–05
Pb-212	3.3 E–03	4.3 E–03	2.1 E–03	2.8 E–03
Pb-214	3.0 E–06	5.3 E–06	2.2 E–06	3.8 E–06
Bi-210	4.5 E–03	4.0 E–04	2.9 E–03	3.5 E–03
Bi-211	8.1 E–14	2.6 E–12	6.5 E–14	2.1 E–12
Bi-212	2.7 E–04	4.1 E–04	1.8 E–04	2.7 E–04
Bi-213	7.9 E–06	1.2 E–05	5.5 E–06	8.4 E–06
Bi-214	2.0 E–06	4.0 E–06	1.5 E–06	2.9 E–06
Po-210	5.2 E–01	2.2 E–05	3.5 E–01	2.0 E–05
Po-211[c]	0.0	0.0	0.0	0.0
Po-212[c]	0.0	0.0	0.0	0.0
Po-213[c]	0.0	0.0	0.0	0.0
Po-214[c]	0.0	0.0	0.0	0.0
Po-215[c]	0.0	0.0	0.0	0.0
Po-216[c]	0.0	0.0	0.0	0.0
Po-218[c]	0.0	0.0	0.0	0.0
At-217[c]	0.0	0.0	0.0	0.0
Rn-219[e]	2.5 E–03	7.3 E–04	1.7 E–03	4.7 E–04

Table 4-9. 200-E Area: Offsite and Onsite MPRs CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Rn-220[e]	4.6 E–06	6.0 E–06	2.9 E–06	3.9 E–06
Rn-222	6.9 E–05	8.6 E–05	3.9 E–05	4.8 E–05
Fr-221	8.8 E–09	4.9 E–08	7.2 E–09	4.0 E–08
Fr-223	4.9 E–06	9.4 E–06	3.7 E–06	6.7 E–06
Ra-223	2.4 E–01	2.3 E–01	1.6 E–01	1.5 E–01
Ra-224	8.5 E–02	9.7 E–02	5.6 E–02	6.2 E–02
Ra-225	1.5 E–01	1.2 E–01	9.8 E–02	7.5 E–02
Ra-226	4.6 E–01	2.5 E–01	3.1 E–01	1.6 E–01
Ra-228	1.9 E–01	7.0 E–02	1.3 E–01	4.5 E–02
Ac-225	1.4 E–01	1.7 E–01	9.1 E–02	1.1 E–01
Ac-227	1.5 E+01	1.8 E+01	9.5 E+00	1.1 E+01
Ac-228	1.6 E–03	2.1 E–03	1.0 E–03	1.3 E–03
Th-227	2.6 E–01	3.3 E–01	1.7 E–01	2.1 E–01
Th-228	5.6 E+00	7.1 E+00	3.6 E+00	4.5 E+00
Th-229	1.6 E+01	2.0 E+01	1.0 E+01	1.3 E+01
Th-230	5.6 E+00	7.0 E+00	3.6 E+00	4.5 E+00
Th-231	2.4 E–05	2.8 E–05	1.6 E–05	1.8 E–05
Th-232	*8.0 E+00*	*1.0 E+01*	*5.2 E+00*	*6.4 E+00*
Th-232+D[d]	9.2 E+00	1.2 E+01	6.0 E+00	7.5 E+00
Th-234	2.4 E–03	1.0 E–03	1.6 E–03	6.6 E–04
Pa-231	1.2 E+01	1.4 E+01	7.5 E+00	8.6 E+00
Pa-233	1.0 E–03	5.2 E–04	7.0 E–04	5.0 E–04
Pa-234	6.9 E–05	7.3 E–05	4.6 E–05	6.0 E–05
Pa-234m[c]	0.0	0.0	0.0	0.0
U-232	1.1 E+01	1.3 E+01	7.2 E+00	8.5 E+00
U-233	3.1 E+00	3.7 E+00	2.0 E+00	2.4 E+00
U-234	3.1 E+00	3.7 E+00	2.0 E+00	2.3 E+00
U-235	3.0 E+00	3.5 E+00	1.9 E+00	2.2 E+00
U-236	2.9 E+00	3.5 E+00	1.9 E+00	2.2 E+00
U-237	3.1 E–04	1.5 E–04	2.1 E–04	1.2 E–04
U-238	2.8 E+00	3.3 E+00	1.8 E+00	2.1 E+00
U-240	5.1 E–05	6.5 E–05	3.3 E–05	4.2 E–05
Np-237	1.2 E+01	1.4 E+01	7.5 E+00	8.7 E+00
Np-238	7.9 E–04	9.3 E–04	5.2 E–04	6.2 E–04
Np-239	1.2 E–04	9.4 E–05	8.0 E–05	7.2 E–05
Np-240	8.0 E–06	1.1 E–05	5.5 E–06	8.0 E–06
Np-240m	8.2 E–09	2.8 E–08	6.6 E–09	2.2 E–08
Pu-236	2.0 E+00	2.5 E+00	1.3 E+00	1.6 E+00
Pu-238	7.6 E+00	8.9 E+00	5.0 E+00	5.6 E+00
Pu-239	8.2 E+00	9.5 E+00	5.4 E+00	6.1 E+00
Pu-240	8.2 E+00	9.5 E+00	5.3 E+00	6.1 E+00
Pu-241	*1.3E–01*	1.5E–01	*8.4E–02*	*9.2E–02*
Pu-241+D[d]	1.3E–01	1.5E–01	8.4E–02	9.3E–02

Table 4-9. 200-E Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Pu-242	7.8 E+00	9.1 E+00	5.1 E+00	5.8 E+00
Pu-243	4.4E–06	5.8E–06	2.9E–06	3.8E–06
Pu-244	7.8 E+00	9.0 E+00	5.1 E+00	5.7 E+00
Am-241	1.3 E+01	1.5 E+01	8.2 E+00	9.6 E+00
Am-242	1.2E–03	1.6E–03	7.9E–04	1.0E–03
Am-242m	1.2 E+01	1.5 E+01	7.9 E+00	9.3 E+00
Am-243	1.3 E+01	1.5 E+01	8.2 E+00	9.6 E+00
Cm-242	4.1E–01	5.0E–01	2.7E–01	3.2E–01
Cm-243	8.5 E+00	1.0 E+01	5.5 E+00	6.5 E+00
Cm-244	6.7 E+00	8.0 E+00	4.3 E+00	5.1 E+00
Cm-245	1.3 E+01	1.6 E+01	8.5 E+00	1.0 E+01
Cm-246	1.3 E+01	1.6 E+01	8.4 E+00	9.9 E+00
Cm-247	1.2 E+01	1.4 E+01	7.8 E+00	9.2 E+00
Cm-248	4.7 E+01	5.7 E+01	3.1 E+01	3.6 E+01
Cf-252	3.5 E+00	4.3 E+00	2.3 E+00	2.8 E+00

a Worker assumed to work the maximum possible 8,766 hours in a year.
b Dose factors for this nuclide not included in the CAP88-PC library; thus, substituting the dose factors of the radionuclide in parentheses is recommended.
c Factor is ≤1.0 E–11, or effectively zero, considering also the scarcity and short half-life of the nuclide.
d "+D" indicates factors from in-grown progeny are also included.
e Short-lived Rn isotopes modeled on dose from their longer-lived progeny. Yet, 1 Ci of Rn does not equal 1Ci of Pb. Each Ci of Rn-219 released generates 0.0018 Ci of Pb-210, and each Ci of Rn-220, 0.0014 Ci of Pb-212. Dose based on Pb progeny multiplied by appropriate equilibrium factor (HNF-3602 1999).

Table 4-10. 200-W Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
H-3	2.5 E–05	1.1 E–05	1.4 E–05	5.6 E–06
Be-7	1.5 E–04	2.5 E–04	1.2 E–04	1.7 E–04
Be-10[b]	(Sr–90)	(Sr–90)	(Sr–90)	(Sr–90)
C-11	3.8 E–07	7.0 E–07	3.4 E–07	5.4 E–07
C-14	2.0 E–03	3.0 E–04	1.1 E–03	1.7 E–04
C-15[c]	0.0	0.0	0.0	0.0
N-13	3.6 E–08	8.9 E–08	3.2 E–08	6.7 E–08
O-15[c]	0.0	0.0	0.0	0.0
F-18	4.8 E–06	9.8 E–06	4.0 E–06	7.1 E–06
Na-22	1.0 E–01	1.6 E–01	7.7 E–02	1.1 E–01
Na-24	1.5 E–04	2.8 E–04	1.2 E–04	1.9 E–04
P-32	2.3 E–03	3.2 E–04	1.7 E–03	2.5 E–04
S-35	3.2 E–04	3.5 E–05	2.5 E–04	3.1 E–05
Ar-41	6.3 E–06	1.3 E–05	4.1 E–06	7.2 E–06
K-40	9.6 E–02	1.0 E–01	7.4 E–02	6.9 E–02
Ca-41	8.0 E–06	1.5 E–05	6.1 E–06	1.0 E–05
Sc-46	9.4 E–03	1.5 E–02	7.3 E–03	1.0 E–02
Cr-51	6.8 E–05	9.4 E–05	5.3 E–05	6.4 E–05
Mn-54	1.3 E–02	2.3 E–02	9.9 E–03	1.6 E–02
Mn-56	1.5 E–05	3.0 E–05	1.2 E–05	2.1 E–05
Fe-55	1.8 E–04	6.8 E–05	1.4 E–04	4.8 E–05
Fe-59	3.7 E–03	4.7 E–03	2.8 E–03	3.3 E–03
Co-57	2.2 E–03	3.6 E–03	1.7 E–03	2.4 E–03
Co-58	4.3 E–03	6.5 E–03	3.3 E–03	4.4 E–03
Co-60	1.9 E–01	3.4 E–01	1.5 E–01	2.3 E–01
Ni-59	2.4 E–04	3.3 E–04	1.9 E–04	2.2 E–04
Ni-63	2.0 E–04	7.8 E–05	1.6 E–04	5.3 E–05
Ni-65	5.8 E–06	1.2 E–05	4.7 E–06	8.4 E–06
Cu-64	1.1 E–05	2.0 E–05	8.1 E–06	1.4 E–05
Zn-65	1.9 E–02	1.3 E–02	1.5 E–02	9.4 E–03
Zn-69m	2.9 E–05	3.7 E–07	2.2 E–05	2.8 E–07
Zn-69	1.9 E–07	5.3 E–05	1.6 E–07	3.6 E–05
Ga-67	4.7 E–05	6.6 E–05	3.6 E–05	4.5 E–05
As-76	1.0 E–04	1.8 E–04	7.6 E–05	1.2 E–04
Se-79[b]	(Pu–241)	(Pu–241)	(Pu–241)	(Pu–241)
Br-82	2.4 E–04	4.0 E–04	1.9 E–04	2.7 E–04
Br-83	4.4 E–08	8.9 E–08	3.6 E–08	6.3 E–08
Br-84	1.7 E–06	3.1 E–06	1.5 E–06	2.4 E–06
Br-85[c]	0.0	0.0	0.0	0.0
Kr-83m	1.1 E–09	2.3 E–09	7.4 E–10	1.3 E–09

Table 4-10. 200-W Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Kr-85	5.6 E–08	9.8 E–08	3.0 E–08	4.8 E–08
Kr-85m	1.5 E–06	2.9 E–06	8.7 E–07	1.5 E–06
Kr-87	3.0 E–06	6.0 E–06	2.0 E–06	3.5 E–06
Kr-88	1.6 E–05	3.1 E–05	9.7 E–06	1.7 E–05
Kr-89[c]	0.0	1.2 E–10	0.0	0.0
Kr-90[c]	0.0	0.0	0.0	0.0
Rb-86	2.2 E–03	5.3 E–04	1.7 E–03	3.9 E–04
Rb-87	7.4 E–03	7.6 E–04	5.7 E–03	6.8 E–04
Rb-88	2.2 E–07	4.2 E–07	2.0 E–07	3.3 E–07
Rb-89	4.0 E–07	7.8 E–07	3.5 E–07	6.0 E–07
Rb-90	5.4 E–13	9.9 E–12	4.8 E–13	7.4 E–12
Rb-90m	4.5 E–10	2.8 E–09	3.9 E–10	2.1 E–09
Sr-89	1.3 E–03	2.4 E–04	1.0 E–03	1.7 E–04
Sr-90	*8.8 E–02*	*1.1 E–02*	*6.8 E–02*	*8.7 E–03*
Sr-90+D[d]	8.8 E–02	1.1 E–02	6.8 E–02	8.7 E–03
Sr-91	3.0 E–05	5.7 E–05	2.3 E–05	3.8 E–05
Sr-92	1.4 E–05	2.8 E–05	1.1 E–05	1.9 E–05
Y-90	2.6 E–04	2.9 E–04	2.0 E–04	1.9 E–04
Y-90m	5.1 E–06	1.0 E–05	4.1 E–06	7.2 E–06
Y-91	2.0 E–03	1.6 E–03	1.5 E–03	1.0 E–03
Y-91m	9.7 E–07	1.9 E–06	8.6 E–07	1.4 E–06
Y-92	1.3 E–05	2.6 E–05	1.0 E–05	1.8 E–05
Y-93	4.0 E–05	7.6 E–05	3.0 E–05	5.0 E–05
Zr-93	9.9 E–04	1.5 E–03	7.4 E–04	9.9 E–04
Zr-95	*3.0 E–03*	*4.7 E–03*	*2.3 E–03*	*3.2 E–03*
Zr-95+D[d]	5.5 E–03	9.1 E–03	4.2 E–03	6.2 E–03
Nb-93m	1.6 E–03	1.3 E–03	1.2 E–03	9.2 E–04
Nb-94	6.3 E–01	1.1 E+00	4.9 E–01	7.8 E–01
Nb-95	3.7 E–03	2.8 E–03	2.9 E–03	1.9 E–03
Nb-95m	2.3 E–04	1.1 E–04	1.8 E–04	7.6 E–05
Nb-97	2.3 E–06	4.6 E–06	2.0 E–06	3.5 E–06
Nb-97m[c]	0.0	0.0	0.0	0.0
Mo-93	2.2 E–03	4.0 E–03	1.7 E–03	2.8 E–03
Mo-99	*1.3 E–04*	*1.7 E–04*	*1.0 E–04*	*1.2 E–04*
Mo-99+D[d]	1.5 E–04	2.1 E–04	1.1 E–04	1.4 E–04
Tc-97	4.5 E–03	4.7 E–03	3.5 E–03	3.3 E–03
Tc-99	1.8 E–02	1.8 E–03	1.4 E–02	1.7 E–03
Tc-99m	2.4 E–06	3.0 E–05	1.9 E–06	2.1 E–05
Tc-101	4.5 E–08	9.1 E–08	4.0 E–08	6.9 E–08
Ru-97	5.1 E–05	8.0 E–05	3.9 E–05	5.4 E–05

Table 4-10. 200-W Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Ru-103	*1.4 E–03*	*2.0 E–03*	*1.1 E–03*	*1.4 E–03*
Ru-103+D[d]	1.4 E–03	2.0 E–03	1.1 E–03	1.4 E–03
Ru-105	1.5 E–05	3.0 E–05	1.2 E–05	2.1 E–05
Ru-106	*1.2 E–02*	*1.5 E–02*	*9.1 E–03*	*9.9 E–03*
Ru-106+D[d]	1.6 E–02	2.2 E–02	1.2 E–02	1.4 E–02
Rh-103m	2.4 E–08	4.7 E–08	2.1 E–08	3.6 E–08
Rh-105	3.6 E–05	4.5 E–05	2.8 E–05	3.0 E–05
Rh-105m[c]	0.0	0.0	0.0	0.0
Rh-106[c]	0.0	0.0	0.0	0.0
Pd-107	2.9 E–04	4.1 E–04	2.2 E–04	2.7 E–04
Pd-109	2.5 E–05	4.4 E–05	1.9 E–05	2.9 E–05
Ag-109m[c]	0.0	0.0	0.0	0.0
Ag-110[c]	0.0	0.0	0.0	0.0
Ag-110m	3.8 E–02	6.1 E–02	2.9 E–02	4.2 E–02
Ag-111	7.8 E–04	2.7 E–04	6.0 E–04	2.0 E–04
Cd-113[b]	(Pu–241)	(Pu–241)	(Pu–241)	(Pu–241)
Cd-113m[b]	(Pu–241)	(Pu–241)	(Pu–241)	(Pu–241)
Cd-115	1.5 E–04	1.8 E–04	1.1 E–04	1.2 E–04
Cd-115m	2.8 E–03	1.5 E–03	2.1 E–03	1.0 E–03
In-113m	1.3 E–06	2.6 E–06	1.1 E–06	1.9 E–06
In-115	4.7 E–02	3.3 E–02	3.6 E–02	2.2 E–02
In-115m	3.5 E–06	7.0 E–06	2.7 E–06	4.8 E–06
Sn-113	1.7 E–03	6.1 E–04	1.3 E–03	4.4 E–04
Sn-123	4.0 E–05	7.4 E–05	3.1 E–05	5.1 E–05
Sn-125	1.8 E–03	7.9 E–04	1.4 E–03	5.3 E–04
Sn-126	3.7 E–02	4.6 E–02	2.8 E–02	3.2 E–02
Sb-124	6.7 E–03	1.0 E–02	5.2 E–03	6.9 E–03
Sb-125	2.1 E–02	3.7 E–02	1.6 E–02	2.5 E–02
Sb-126	2.6 E–03	3.5 E–03	2.0 E–03	2.4 E–03
Sb-126m	5.0 E–07	9.3 E–07	4.4 E–07	7.2 E–07
Sb-127	3.6 E–04	4.3 E–04	2.7 E–04	2.9 E–04
Te-125m	8.1 E–04	3.6 E–04	6.2 E–04	2.5 E–04
Te-127	5.7 E–06	1.1 E–05	4.3 E–06	7.2 E–06
Te-127m	2.0 E–03	8.2 E–04	1.5 E–03	5.6 E–04
Te-129	6.1 E–07	1.2 E–06	5.3 E–07	9.1 E–07
Te-129m	2.0 E–03	9.1 E–04	1.5 E–03	6.2 E–04
Te-131	3.4 E–07	6.1 E–07	3.0 E–07	4.8 E–07
Te-131m	1.8 E–04	3.1 E–04	1.3 E–04	2.1 E–04
Te-132	3.2 E–04	3.2 E–04	2.4 E–04	2.1 E–04
Te-133	8.0 E–08	1.7 E–07	7.1 E–08	1.3 E–07

Table 4-10. 200-W Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Te-133m	4.4 E–06	8.5 E–06	3.8 E–06	6.5 E–06
Te-134	1.1 E–06	2.1 E–06	1.0 E–06	1.7 E–06
I-122[c]	0.0	0.0	0.0	0.0
I-123	2.4 E–06	2.4 E–06	5.5 E–06	9.9 E–06
I-125	4.5 E–03	2.5 E–04	1.1 E–02	5.2 E–04
I-129	7.6 E–02	8.1 E–03	1.8 E–01	2.5 E–02
I-130	2.7 E–05	2.7 E–05	6.0 E–05	1.1 E–04
I-131	2.5 E–03	2.0 E–04	5.8 E–03	5.7 E–04
I-132	3.5 E–06	3.4 E–06	6.8 E–06	1.2 E–05
I-133	2.8 E–05	1.6 E–05	6.4 E–05	6.6 E–05
I-134	9.6 E–07	8.5 E–07	1.7 E–06	2.6 E–06
I-135	8.5 E–06	8.8 E–06	1.9 E–05	3.6 E–05
Xe-122	9.9 E–07	1.8 E–06	5.4 E–07	8.7 E–07
Xe-123	3.5 E–06	7.1 E–06	2.2 E–06	3.9 E–06
Xe-125	3.5 E–06	6.3 E–06	1.9 E–06	3.2 E–06
Xe-127	4.4 E–06	7.6 E–06	2.3 E–06	3.7 E–06
Xe-131m	1.6 E–07	2.8 E–07	8.5 E–08	1.4 E–07
Xe-133	5.7 E–07	1.0 E–06	3.1 E–07	4.9 E–07
Xe-133m	4.9 E–07	8.6 E–07	2.6 E–07	4.2 E–07
Xe-135	3.1 E–06	5.6 E–06	1.7 E–06	3.1 E–06
Xe-135m	9.5 E–08	1.9 E–07	7.0 E–08	1.2 E–07
Xe-137[c]	0.0	0.0	0.0	0.0
Xe-138	2.2 E–07	4.5 E–07	1.6 E–07	2.8 E–07
Cs-134	7.8 E–02	1.0 E–01	6.0 E–02	7.0 E–02
Cs-134m	5.2 E–07	1.1 E–06	4.2 E–07	7.4 E–07
Cs-135	3.5 E–03	3.9 E–04	2.7 E–03	3.4 E–04
Cs-136	2.9 E–03	2.8 E–03	2.2 E–03	1.9 E–03
Cs-137	*2.1 E–02*	*2.5 E–03*	*1.6 E–02*	*2.1 E–03*
Cs-137+D[d]	1.9 E–01	3.1 E–01	1.5 E–01	2.1 E–01
Cs-138	2.3 E–06	4.3 E–06	2.1 E–06	3.3 E–06
Cs-139	8.8 E–09	2.3 E–08	7.8 E–09	1.7 E–08
Ba-133	5.9 E–02	1.1 E–01	4.5 E–02	7.3 E–02
Ba-133m	2.4 E–05	3.0 E–05	1.8 E–05	2.0 E–05
Ba-137m[c]	0.0	0.0	0.0	0.0
Ba-139	9.2 E–07	1.9 E–06	7.8 E–07	1.4 E–06
Ba-140	*8.3 E–04*	*3.7 E–04*	*6.4 E–04*	*2.5 E–04*
Ba-140+D[d]	2.1 E–03	2.8 E–03	1.6 E–03	1.9 E–03
Ba-141	2.4 E–07	4.6 E–07	2.2 E–07	3.6 E–07
Ba-142	4.4 E–08	1.1 E–07	3.9 E–08	7.7 E–08
La-140	3.0 E–04	5.0 E–04	2.3 E–04	3.4 E–04

Table 4-10. 200-W Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
La-141	4.0 E–07	8.0 E–07	3.2 E–07	5.6 E–07
La-142	1.1 E–05	2.2 E–05	9.2 E–06	1.6 E–05
Ce-141	5.9 E–04	5.4 E–04	4.5 E–04	3.6 E–04
Ce-143	8.8 E–05	1.5 E–04	6.7 E–05	9.7 E–05
Ce-144	*9.6 E–03*	*1.2 E–02*	*7.2 E–03*	*8.1 E–03*
Ce-144+D[d]	1.0 E–02	1.3 E–02	7.5 E–03	8.6 E–03
Pr-143	4.6 E–04	2.7 E–04	3.5 E–04	1.8 E–04
Pr-144	3.9 E–08	7.4 E–08	3.4 E–08	5.7 E–08
Pr-144m	4.2 E–10	1.4 E–09	3.7 E–10	1.0 E–09
Nd-147	4.5 E–04	3.7 E–04	3.4 E–04	2.4 E–04
Pm-147	8.4 E–04	1.2 E–03	6.2 E–04	8.0 E–04
Pm-148	6.6 E–04	6.3 E–04	5.0 E–04	4.2 E–04
Pm-148m	6.1 E–03	9.0 E–03	4.7 E–03	6.1 E–03
Pm-149	8.2 E–05	1.0 E–04	6.2 E–05	6.7 E–05
Pm-151	2.1 E–05	4.0 E–05	1.7 E–05	2.7 E–05
Sm-147	1.3 E+00	2.4 E+00	9.6 E–01	1.5 E+00
Sm-151	5.8 E–04	9.5 E–04	4.3 E–04	6.2 E–04
Sm-153	5.8 E–05	7.9 E–05	4.4 E–05	5.2 E–05
Eu-152	1.9 E–01	3.4 E–01	1.5 E–01	2.4 E–01
Eu-152m	6.9 E–06	1.3 E–05	5.4 E–06	9.0 E–06
Eu-154	1.5 E–01	2.8 E–01	1.2 E–01	1.9 E–01
Eu-155	6.3 E–03	1.1 E–02	4.8 E–03	7.4 E–03
Eu-156	1.9 E–03	2.2 E–03	1.5 E–03	1.5 E–03
Gd-152[b]	(Pu–239)	(Pu–239)	(Pu–239)	(Pu–239)
Tb-160	5.0 E–03	7.5 E–03	3.9 E–03	5.1 E–03
Ho-166	6.6 E–05	1.1 E–04	4.9 E–05	7.2 E–05
Ho-166m	6.2 E–01	1.1 E+00	4.8 E–01	7.8 E–01
Hf-181	1.9 E–03	2.5 E–03	1.5 E–03	1.7 E–03
W-181	3.6 E–04	4.8 E–04	2.7 E–04	3.3 E–04
W-185	4.7 E–04	5.1 E–05	3.6 E–04	4.3 E–05
W-187	3.8 E–05	6.6 E–05	2.9 E–05	4.5 E–05
Re-187	1.4 E–05	2.4 E–06	1.0 E–05	1.8 E–06
Ir-192	4.3 E–03	6.5 E–03	3.3 E–03	4.4 E–03
Hg-203	2.7 E–03	1.3 E–03	2.1 E–03	9.6 E–04
Tl-207	5.3 E–12	2.8 E–11	4.6 E–12	2.1 E–11
Tl-208	8.5 E–12	1.0 E–10	7.4 E–12	7.8 E–11
Tl-209	2.2 E–14	6.6 E–13	1.9 E–14	4.9 E–13
Pb-209	8.4 E–07	1.7 E–06	6.6 E–07	1.2 E–06
Pb-210	*1.1 E+00*	*4.6 E–01*	*8.4 E–01*	*3.1 E–01*
Pb-210+D[d]	1.1 E+00	4.6 E–01	8.4 E–01	3.1 E–01

Table 4-10. 200-W Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Pb-211	1.5 E–05	2.8 E–05	1.3 E–05	2.2 E–05
Pb-212	2.3 E–03	4.4 E–03	1.7 E–03	2.9 E–03
Pb-214	1.1 E–06	2.0 E–06	9.6 E–07	1.5 E–06
Bi-210	3.4 E–03	6.1 E–03	2.5 E–03	4.0 E–03
Bi-211	1.0 E–14	3.4 E–13	8.8 E–15	2.5 E–13
Bi-212	1.0 E–04	2.0 E–04	9.0 E–05	1.5 E–04
Bi-213	2.9 E–06	5.6 E–06	2.6 E–06	4.3 E–06
Bi-214	7.5 E–07	1.4 E–06	6.6 E–07	1.1 E–06
Po-210	4.1 E–01	2.8 E–01	3.1 E–01	1.8 E–01
Po-211[c]	0.0	0.0	0.0	0.0
Po-212[c]	0.0	0.0	0.0	0.0
Po-213[c]	0.0	0.0	0.0	0.0
Po-214[c]	0.0	0.0	0.0	0.0
Po-215[c]	0.0	0.0	0.0	0.0
Po-216[c]	0.0	0.0	0.0	0.0
Po-218[c]	0.0	0.0	0.0	0.0
At-217[c]	0.0	0.0	0.0	0.0
Rn-219[e]	2.0 E–03	8.3 E–04	1.5 E–03	5.5 E–04
Rn-220[e]	3.2 E–06	6.2 E–06	2.4 E–06	4.0 E–06
Rn-222	7.0 E–05	1.2 E–04	3.7 E–05	6.0 E–05
Fr-221	2.6 E–09	1.4 E–08	2.3 E–09	1.0 E–08
Fr-223	1.8 E–06	3.3 E–06	1.6 E–06	2.6 E–06
Ra-223	1.8 E–01	2.6 E–01	1.4 E–01	1.7 E–01
Ra-224	6.5 E–02	1.1 E–01	4.9 E–02	7.1 E–02
Ra-225	1.2 E–01	1.3 E–01	8.7 E–02	8.7 E–02
Ra-226	3.6 E–01	2.9 E–01	2.7 E–01	1.9 E–01
Ra-228	1.5 E–01	7.9 E–02	1.1 E–01	5.3 E–02
Ac-225	1.1 E–01	1.9 E–01	8.0 E–02	1.3 E–01
Ac-227	1.1 E+01	2.0 E+01	8.4 E+00	1.3 E+01
Ac-228	9.8 E–04	2.0 E–03	7.5 E–04	1.3 E–03
Th-227	2.0 E–01	3.7 E–01	1.5 E–01	2.4 E–01
Th-228	4.3 E+00	8.0 E+00	3.2 E+00	5.2 E+00
Th-229	1.2 E+01	2.2 E+01	8.9 E+00	1.4 E+01
Th-230	4.3 E+00	7.9 E+00	3.2 E+00	5.1 E+00
Th-231	1.8 E–05	3.0 E–05	1.3 E–05	2.0 E–05
Th-232	*6.2 E+00*	1.1 E+01	*4.5 E+00*	*7.4 E+00*
Th-232+D[d]	7.2 E+00	1.3 E+01	5.3 E+00	8.7 E+00
Th-234	1.9 E–03	1.2 E–03	1.4 E–03	7.7 E–04
Pa-231	8.9 E+00	1.5 E+01	6.6 E+00	9.9 E+00
Pa-233	8.1 E–04	8.6 E–04	6.2 E–04	5.8 E–04

Table 4-10. 200-W Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Pa-234	4.5 E–05	8.7 E–05	3.5 E–05	5.9 E–05
Pa-234m[c]	0.0	0.0	0.0	0.0
U-232	8.6 E+00	1.5 E+01	6.3 E+00	9.9 E+00
U-233	2.4 E+00	4.2 E+00	1.8 E+00	2.8 E+00
U-234	2.4 E+00	4.2 E+00	1.8 E+00	2.7 E+00
U-235	2.3 E+00	4.0 E+00	1.7 E+00	2.6 E+00
U-236	2.3 E+00	3.9 E+00	1.7 E+00	2.6 E+00
U-237	2.4 E–04	2.1 E–04	1.8 E–04	1.4 E–04
U-238	2.1 E+00	3.7 E+00	1.6 E+00	2.4 E+00
U-240	3.6 E–05	6.8 E–05	2.7 E–05	4.5 E–05
Np-237	8.9 E+00	1.6 E+01	6.6 E+00	1.0 E+01
Np-238	6.0 E–04	1.1 E–03	4.5 E–04	7.1 E–04
Np-239	9.1 E–05	1.2 E–04	6.9 E–05	8.1 E–05
Np-240	3.2 E–06	6.3 E–06	2.8 E–06	4.7 E–06
Np-240m	2.9 E–09	8.9 E–09	2.5 E–09	6.6 E–09
Pu-236	1.6 E+00	2.8 E+00	1.2 E+00	1.8 E+00
Pu-238	5.9 E+00	1.0 E+01	4.4 E+00	6.5 E+00
Pu-239	6.4 E+00	1.1 E+01	4.7 E+00	7.0 E+00
Pu-240	6.4 E+00	1.1 E+01	4.7 E+00	7.0 E+00
Pu-241	*1.0 E–01*	*1.6 E–01*	*7.4 E–02*	*1.1 E–01*
Pu-241+D[d]	1.0 E–01	1.6 E–01	7.4 E–02	1.1 E–01
Pu-242	6.1 E+00	1.0 E+01	4.5 E+00	6.7 E+00
Pu-243	2.7 E–06	5.4 E–06	2.1 E–06	3.6 E–06
Pu-244	6.0 E+00	1.0 E+01	4.5 E+00	6.6 E+00
Am-241	9.8 E+00	1.7 E+01	7.2 E+00	1.1 E+01
Am-242	8.6 E–04	1.7 E–03	6.5 E–04	1.1 E–03
Am-242m	9.4 E+00	1.7 E+01	7.0 E+00	1.1 E+01
Am-243	9.8 E+00	1.7 E+01	7.3 E+00	1.1 E+01
Cm-242	3.2 E–01	5.7 E–01	2.4 E–01	3.7 E–01
Cm-243	6.6 E+00	1.2 E+01	4.9 E+00	7.5 E+00
Cm-244	5.2 E+00	9.0 E+00	3.8 E+00	5.9 E+00
Cm-245	1.0 E+01	1.8 E+01	7.5 E+00	1.2 E+01
Cm-246	1.0 E+01	1.8 E+01	7.4 E+00	1.1 E+01
Cm-247	9.3 E+00	1.6 E+01	6.9 E+00	1.1 E+01
Cm-248	3.7 E+01	6.4 E+01	2.7 E+01	4.2 E+01
Cf-252	2.8 E+00	4.9 E+00	2.0 E+00	3.2 E+00

a Worker assumed to work the maximum possible 8,766 hours in a year.
b Dose factors for this nuclide not included in the CAP88-PC library; thus, substituting the dose factors of the radionuclide in parentheses is recommended.
c Factor is ≤1.0 E–11, or effectively zero, considering also the scarcity and short half-life of the nuclide.
d "+D" indicates factors from in-grown progeny are also included.
e Short-lived Rn isotopes modeled on dose from their longer-lived progeny. Yet, 1 Ci of Rn does not equal 1 Ci of Pb. Each Ci of Rn-219 released generates 0.0018 Ci of Pb-210, and each Ci of Rn-220, 0.0014 Ci of Pb-212. Dose based on Pb progeny multiplied by appropriate equilibrium factor (HNF-3602 1999).

Table 4-11. 300 Area East and West Sections: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective Release Height			
	<40 m		≥40 m	
	East	West	East	West
H-3	4.8 E–04	3.4 E–04	1.4 E–04	1.2 E–04
Be-7	4.5 E–03	3.3 E–03	1.5 E–03	1.2 E–03
Be-10[a]	(Sr–90)	(Sr–90)	(Sr–90)	(Sr–90)
C-11	2.8 E–04	1.9 E–04	8.8 E–05	7.0 E–05
C-14	3.7 E–02	2.7 E–02	1.1 E–02	9.2 E–03
C-15[b]	0.0	0.0	0.0	0.0
N-13	2.2 E–04	1.4 E–04	7.1 E–05	5.5 E–05
O-15	8.1 E–05	4.3 E–05	2.9 E–05	1.8 E–05
F-18	4.4 E–04	3.1 E–04	1.4 E–04	1.1 E–04
Na-22	3.0 E+00	2.1 E+00	9.7 E–01	8.1 E–01
Na-24	5.5 E–03	3.9 E–03	1.7 E–03	1.4 E–03
P-32	6.7 E–02	4.8 E–02	2.2 E–02	1.8 E–02
S-35	9.5 E–03	6.8 E–03	3.1 E–03	2.6 E–03
Ar-41	4.0 E–04	2.8 E–04	1.2 E–04	9.8 E–05
K-40	2.9 E+00	2.1 E+00	9.3 E–01	7.7 E–01
Ca-41	2.4 E–04	1.7 E–04	7.7 E–05	6.4 E–05
Sc-46	2.8 E–01	2.0 E–01	9.1 E–02	7.6 E–02
Cr-51	2.0 E–03	1.5 E–03	6.6 E–04	5.5 E–04
Mn-54	3.8 E–01	2.7 E–01	1.2 E–01	1.0 E–01
Mn-56	1.1 E–03	7.5 E–04	3.3 E–04	2.7 E–04
Fe-55	5.4 E–03	3.9 E–03	1.7 E–03	1.4 E–03
Fe-59	1.1 E–01	7.9 E–02	3.5 E–02	3.0 E–02
Co-57	6.6 E–02	4.8 E–02	2.1 E–02	1.8 E–02
Co-58	1.3 E–01	9.1 E–02	4.1 E–02	3.4 E–02
Co-60	5.7 E+00	4.1 E+00	1.9 E+00	1.6 E+00
Ni-59	7.1 E–03	5.1 E–03	2.3 E–03	1.9 E–03
Ni-63	6.1 E–03	4.4 E–03	2.0 E–03	1.6 E–03
Ni-65	4.2 E–04	3.0 E–04	1.3 E–04	1.1 E–04
Cu-64	3.9 E–04	2.8 E–04	1.2 E–04	1.0 E–04
Zn-65	5.7 E–01	4.1 E–01	1.9 E–01	1.6 E–01
Zn-69m	1.1 E–03	7.6 E–04	3.3 E–04	2.7 E–04
Zn-69	3.3 E–05	2.3 E–05	1.0 E–05	8.3 E–06
Ga-67	1.5 E–03	1.0 E–03	4.6 E–04	3.9 E–04
As-76	3.4 E–03	2.5 E–03	1.0 E–03	8.8 E–04
Se-79[a]	(Pu–241)	(Pu–241)	(Pu–241)	(Pu–241)
Br-82	7.7 E–03	5.6 E–03	2.5 E–03	2.1 E–03
Br-83	3.2 E–06	2.3 E–06	1.0 E–06	8.4 E–07
Br-84	5.8 E–04	4.0 E–04	1.8 E–04	1.5 E–04
Br-85	7.4 E–06	4.3 E–06	2.6 E–06	1.8 E–06
Kr-83m	7.1 E–08	5.1 E–08	2.1 E–08	1.8 E–08

Table 4-11. 300 Area East and West Sections: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective Release Height			
	<40 m		≥40 m	
	East	West	East	West
Kr-85	1.1 E–06	7.7 E–07	3.1 E–07	2.6 E–07
Kr-85m	5.0 E–05	3.6 E–05	1.5 E–05	1.2 E–05
Kr-87	2.6 E–04	1.9 E–04	7.8 E–05	6.5 E–05
Kr-88	6.9 E–04	5.0 E–04	2.1 E–04	1.7 E–04
Kr-89	2.4 E–04	1.4 E–04	8.1 E–05	5.6 E–05
Kr-90	6.5 E–06	1.6 E–06	2.4 E–06	7.0 E–07
Rb-86	6.7 E–02	4.8 E–02	2.2 E–02	1.8 E–02
Rb-87	2.2 E–01	1.6 E–01	7.1 E–02	5.9 E–02
Rb-88	2.2 E–04	1.5 E–04	7.1 E–05	5.6 E–05
Rb-89	5.6 E–04	3.8 E–04	1.8 E–04	1.4 E–04
Rb-90	2.5 E–04	1.4 E–04	9.0 E–05	6.0 E–05
Rb-90m	5.2 E–04	3.2 E–04	1.8 E–04	1.3 E–04
Sr-89	4.0 E–02	2.9 E–02	1.3 E–02	1.1 E–02
Sr-90	*2.6 E+00*	*1.9 E+00*	*8.5 E–01*	*7.1 E–01*
Sr-90+D[c]	2.6 E+00	1.9 E+00	8.5 E–01	7.1 E–01
Sr-91	1.2 E–03	8.4 E–04	3.6 E–04	3.0 E–04
Sr-92	9.4 E–04	6.7 E–04	2.9 E–04	2.4 E–04
Y-90	8.3 E–03	5.9 E–03	2.6 E–03	2.2 E–03
Y-90m	3.1 E–04	2.2 E–04	9.7 E–05	8.1 E–05
Y-91	6.0 E–02	4.3 E–02	1.9 E–02	1.6 E–02
Y-91m	1.9 E–04	1.3 E–04	5.9 E–05	4.9 E–05
Y-92	7.5 E–04	5.4 E–04	2.3 E–04	1.9 E–04
Y-93	1.6 E–03	1.1 E–03	4.7 E–04	4.0 E–04
Zr-93	3.1 E–02	2.2 E–02	9.4 E–03	7.9 E–03
Zr-95	*9.1 E–02*	*6.5 E–02*	*2.9 E–02*	*2.5 E–02*
Zr-95+D[c]	1.6 E–01	1.2 E–01	5.3 E–02	4.4 E–02
Nb-93m	4.9 E–02	3.5 E–02	1.5 E–02	1.3 E–02
Nb-94	1.9 E+01	1.4 E+01	6.1 E+00	5.1 E+00
Nb-95	1.1 E–01	8.0 E–02	3.6 E–02	3.0 E–02
Nb-95m	7.1 E–03	5.1 E–03	2.3 E–03	1.9 E–03
Nb-97	3.1 E–04	2.2 E–04	9.6 E–05	7.9 E–05
Nb-97m	2.1 E–05	8.3 E–06	7.6 E–06	3.6 E–06
Mo-93	6.5 E–02	4.7 E–02	2.1 E–02	1.8 E–02
Mo-99	*4.2 E–03*	*3.0 E–03*	*1.3 E–03*	*1.1 E–03*
Mo-99+D[c]	4.8 E–03	3.4 E–03	1.5 E–03	1.2 E–03
Tc-97	1.3 E–01	9.6 E–02	4.3 E–02	3.6 E–02
Tc-99	5.2 E–01	3.8 E–01	1.7 E–01	1.4 E–01
Tc-99m	1.1 E–04	7.8 E–05	3.4 E–05	2.8 E–05
Tc-101	8.0 E–05	5.3 E–05	2.6 E–05	2.0 E–05
Ru-97	1.6 E–03	1.1 E–03	5.0 E–04	4.2 E–04

Table 4-11. 300 Area East and West Sections: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective Release Height			
	<40 m		≥40 m	
	East	West	East	West
Ru-103	*4.3 E–02*	*3.1 E–02*	*1.4 E–02*	*1.2 E–02*
Ru-103+D[c]	4.3 E–02	3.1 E–02	1.4 E–02	1.2 E–02
Ru-105	7.8 E–04	5.6 E–04	2.4 E–04	2.0 E–04
Ru-106	*3.7 E–01*	*2.7 E–01*	*1.1 E–01*	*9.6 E–02*
Ru-106+D[c]	4.8 E–01	3.4 E–01	1.5 E–01	1.2 E–01
Rh-103m	4.2 E–06	2.9 E–06	1.3 E–06	1.1 E–06
Rh-105	1.2 E–03	8.5 E–04	3.7 E–04	3.1 E–04
Rh-105m	4.1 E–07	1.4 E–07	1.5 E–07	5.9 E–08
Rh-106	7.4 E–07	1.7 E–07	2.8 E–07	7.6 E–08
Pd-107	8.9 E–03	6.4 E–03	2.7 E–03	2.3 E–03
Pd-109	9.2 E–04	6.6 E–04	2.8 E–04	2.3 E–04
Ag-109m	4.5 E–08	1.4 E–08	1.7 E–08	6.0 E–09
Ag-110	4.8 E–08	8.5 E–09	1.9 E–08	3.9 E–09
Ag-110m	1.1 E+00	8.0 E–01	3.6 E–01	3.0 E–01
Ag-111	2.4 E–02	1.7 E–02	7.6 E–03	6.3 E–03
Cd-113[a]	(Pu–241)	(Pu–241)	(Pu–241)	(Pu–241)
Cd-113m[a]	(Pu–241)	(Pu–241)	(Pu–241)	(Pu–241)
Cd-115	4.6 E–03	3.3 E–03	1.5 E–03	1.2 E–03
Cd-115m	8.3 E–02	6.0 E–02	2.7 E–02	2.2 E–02
In-113m	1.3 E–04	9.0 E–05	3.9 E–05	3.2 E–05
In-115	1.4 E+00	1.0 E+00	4.5 E–01	3.7 E–01
In-115m	1.8 E–04	1.3 E–04	5.6 E–05	4.7 E–05
Sn-113	5.1 E–02	3.7 E–02	1.7 E–02	1.4 E–02
Sn-123	1.2 E–03	8.6 E–04	3.9 E–04	3.2 E–04
Sn-125	5.5 E–02	4.0 E–02	1.8 E–02	1.5 E–02
Sn-126	1.1 E+00	7.9 E–01	3.5 E–01	3.0 E–01
Sb-124	2.0 E–01	1.4 E–01	6.5 E–02	5.4 E–02
Sb-125	6.1 E–01	4.4 E–01	2.0 E–01	1.6 E–01
Sb-126	7.6 E–02	5.5 E–02	2.5 E–02	2.1 E–02
Sb-126m	4.3 E–04	2.9 E–04	1.4 E–04	1.1 E–04
Sb-127	1.1 E–02	8.0 E–03	3.5 E–03	2.9 E–03
Te-125m	2.4 E–02	1.7 E–02	7.7 E–03	6.4 E–03
Te-127	2.3 E–04	1.6 E–04	6.9 E–05	5.8 E–05
Te-127m	5.9 E–02	4.3 E–02	1.9 E–02	1.6 E–02
Te-129	8.6 E–05	6.0 E–05	2.6 E–05	2.2 E–05
Te-129m	5.8 E–02	4.2 E–02	1.9 E–02	1.6 E–02
Te-131	1.7 E–04	1.2 E–04	5.3 E–05	4.3 E–05
Te-131m	5.8 E–03	4.2 E–03	1.8 E–03	1.5 E–03
Te-132	9.8 E–03	7.1 E–03	3.1 E–03	2.6 E–03
Te-133	2.1 E–04	1.4 E–04	6.9 E–05	5.4 E–05

Table 4-11. 300 Area East and West Sections: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective Release Height			
	<40 m		≥40 m	
	East	West	East	West
Te-133m	7.6 E–04	5.3 E–04	2.4 E–04	1.9 E–04
Te-134	2.7 E–04	1.9 E–04	8.5 E–05	6.9 E–05
I-122	1.0 E–04	5.4 E–05	5.0 E–05	3.4 E–05
I-123	2.0 E–03	1.3 E–03	8.7 E–04	7.1 E–04
I-125	3.3 E+00	2.1 E+00	1.5 E+00	1.2 E+00
I-129	5.6 E+01	3.6 E+01	2.4 E+01	2.0 E+01
I-130	2.2 E–02	1.4 E–02	9.6 E–03	7.8 E–03
I-131	1.8 E+00	1.2 E+00	8.0 E–01	6.5 E–01
I-132	4.3 E–03	2.7 E–03	1.9 E–03	1.5 E–03
I-133	2.2 E–02	1.4 E–02	9.6 E–03	7.8 E–03
I-134	2.1 E–03	1.3 E–03	9.1 E–04	7.2 E–04
I-135	7.8 E–03	4.9 E–03	3.4 E–03	2.7 E–03
Xe-122	2.1 E–05	1.5 E–05	6.2 E–06	5.3 E–06
Xe-123	1.9 E–04	1.4 E–04	5.7 E–05	4.7 E–05
Xe-125	7.8 E–05	5.6 E–05	2.3 E–05	1.9 E–05
Xe-127	8.2 E–05	5.9 E–05	2.4 E–05	2.0 E–05
Xe-131m	3.0 E–06	2.2 E–06	8.8 E–07	7.4 E–07
Xe-133	1.1 E–05	7.9 E–06	3.2 E–06	2.7 E–06
Xe-133m	9.6 E–06	6.9 E–06	2.8 E–06	2.4 E–06
Xe-135	7.7 E–05	5.6 E–05	2.3 E–05	1.9 E–05
Xe-135m	1.0 E–04	6.7 E–05	3.1 E–05	2.5 E–05
Xe-137	2.6 E–05	1.6 E–05	8.7 E–06	6.2 E–06
Xe-138	2.9 E–04	1.9 E–04	9.0 E–05	7.1 E–05
Cs-134	2.3 E+00	1.7 E+00	7.5 E–01	6.3 E–01
Cs-134m	3.4 E–05	2.5 E–05	1.1 E–05	8.8 E–06
Cs-135	1.0 E–01	7.4 E–02	3.3 E–02	2.8 E–02
Cs-136	8.6 E–02	6.2 E–02	2.8 E–02	2.3 E–02
Cs-137	*6.2 E–01*	*4.4 E–01*	*2.0 E–01*	*1.7 E–01*
Cs-137+D[c]	5.5 E+00	4.0 E+00	1.8 E+00	1.5 E+00
Cs-138	7.9 E–04	5.4 E–04	2.5 E–04	2.0 E–04
Cs-139	6.7 E–05	4.3 E–05	2.2 E–05	1.7 E–05
Ba-133	1.7 E+00	1.3 E+00	5.6 E–01	4.7 E–01
Ba-133m	7.6 E–04	5.5 E–04	2.4 E–04	2.0 E–04
Ba-137m	5.9 E–05	3.3 E–05	2.1 E–05	1.4 E–05
Ba-139	1.1 E–04	7.7 E–05	3.3 E–05	2.8 E–05
Ba-140	*2.5 E–02*	*1.8 E–02*	*7.9 E–03*	*6.6 E–03*
Ba-140+D[c]	6.3 E–02	4.6 E–02	2.1 E–02	1.7 E–02
Ba-141	2.3 E–04	1.5 E–04	7.3 E–05	5.8 E–05
Ba-142	2.0 E–04	1.3 E–04	6.4 E–05	5.0 E–05
La-140	9.7 E–03	7.0 E–03	3.1 E–03	2.6 E–03

Table 4-11. 300 Area East and West Sections: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective Release Height			
	<40 m		≥40 m	
	East	West	East	West
La-141	2.2 E–05	1.6 E–05	6.8 E–06	5.7 E–06
La-142	1.1 E–03	8.0 E–04	3.5 E–04	2.9 E–04
Ce-141	1.8 E–02	1.3 E–02	5.6 E–03	4.7 E–03
Ce-143	2.9 E–03	2.1 E–03	9.0 E–04	7.5 E–04
Ce-144	*2.9 E–01*	*2.1 E–01*	*9.0 E–02*	*7.6 E–02*
Ce-144+D[c]	3.0 E–01	2.2 E–01	9.4 E–02	7.9 E–02
Pr-143	1.4 E–02	1.0 E–02	4.4 E–03	3.7 E–03
Pr-144	4.2 E–05	2.8 E–05	1.3 E–05	1.0 E–05
Pr-144m	1.2 E–05	7.4 E–06	3.9 E–06	2.9 E–06
Nd-147	1.4 E–02	9.8 E–03	4.3 E–03	3.6 E–03
Pm-147	2.6 E–02	1.8 E–02	7.8 E–03	6.6 E–03
Pm-148	2.0 E–02	1.5 E–02	6.4 E–03	5.4 E–03
Pm-148m	1.8 E–01	1.3 E–01	5.8 E–02	4.9 E–02
Pm-149	2.6 E–03	1.9 E–03	8.1 E–04	6.8 E–04
Pm-151	7.0 E–04	5.0 E–04	2.3 E–04	1.9 E–04
Sm-147	4.0 E+01	2.9 E+01	1.2 E+01	1.0 E+01
Sm-151	1.8 E–02	1.3 E–02	5.4 E–03	4.5 E–03
Sm-153	1.9 E–03	1.3 E–03	5.8 E–04	4.8 E–04
Eu-152	5.6 E+00	4.0 E+00	1.8 E+00	1.5 E+00
Eu-152m	2.7 E–04	1.9 E–04	8.6 E–05	7.1 E–05
Eu-154	4.6 E+00	3.3 E+00	1.5 E+00	1.2 E+00
Eu-155	1.9 E–01	1.3 E–01	6.0 E–02	5.0 E–02
Eu-156	5.7 E–02	4.1 E–02	1.8 E–02	1.5 E–02
Gd-152[a]	(Pu–239)	(Pu–239)	(Pu–239)	(Pu–239)
Tb-160	1.5 E–01	1.1 E–01	4.8 E–02	4.0 E–02
Ho-166	2.2 E–03	1.6 E–03	6.8 E–04	5.7 E–04
Ho-166m	1.8 E+01	1.3 E+01	6.0 E+00	5.0 E+00
Hf-181	5.7 E–02	4.1 E–02	1.8 E–02	1.5 E–02
W-181	1.1 E–02	7.5 E–03	3.4 E–03	2.8 E–03
W-185	1.4 E–02	1.0 E–02	4.5 E–03	3.8 E–03
W-187	1.3 E–03	9.1 E–04	4.0 E–04	3.3 E–04
R E–187	4.0 E–04	2.9 E–04	1.3 E–04	1.1 E–04
Ir-192	1.3 E–01	9.1 E–02	4.1 E–02	3.4 E–02
Hg-203	7.9 E–02	5.7 E–02	2.6 E–02	2.1 E–02
Tl-207	2.5 E–06	1.5 E–06	8.4 E–07	6.1 E–07
Tl-208	4.4 E–04	2.6 E–04	1.6 E–04	1.1 E–04
Tl-209	1.9 E–04	1.0 E–04	6.7 E–05	4.3 E–05
Pb-209	5.2 E–05	3.7 E–05	1.6 E–05	1.3 E–05
Pb-210	*3.3 E+01*	*2.4 E+01*	*1.1 E+01*	*8.8 E+00*
Pb-210+D[c]	3.3 E+01	2.4 E+01	1.1 E+01	8.8 E+00

Table 4-11. 300 Area East and West Sections: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective Release Height			
	<40 m		≥40 m	
	East	West	East	West
Pb-211	4.4 E–03	3.1 E–03	1.4 E–03	1.1 E–03
Pb-212	8.9 E–02	6.4 E–02	2.7 E–02	2.2 E–02
Pb-214	4.9 E–04	3.3 E–04	1.5 E–04	1.2 E–04
Bi-210	1.1 E–01	7.8 E–02	3.3 E–02	2.7 E–02
Bi-211	1.6 E–04	8.6 E–05	5.6 E–05	3.6 E–05
Bi-212	1.7 E–02	1.2 E–02	5.1 E–03	4.2 E–03
Bi-213	6.4 E–04	4.4 E–04	2.0 E–04	1.6 E–04
Bi-214	5.8 E–04	3.9 E–04	1.9 E–04	1.5 E–04
Po-210	1.2 E+01	8.8 E+00	3.9 E+00	3.2 E+00
Po-211[a]	0.0	0.0	0.0	0.0
Po-212[a]	0.0	0.0	0.0	0.0
Po-213[a]	0.0	0.0	0.0	0.0
Po-214[a]	0.0	0.0	0.0	0.0
Po-215[a]	0.0	0.0	0.0	0.0
Po-216[a]	0.0	0.0	0.0	0.0
Po-218	1.0 E–05	5.9 E–06	3.6 E–06	2.5 E–06
At-217[a]	0.0	0.0	0.0	0.0
Rn-219[d]	5.9 E–02	4.3 E–02	2.0 E–02	1.6 E–02
Rn-220[d]	1.2 E–04	9.0 E–05	3.8 E–05	3.1 E–05
Rn-222	1.4 E–03	9.7 E–04	4.0 E–04	3.3 E–04
Fr-221	1.1 E–03	6.9 E–04	3.8 E–04	2.8 E–04
Fr-223	1.2 E–03	8.0 E–04	3.7 E–04	3.0 E–04
Ra-223	5.7 E+00	4.1 E+00	1.7 E+00	1.5 E+00
Ra-224	2.1 E+00	1.5 E+00	6.3 E–01	5.3 E–01
Ra-225	3.5 E+00	2.5 E+00	1.1 E+00	9.1 E–01
Ra-226	1.1 E+01	7.8 E+00	3.4 E+00	2.8 E+00
Ra-228	4.4 E+00	3.2 E+00	1.4 E+00	1.2 E+00
Ac-225	3.4 E+00	2.4 E+00	1.0 E+00	8.5 E–01
Ac-227	3.5 E+02	2.5 E+02	1.1 E+02	8.9 E+01
Ac-228	4.5 E–02	3.2 E–02	1.4 E–02	1.1 E–02
Th-227	6.3 E+00	4.5 E+00	1.9 E+00	1.6 E+00
Th-228	1.3 E+02	9.6 E+01	4.0 E+01	3.4 E+01
Th-229	3.7 E+02	2.7 E+02	1.1 E+02	9.4 E+01
Th-230	1.3 E+02	9.6 E+01	4.0 E+01	3.4 E+01
Th-231	6.0 E–04	4.3 E–04	1.8 E–04	1.5 E–04
Th-232	*1.9 E+02*	*1.4 E+02*	*5.8 E+01*	*4.8 E+01*
Th-232+D[c]	2.2 E+02	1.6 E+02	6.7 E+01	5.6 E+01
Th-234	5.6 E–02	4.0 E–02	1.8 E–02	1.5 E–02
Pa-231	2.8 E+02	2.0 E+02	8.3 E+01	7.0 E+01
Pa-233	2.4 E–02	1.8 E–02	7.8 E–03	6.5 E–03

Table 4-11. 300 Area East and West Sections: Offsite MPR CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective Release Height			
	<40 m		≥40 m	
	East	West	East	West
Pa-234	2.0 E–03	1.4 E–03	6.1 E–04	5.1 E–04
Pa-234m	6.8 E–07	3.0 E–07	2.5 E–07	1.3 E–07
U-232	2.7 E+02	1.9 E+02	8.0 E+01	6.7 E+01
U-233	7.5 E+01	5.4 E+01	2.3 E+01	1.9 E+01
U-234	7.4 E+01	5.3 E+01	2.2 E+01	1.9 E+01
U-235	7.1 E+01	5.1 E+01	2.1 E+01	1.8 E+01
U-236	7.0 E+01	5.0 E+01	2.1 E+01	1.8 E+01
U-237	7.2 E–03	5.2 E–03	2.3 E–03	1.9 E–03
U-238	6.6 E+01	4.7 E+01	2.0 E+01	1.7 E+01
U-240	1.4 E–03	9.6 E–04	4.1 E–04	3.4 E–04
Np-237	2.8 E+02	2.0 E+02	8.3 E+01	7.0 E+01
Np-238	1.9 E–02	1.4 E–02	5.9 E–03	4.9 E–03
Np-239	2.9 E–03	2.1 E–03	9.1 E–04	7.6 E–04
Np-240	4.7 E–04	3.3 E–04	1.5 E–04	1.2 E–04
Np-240m	6.8 E–05	4.3 E–05	2.3 E–05	1.7 E–05
Pu-236	4.8 E+01	3.5 E+01	1.5 E+01	1.2 E+01
Pu-238	1.8 E+02	1.3 E+02	5.5 E+01	4.6 E+01
Pu-239	2.0 E+02	1.4 E+02	6.0 E+01	5.0 E+01
Pu-240	2.0 E+02	1.4 E+02	6.0 E+01	5.0 E+01
Pu-241	*3.1 E+00*	*2.2 E+00*	*9.4 E–01*	*7.9 E–01*
Pu-241+D[c]	3.1 E+00	2.2 E+00	9.4 E–01	7.9 E–01
Pu-242	1.9 E+02	1.4 E+02	5.7 E+01	4.8 E+01
Pu-243	1.4 E–04	9.6 E–05	4.1 E–05	3.4 E–05
Pu-244	1.9 E+02	1.3 E+02	5.6 E+01	4.7 E+01
Am-241	3.0 E+02	2.2 E+02	9.2 E+01	7.7 E+01
Am-242	3.2 E–02	2.3 E–02	9.5 E–03	7.9 E–03
Am-242m	2.9 E+02	2.1 E+02	8.8 E+01	7.4 E+01
Am-243	3.0 E+02	2.2 E+02	9.2 E+01	7.7 E+01
Cm-242	9.9 E+00	7.1 E+00	3.0 E+00	2.5 E+00
Cm-243	2.0 E+02	1.5 E+02	6.1 E+01	5.2 E+01
Cm-244	1.6 E+02	1.2 E+02	4.8 E+01	4.1 E+01
Cm-245	3.1 E+02	2.3 E+02	9.5 E+01	7.9 E+01
Cm-246	3.1 E+02	2.2 E+02	9.3 E+01	7.8 E+01
Cm-247	2.9 E+02	2.1 E+02	8.7 E+01	7.3 E+01
Cm-248	1.1 E+03	8.2 E+02	3.4 E+02	2.9 E+02
Cf-252	8.5 E+01	6.1 E+01	2.6 E+01	2.2 E+01

[a] Dose factors for this nuclide not included in the CAP88-PC library; thus, substituting the dose factors of the radionuclide in parentheses is recommended.

[b] Factor is ≤1.0 E–11, or effectively zero, considering also the scarcity and short half-life of the nuclide.

[c] "+D" indicates factors from in-grown progeny are also included.

[d] Short-lived Rn isotopes modeled on dose from their longer-lived progeny. Yet, 1 Ci of Rn does not equal 1Ci of Pb. Each Ci of Rn-219 released generates 0.0018 Ci of Pb-210, and each Ci of Rn-220, 0.0014 Ci of Pb-212. Dose based on Pb progeny multiplied by appropriate equilibrium factor (HNF-3602 1999).

Table 4-12. 400 Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
H-3	3.4 E–05	1.7 E–05	1.9 E–05	9.2 E–06
Be-7	2.9 E–04	7.0 E–04	1.9 E–04	4.0 E–04
Be-10[b]	(Sr-90)	(Sr-90)	(Sr-90)	(Sr-90)
C-11	5.3 E–06	2.9 E–05	3.7 E–06	1.6 E–05
C-14	2.6 E–03	3.3 E–04	1.5 E–03	1.9 E–04
C-15[b]	0.0	0.0	0.0	0.0
N-13	1.6 E–06	1.6 E–05	1.2 E–06	9.2 E–06
O-15	1.0 E–09	3.8 E–07	7.7 E–10	2.4 E–07
F-18	2.0 E–05	6.6 E–05	1.3 E–05	3.7 E–05
Na-22	1.9 E–01	4.6 E–01	1.3 E–01	2.6 E–01
Na-24	3.3 E–04	8.9 E–04	2.1 E–04	4.9 E–04
P-32	4.3 E–03	7.8 E–04	2.8 E–03	4.7 E–04
S-35	6.0 E–04	7.4 E–05	4.0 E–04	5.1 E–05
Ar-41	2.1 E–05	6.3 E–05	1.2 E–05	3.2 E–05
K-40	1.8 E–01	2.7 E–01	1.2 E–01	1.6 E–01
Ca-41	1.5 E–05	4.1 E–05	9.9 E–06	2.3 E–05
Sc-46	1.8 E–02	4.2 E–02	1.2 E–02	2.4 E–02
Cr-51	1.3 E–04	2.6 E–04	8.5 E–05	1.5 E–04
Mn-54	2.4 E–02	6.4 E–02	1.6 E–02	3.6 E–02
Mn-56	5.3 E–05	1.6 E–04	3.4 E–05	9.0 E–05
Fe-55	3.4 E–04	1.8 E–04	2.2 E–04	1.0 E–04
Fe-59	6.9 E–03	1.3 E–02	4.6 E–03	7.5 E–03
Co-57	4.2 E–03	9.9 E–03	2.8 E–03	5.6 E–03
Co-58	8.0 E–03	1.8 E–02	5.3 E–03	1.0 E–02
Co-60	3.6 E–01	9.5 E–01	2.4 E–01	5.4 E–01
Ni-59	4.5 E–04	9.1 E–04	3.0 E–04	5.1 E–04
Ni-63	3.8 E–04	2.1 E–04	2.5 E–04	1.2 E–04
Ni-65	2.1 E–05	6.6 E–05	1.4 E–05	3.6 E–05
Cu-64	2.3 E–05	6.5 E–05	1.5 E–05	3.6 E–05
Zn-65	3.6 E–02	3.6 E–02	2.4 E–02	2.1 E–02
Zn-69m	6.3 E–05	4.5 E–06	4.0 E–05	2.5 E–06
Zn-69	1.2 E–06	1.7 E–04	7.9 E–07	9.3 E–05
Ga-67	9.0 E–05	1.9 E–04	5.9 E–05	1.1 E–04
As-76	2.1 E–04	5.3 E–04	1.3 E–04	2.9 E–04
Se-79[b]	(Pu-241)	(Pu-241)	(Pu-241)	(Pu-241)
Br-82	4.8 E–04	1.2 E–03	3.1 E–04	6.6 E–04
Br-83	1.6 E–07	5.0 E–07	1.0 E–07	2.8 E–07
Br-84	1.6 E–05	7.0 E–05	1.1 E–05	3.9 E–05
Br-85	8.8 E–10	9.3 E–08	6.6 E–10	5.7 E–08
Kr-83m	3.8 E–09	1.1 E–08	2.2 E–09	5.8 E–09

Table 4-12. 400 Area: Offsite and Onsite MPRs CAP88-PC
Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Kr-85	7.5 E–08	1.9 E–07	4.2 E–08	9.6 E–08
Kr-85m	3.1 E–06	8.4 E–06	1.8 E–06	4.3 E–06
Kr-87	1.3 E–05	4.0 E–05	7.3 E–06	2.1 E–05
Kr-88	4.0 E–05	1.2 E–04	2.3 E–05	5.9 E–05
Kr-89	5.3 E–08	3.9 E–06	3.7 E–08	2.3 E–06
Kr-90[c]	0.0	0.0	0.0	0.0
Rb-86	4.2 E–03	1.4 E–03	2.8 E–03	7.9 E–04
Rb-87	1.4 E–02	1.6 E–03	9.2 E–03	1.1 E–03
Rb-88	3.7 E–06	2.2 E–05	2.6 E–06	1.3 E–05
Rb-89	8.0 E–06	5.3 E–05	5.6 E–06	3.0 E–05
Rb-90	1.8 E–08	2.5 E–06	1.3 E–08	1.6 E–06
Rb-90m	4.0 E–07	1.5 E–05	3.0 E–07	9.0 E–06
Sr-89	2.5 E–03	6.4 E–04	1.7 E–03	3.6 E–04
Sr-90	*1.7 E–01*	*2.7 E–02*	*1.1 E–01*	1.6 E–02
Sr-90+D[d]	1.7 E–01	2.7 E–02	1.1 E–01	1.6 E–02
Sr-91	6.9 E–05	1.9 E–04	4.4 E–05	1.1 E–04
Sr-92	4.7 E–05	1.5 E–04	3.1 E–05	8.0 E–05
Y-90	5.1 E–04	8.3 E–04	3.3 E–04	4.4 E–04
Y-90m	1.6 E–05	5.0 E–05	1.1 E–05	2.7 E–05
Y-91	3.7 E–03	4.4 E–03	2.4 E–03	2.4 E–03
Y-91m	6.7 E–06	2.6 E–05	4.4 E–06	1.4 E–05
Y-92	3.9 E–05	1.2 E–04	2.5 E–05	6.5 E–05
Y-93	9.1 E–05	2.6 E–04	5.8 E–05	1.4 E–04
Zr-93	1.9 E–03	4.2 E–03	1.2 E–03	2.3 E–03
Zr-95	5.7 E–03	1.3 E–02	3.8 E–03	7.3 E–03
Zr-95+D[d]	1.0 E–02	2.5 E–02	6.8 E–03	1.4 E–02
Nb-93m	3.0 E–03	3.7 E–03	2.0 E–03	2.0 E–03
Nb-94	1.2 E+00	3.2 E+00	7.9 E–01	1.8 E+00
Nb-95	7.0 E–03	7.5 E–03	4.7 E–03	4.3 E–03
Nb-95m	4.4 E–04	3.0 E–04	2.9 E–04	1.7 E–04
Nb-97	1.3 E–05	4.4 E–05	8.3 E–06	2.5 E–05
Nb-97m[c]	0.0	3.3 E–09	0.0	2.1 E–09
Mo-93	4.1 E–03	1.1 E–02	2.7 E–03	6.4 E–03
Mo-99	2.6 E–04	5.0 E–04	1.7 E–04	2.7 E–04
Mo-99+D[d]	2.9 E–04	6.0 E–04	1.9 E–04	3.3 E–04
Tc-97	8.4 E–03	1.3 E–02	5.6 E–03	7.4 E–03
Tc-99	3.3 E–02	3.6 E–03	2.2 E–02	2.6 E–03
Tc-99m	6.2 E–06	1.1 E–04	4.0 E–06	6.3 E–05
Tc-101	1.0 E–06	7.2 E–06	7.2 E–07	4.1 E–06
Ru-97	9.8 E–05	2.3 E–04	6.4 E–05	1.3 E–04

Table 4-12. 400 Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Ru-103	2.7 E–03	5.6 E–03	1.8 E–03	3.2 E–03
Ru-103+D[d]	2.7 E–03	5.6 E–03	1.8 E–03	3.2 E–03
Ru-105	4.3 E–05	1.3 E–04	2.8 E–05	6.9 E–05
Ru-106	2.3 E–02	4.2 E–02	1.5 E–02	2.3 E–02
Ru-106+D[d]	3.0 E–02	6.0 E–02	1.9 E–02	3.3 E–02
Rh-103m	1.5 E–07	5.7 E–07	1.0 E–07	3.1 E–07
Rh-105	7.2 E–05	1.3 E–04	4.7 E–05	7.2 E–05
Rh-105m[c]	0.0	0.0	0.0	0.0
Rh-106[c]	0.0	0.0	0.0	0.0
Pd-107	5.5 E–04	1.1 E–03	3.5 E–04	6.1 E–04
Pd-109	5.4 E–05	1.4 E–04	3.4 E–05	7.7 E–05
Ag-109m[c]	0.0	0.0	0.0	0.0
Ag-110[c]	0.0	0.0	0.0	0.0
Ag-110m	7.1 E–02	1.7 E–01	4.7 E–02	9.6 E–02
Ag-111	1.5 E–03	7.2 E–04	9.8 E–04	4.1 E–04
Cd-113[b]	(Pu-241)	(Pu-241)	(Pu-241)	(Pu-241)
Cd-113m[b]	(Pu-241)	(Pu-241)	(Pu-241)	(Pu-241)
Cd-115	2.9 E–04	5.4 E–04	1.9 E–04	2.9 E–04
Cd-115m	5.3 E–03	4.2 E–03	3.4 E–03	2.3 E–03
In-113m	5.7 E–06	1.9 E–05	3.7 E–06	1.0 E–05
In-115	8.8 E–02	9.2 E–02	5.8 E–02	5.0 E–02
In-115m	9.9 E–06	3.0 E–05	6.4 E–06	1.6 E–05
Sn-113	3.3 E–03	1.6 E–03	2.2 E–03	9.2 E–04
Sn-123	7.6 E–05	2.1 E–04	5.0 E–05	1.2 E–04
Sn-125	3.5 E–03	2.2 E–03	2.3 E–03	1.2 E–03
Sn-126	6.9 E–02	1.3 E–01	4.6 E–02	7.3 E–02
Sb-124	1.3 E–02	2.8 E–02	8.4 E–03	1.6 E–02
Sb-125	3.8 E–02	1.0 E–01	2.6 E–02	5.8 E–02
Sb-126	4.8 E–03	9.8 E–03	3.2 E–03	5.5 E–03
Sb-126m	7.7 E–06	4.4 E–05	5.3 E–06	2.5 E–05
Sb-127	6.9 E–04	1.2 E–03	4.5 E–04	6.9 E–04
Te-125m	1.5 E–03	9.9 E–04	1.0 E–03	5.5 E–04
Te-127	1.3 E–05	3.7 E–05	8.4 E–06	2.0 E–05
Te-127m	3.7 E–03	2.2 E–03	2.5 E–03	1.2 E–03
Te-129	3.4 E–06	1.2 E–05	2.2 E–06	6.7 E–06
Te-129m	3.7 E–03	2.5 E–03	2.4 E–03	1.4 E–03
Te-131	3.9 E–06	1.9 E–05	2.7 E–06	1.1 E–05
Te-131m	3.5 E–04	9.2 E–04	2.3 E–04	5.1 E–04
Te-132	6.1 E–04	9.2 E–04	4.0 E–04	5.0 E–04
Te-133	2.3 E–06	1.8 E–05	1.6 E–06	1.0 E–05

Table 4-12. 400 Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Te-133m	2.8 E–05	1.4 E–04	1.8 E–05	5.8 E–05
Te-134	8.7 E–06	3.5 E–05	5.8 E–06	2.0 E–05
I-122	9.9 E–09	9.6 E–07	1.8 E–08	1.3 E–06
I-123	2.1 E–05	1.2 E–04	4.6 E–05	1.7 E–04
I-125	3.7 E–02	3.0 E–03	7.9 E–02	4.8 E–03
I-129	6.2 E–01	2.2 E–01	1.3 E+00	3.2 E–01
I-130	2.3 E–04	1.4 E–03	5.0 E–04	1.9 E–03
I-131	2.0 E–02	5.0 E–03	4.4 E–02	7.2 E–03
I-132	3.9 E–05	2.7 E–04	8.2 E–05	3.7 E–04
I-133	2.4 E–04	7.8 E–04	5.1 E–04	1.1 E–03
I-134	1.4 E–05	1.1 E–04	3.0 E–05	1.6 E–04
I-135	7.9 E–05	5.1 E–04	1.7 E–04	7.0 E–04
Xe-122	1.5 E–06	3.7 E–06	8.2 E–07	1.9 E–06
Xe-123	1.1 E–05	3.1 E–05	6.1 E–06	1.6 E–05
Xe-125	5.3 E–06	1.4 E–05	3.0 E–06	7.0 E–06
Xe-127	5.8 E–06	1.5 E–05	3.3 E–06	7.4 E–06
Xe-131m	2.1 E–07	5.4 E–07	1.2 E–07	2.7 E–07
Xe-133	7.8 E–07	2.0 E–06	4.4 E–07	1.0 E–06
Xe-133m	6.7 E–07	1.7 E–06	3.8 E–07	8.7 E–07
Xe-135	5.1 E–06	1.4 E–05	2.9 E–06	6.9 E–06
Xe-135m	1.6 E–06	9.8 E–06	1.0 E–06	5.3 E–06
Xe-137	1.4 E–08	6.3 E–07	9.7 E–09	3.6 E–07
Xe-138	4.1 E–06	2.7 E–05	2.6 E–06	1.5 E–05
Cs-134	1.5 E–01	2.8 E–01	9.7 E–02	1.6 E–01
Cs-134m	1.8 E–06	5.4 E–06	1.1 E–06	3.0 E–06
Cs-135	6.5 E–03	8.7 E–04	4.3 E–03	5.7 E–04
Cs-136	5.4 E–03	7.8 E–03	3.6 E–03	4.4 E–03
Cs-137	3.9 E–02	5.4 E–03	2.6 E–02	3.5 E–03
Cs-137+D[d]	3.5 E–01	8.5 E–01	2.3 E–01	4.8 E–01
Cs-138	2.2 E–05	9.5 E–05	1.5 E–05	5.3 E–05
Cs-139	4.5 E–07	4.7 E–06	3.3 E–07	2.7 E–06
Ba-133	1.1 E–01	3.0 E–01	7.3 E–02	1.7 E–01
Ba-133m	4.7 E–05	8.6 E–05	3.1 E–05	4.7 E–05
Ba-137m	3.6 E–09	5.5 E–07	2.7 E–09	3.4 E–07
Ba-139	4.6 E–06	1.6 E–05	3.0 E–06	8.7 E–06
Ba-140	1.6 E–03	1.0 E–03	1.0 E–03	5.6 E–04
Ba-140+D[d]	4.0 E–03	7.7 E–03	2.7 E–03	4.3 E–03
Ba-141	3.9 E–06	2.3 E–05	2.7 E–06	1.3 E–05
Ba-142	1.7 E–06	1.5 E–05	1.2 E–06	8.7 E–06
La-140	6.0 E–04	1.5 E–03	3.9 E–04	8.2 E–04

Table 4-12. 400 Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
La-141	1.2 E–06	3.5 E–06	7.7 E–07	2.0 E–06
La-142	5.0 E–05	1.7 E–04	3.3 E–05	9.2 E–05
Ce-141	1.1 E–03	1.5 E–03	7.3 E–04	8.3 E–04
Ce-143	1.8 E–04	4.3 E–04	1.1 E–04	2.4 E–04
Ce-144	1.8 E–02	3.5 E–02	1.2 E–02	1.9 E–02
Ce-144+D[d]	1.9 E–02	3.7 E–02	1.2 E–02	2.0 E–02
Pr-143	8.7 E–04	7.5 E–04	5.7 E–04	4.1 E–04
Pr-144	6.7 E–07	4.1 E–06	4.7 E–07	2.3 E–06
Pr-144m	4.4 E–08	6.5 E–07	3.2 E–08	3.8 E–07
Nd-147	8.5 E–04	1.0 E–03	5.6 E–04	5.6 E–04
Pm-147	1.6 E–03	3.4 E–03	1.0 E–03	1.9 E–03
Pm-148	1.3 E–03	1.8 E–03	8.3 E–04	9.8 E–04
Pm-148m	1.1 E–02	2.5 E–02	7.5 E–03	1.4 E–02
Pm-149	1.6 E–04	3.0 E–04	1.0 E–04	1.6 E–04
Pm-151	4.3 E–05	1.2 E–04	2.8 E–05	6.7 E–05
Sm-147	2.5 E+00	6.6 E+00	1.6 E+00	3.6 E+00
Sm-151	1.1 E–03	2.7 E–03	7.0 E–04	1.4 E–03
Sm-153	1.1 E–04	2.3 E–04	7.4 E–05	1.2 E–04
Eu-152	3.6 E–01	9.6 E–01	2.4 E–01	5.5 E–01
Eu-152m	1.6 E–05	4.5 E–05	1.0 E–05	2.5 E–05
Eu-154	2.9 E–01	7.8 E–01	1.9 E–01	4.4 E–01
Eu-155	1.2 E–02	3.1 E–02	7.7 E–03	1.7 E–02
Eu-156	3.6 E–03	6.1 E–03	2.4 E–03	3.4 E–03
Gd-152[b]	(Pu-239)	(Pu-239)	(Pu-239)	(Pu-239)
Tb-160	9.4 E–03	2.1 E–02	6.2 E–03	1.2 E–02
Ho-166	1.4 E–04	3.3 E–04	8.6 E–05	1.8 E–04
Ho-166m	1.2 E+00	3.2 E+00	7.7 E–01	1.8 E+00
Hf-181	3.6 E–03	7.2 E–03	2.4 E–03	4.0 E–03
W-181	6.6 E–04	1.4 E–03	4.4 E–04	7.7 E–04
W-185	8.8 E–04	1.2 E–04	5.8 E–04	7.5 E–05
W-187	7.7 E–05	2.0 E–04	5.0 E–05	1.1 E–04
Re-187	2.5 E–05	6.1 E–06	1.7 E–05	3.6 E–06
Ir-192	8.0 E–03	1.8 E–02	5.3 E–03	1.0 E–02
Hg-203	5.0 E–03	3.6 E–03	3.3 E–03	2.1 E–03
Tl-207	2.8 E–09	8.3 E–08	2.1 E–09	5.0 E–08
Tl-208	7.4 E–08	6.4 E–06	5.6 E–08	4.0 E–06
Tl-209	4.2 E–09	1.1 E–06	3.2 E–09	7.0 E–07
Pb-209	2.7 E–06	8.2 E–06	1.7 E–06	4.5 E–06
Pb-210	2.1 E+00	1.3 E+00	1.4 E+00	6.9 E–01
Pb-210+D[d]	2.1 E+00	1.3 E+00	1.4 E+00	6.9 E–01

Table 4-12. 400 Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Pb-211	1.3 E–04	5.5 E–04	8.7 E–05	3.1 E–04
Pb-212	5.1 E–03	1.5 E–02	3.3 E–03	7.9 E–03
Pb-214	1.2 E–05	5.6 E–05	8.0 E–06	3.1 E–05
Bi-210	6.6 E–03	1.7 E–02	4.2 E–03	9.3 E–03
Bi-211	2.8 E–09	8.5 E–07	2.1 E–09	5.3 E–07
Bi-212	6.3 E–04	2.3 E–03	4.1 E–04	1.3 E–03
Bi-213	2.1 E–05	8.3 E–05	1.4 E–05	4.6 E–05
Bi-214	1.1 E–05	6.1 E–05	7.6 E–06	3.4 E–05
Po-210	7.7 E–01	7.8 E–01	5.0 E–01	4.2 E–01
Po-211[c]	0.0	0.0	0.0	0.0
Po-212[c]	0.0	0.0	0.0	0.0
Po-213[c]	0.0	0.0	0.0	0.0
Po-214[c]	0.0	0.0	0.0	0.0
Po-215[c]	0.0	0.0	0.0	0.0
Po-216[c]	0.0	0.0	0.0	0.0
Po-218	1.7 E–09	1.5 E–07	1.3 E–09	9.1 E–08
At-217[c]	0.0	0.0	0.0	0.0
Rn-219[e]	3.8 E–03	2.0 E–05	2.5 E–03	1.2 E–03
Rn-220[e]	7.1 E–04	2.4 E–04	4.6 E–06	1.1 E–05
Rn-222	9.5 E–05	2.4 E–03	5.4 E–05	1.2 E–04
Fr-221	1.3 E–06	3.8 E–05	9.8 E–07	2.3 E–05
Fr-223	2.4 E–05	1.3 E–04	1.6 E–05	7.1 E–05
Ra-223	3.5 E–01	7.3 E–01	2.3 E–01	4.0 E–01
Ra-224	1.3 E–01	3.1 E–01	8.1 E–02	1.7 E–01
Ra-225	2.2 E–01	3.7 E–01	1.4 E–01	2.0 E–01
Ra-226	6.7 E–01	8.1 E–01	4.4 E–01	4.4 E–01
Ra-228	2.8 E–01	2.2 E–01	1.8 E–01	1.2 E–01
Ac-225	2.1 E–01	5.4 E–01	1.3 E–01	2.9 E–01
Ac-227	2.2 E+01	5.6 E+01	1.4 E+01	3.0 E+01
Ac-228	2.5 E–03	7.4 E–03	1.6 E–03	4.0 E–03
Th-227	3.8 E–01	1.0 E+00	2.4 E–01	5.6 E–01
Th-228	8.2 E+00	2.2 E+01	5.2 E+00	1.2 E+01
Th-229	2.3 E+01	6.2 E+01	1.5 E+01	3.4 E+01
Th-230	8.2 E+00	2.2 E+01	5.2 E+00	1.2 E+01
Th-231	3.6 E–05	9.1 E–05	2.3 E–05	4.9 E–05
Th-232	1.2 E+01	3.2 E+01	7.4 E+00	1.7 E+01
Th-232+D[d]	1.4 E+01	3.7 E+01	8.7 E+00	2.0 E+01
Th-234	3.5 E–03	3.3 E–03	2.3 E–03	1.8 E–03
Pa-231	1.7 E+01	4.3 E+01	1.1 E+01	2.3 E+01
Pa-233	1.5 E–03	2.4 E–03	1.0 E–03	1.3 E–03

Table 4-12. 400 Area: Offsite and Onsite MPRs CAP88-PC Dose-per-Unit Release Factors (mrem/Ci) by Effective Release Height.

Nuclide	Effective release height <40 m		Effective release height ≥40 m	
	Offsite MPR	Onsite MPR[a]	Offsite MPR	Onsite MPR[a]
Pa-234	1.1 E–04	3.2 E–04	7.2 E–05	1.8 E–04
Pa-234m[c]	0.0	2.8 E–10	0.0	1.7 E–10
U-232	1.6 E+01	4.2 E+01	1.0 E+01	2.3 E+01
U-233	4.6 E+00	1.2 E+01	2.9 E+00	6.3 E+00
U-234	4.5 E+00	1.2 E+01	2.9 E+00	6.3 E+00
U-235	4.3 E+00	1.1 E+01	2.8 E+00	6.0 E+00
U-236	4.3 E+00	1.1 E+01	2.7 E+00	5.9 E+00
U-237	4.5 E–04	6.0 E–04	3.0 E–04	3.3 E–04
U-238	4.1 E+00	1.0 E+01	2.6 E+00	5.6 E+00
U-240	7.9 E–05	2.2 E–04	5.0 E–05	1.2 E–04
Np-237	1.7 E+01	4.3 E+01	1.1 E+01	2.3 E+01
Np-238	1.2 E–03	3.1 E–03	7.5 E–04	1.7 E–03
Np-239	1.8 E–04	3.5 E–04	1.2 E–04	1.9 E–04
Np-240	1.8 E–05	6.6 E–05	1.2 E–05	3.7 E–05
Np-240m	2.7 E–07	3.9 E–06	2.0 E–07	2.3 E–06
Pu-236	3.0 E+00	7.8 E+00	1.9 E+00	4.2 E+00
Pu-238	1.1 E+01	2.8 E+01	7.1 E+00	1.5 E+01
Pu-239	1.2 E+01	3.0 E+01	7.7 E+00	1.6 E+01
Pu-240	1.2 E+01	3.0 E+01	7.7 E+00	1.6 E+01
Pu-241	1.9 E–01	4.6 E–01	1.2 E–01	2.5 E–01
Pu-241+D[d]	1.9 E–01	4.6 E–01	1.2 E–01	2.5 E–01
Pu-242	1.2 E+01	2.9 E+01	7.3 E+00	1.5 E+01
Pu-243	7.4 E–06	2.2 E–05	4.7 E–06	1.2 E–05
Pu-244	1.1 E+01	2.8 E+01	7.3 E+00	1.5 E+01
Am-241	1.9 E+01	4.8 E+01	1.2 E+01	2.6 E+01
Am-242	1.9 E–03	5.2 E–03	1.2 E–03	2.8 E–03
Am-242m	1.8 E+01	4.6 E+01	1.1 E+01	2.5 E+01
Am-243	1.9 E+01	4.8 E+01	1.2 E+01	2.6 E+01
Cm-242	6.0 E–01	1.6 E+00	3.8 E–01	8.5 E–01
Cm-243	1.3 E+01	3.2 E+01	7.9 E+00	1.7 E+01
Cm-244	9.8 E+00	2.5 E+01	6.2 E+00	1.4 E+01
Cm-245	1.9 E+01	4.9 E+01	1.2 E+01	2.7 E+01
Cm-246	1.9 E+01	4.9 E+01	1.2 E+01	2.6 E+01
Cm-247	1.8 E+01	4.5 E+01	1.1 E+01	2.5 E+01
Cm-248	7.0 E+01	1.8 E+02	4.4 E+01	9.7 E+01
Cf-252	5.2 E+00	1.4 E+01	3.3 E+00	7.3 E+00

[a] Worker assumed to work the maximum possible 8,766 hours in a year.
[b] Dose factors not included in the CAP88-PC library; thus, substituting the dose factors of the radionuclides in parentheses is recommended.
[c] Factor is ≤1.0 E–11, or effectively zero, considering also the scarcity and short half-life of the nuclide.
[d] "+D" indicates factors from in-grown progeny are also included.
[e] Short-lived Rn isotopes modeled on dose from their longer-lived progeny. Yet, 1 Ci of Rn does not equal 1Ci of Pb. Each Ci of Rn-219 released generates 0.0018 Ci of Pb-210, and each Ci of Rn-220, 0.0014 Ci of Pb-212. Dose based on Pb progeny multiplied by appropriate equilibrium factor (HNF-3602 1999).

5.0 QUALITY ASSURANCE: PTE DETERMINATION AND PEER REVIEW

This section discusses quality assurance (QA) aspects of determining PTEs, as well as providing an example format for documenting the recommended peer review of any PTE determination.

A PTE determination must be sufficiently detailed in its documentation to withstand not only a thorough peer review but also an assessment by an outside inspector or auditor. Performing a PTE determination, which includes the peer-review, should include involvement of the equivalent of a facility design authority, a facility environmental compliance officer, and a regulatory subject matter expert.

Hanford Site prime contractors must follow the quality assurance criteria of 10 CFR 830.120, among which are general requirements pertinent to accurately determining PTE values. In addition to the foundational QA requirement (see §830.121) that a DOE contractor is to have a QA program and also a management program (see §830.122(a)) to implement QA requirements, several other criteria of 10 CFR 830.120 apply to ensuring the accuracy of PTE determinations (note: whereas the criteria wording may not specifically address PTEs, the principles inherent in them apply to the accurate determination of PTEs by organizational processes that assure, or safeguard, that accuracy):

- **§830.122(b) Criterion 2 — Management/Personnel Training and Qualification.**
  (1) Train and qualify personnel to be capable of performing their assigned work.

- **§830.122(d) Criterion 4 — Management/Documents and Records.**
  (1) Prepare, review, approve, issue, use, and revise documents to prescribe processes, specify requirements, or establish design.

- **§830.122(f) Criterion 6 — Performance/Design.**
  (1) Design items and processes using sound engineering/scientific principles and appropriate standards.
  (4) Verify and validate the adequacy of design products using individuals or groups other than those who performed the work.

Furthermore, as applicable, DOE contractors at the Hanford Site are subject to the regulations of WAC 246-247, *Radiation Protection — Air Emissions*. With respect to contractor QA programs, the following applies from WAC 246-247-075(6): "Licensed facilities shall conduct a quality assurance program . . . [that] . . . shall be compatible with applicable national standards such as ANSI/ASME NQA-1-1988, ANSI/ASME NQA-2-1986, QA/R-2, and QA/R-5." Each contractor is accountable for demonstrating compliance with this WAC regulation.

Peer-reviewing PTE determinations is an important QA step to ensuring that the PTE value has been calculated in a technically sound and defensible manner.

An example of a format for documenting the peer review of a PTE determination follows. It may be modified to suit the user's preferences. Regardless of the contractor's choice of a peer-review style, keep in mind that 1) the person or people performing the review need to be qualified and 2) that their documented reviews sufficiently address the essential components of the PTE determination — i.e., the approved PTE method used, calculational steps, radionuclide inventory assumptions and/or measurements, and, as applicable, facility pollution abatement equipment in use for the relevant emission source.

POTENTIAL-TO-EMIT PEER-REVIEW CHECKLIST

Source of PTE Factors: *Calculating Potential-to-Emit Radiological Releases and Doses* (DOE/RL-2006-29)

PTE Application: ______________________________
Description of application (e.g., NOC or stack determination)

Yes	No	NA	
[ ]	[ ]	[ ]	Assumptions and/or factors explicitly stated and supported, which include approved PTE method used (or description of alternate method, if applicable), radionuclide inventory, and, as applicable, pollution abatement equipment in use.
[ ]	[ ]	[ ]	Decontamination factors, airborne dose factors, releases fractions, and/or similar emission reduction factors accurately used in calculations and technically justified.
[ ]	[ ]	[ ]	Applicable pollution abatement equipment entirely accounted for in calculations.
[ ]	[ ]	[ ]	Appropriate dose-per-unit-release factors and/or facility-specific calculations were used.
[ ]	[ ]	[ ]	Sources of data used in calculations identified.
[ ]	[ ]	[ ]	Mathematical formulas accurate.
[ ]	[ ]	[ ]	Hand-calculations (including spreadsheets) checked for errors.
[ ]	[ ]	[ ]	Sufficient documentation is available to support all essential aspects of the PTE determination.
[ ]	[ ]		**Document approved by:** ______________________________ Name, printed

Approval Signature: ______________________________ Date: ______________

This page intentionally left blank.

6.0 DOSE FACTOR PEER REVIEW CHECKLIST

This section provides the peer-review documentation consistent with recommendations in *Recommended Environmental Dose Calculation Methods and Hanford-Specific Parameters* (PNL-3777, Rev. 2).

PEER-REVIEW CHECKLIST

Document Reviewed: *Calculating Potential-to-Emit Radiological Releases and Doses* (DOE/RL-2006-29)

Scope of Review: Use of CAP88-PC and GENII to Generate Dose-per-Unit Release Factors

Yes	No	NA	
[✓]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[✓]	[ ]	[ ]	Computer codes and data files identified in document.
[✓]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[✓]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[✓]	[ ]	[ ]	Mathematical derivations checked, including dimensional consistency of results.
[✓]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[ ]	[ ]	[✓]	Hand-calculations (including spreadsheets) checked for errors.
[✓]	[ ]	[ ]	Software input correct and consistent with descriptions in the document.
[✓]	[ ]	[ ]	Software output consistent with input and with results reported in the document.
[ ]	[ ]	[✓]	Safety margins consistent with good engineering practices.

[✓] [ ] **Document approved by: Kathleen Rhoads**

Signature: *Kathleen Rhoads* Date: *4/13/06*

TECHNICAL REVIEW CHECKLIST
for Radioactive and Nonradioactive Environmental Releases

Document Reviewed: *Calculating Potential-to-Emit Radiological Releases and Doses* (DOE/RL-2006-29)

Scope of Review: Use of CAP88-PC and GENII to Generate Dose-per-Unit Release Factors

YES	NO*	N/A	
[✓]	[ ]	[ ]	1. A detailed technical review and approval of the environmental transport and dose calculation portion of the analysis has been performed and documented.
[✓]	[ ]	[ ]	2. Detailed technical reviews and approvals of scenario and release determinations have been performed and documented.
[✓]	[ ]	[ ]	3. Approved codes were used.
[✓]	[ ]	[ ]	4. Receptor locations were selected according to approved recommendations.
[✓]	[ ]	[ ]	5. All applicable environmental pathways and code options were included and are appropriate for the calculations.
[✓]	[ ]	[ ]	6. Hanford Site data were used.
[ ]	[ ]	[✓]	7. Model adjustments external to the computer program were justified and performed correctly.
[✓]	[ ]	[ ]	8. The analysis is consistent with approved recommendations.
[ ]	[ ]	[✓]	9. Supporting notes, calculations, comments, comment resolutions, or other information is attached. (Use the "Page 1 of X" page numbering format and sign and date each added page.)
[✓]	[ ]		10. **Dose Calculations Approved.**

* All "NO" responses must be explained and the use of nonstandard methods justified.

Reviewer Name: **Kathleen Rhoads**

Kathleen Rhoads
Reviewer Signature

4/13/06
Date

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

This page intentionally left blank.

7.0 REFERENCES

ASTM E 29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*, American Society for Testing and Materials, Annual Book of Standards, Volume 14.02, Designation E 29.

Barnett, J. M., and W. E. Davis, 1996, "Six Methods to Assess Potential Radioactive Air Emissions from a Stack," *Health Physics*, Vol. 71, No. 5, November, pp. 773-778.

Chaki, S., and B. Parks. 2000. *CAP88-PC Version 2.0, Updated User's Guide.* EPA 402-R-00-004. Office of Radiation Programs, U.S. Environmental Protection Agency, Las Vegas, Nevada.

DOE/RL-2005-06. 2005. *Radionuclide Air Emissions Report for the Hanford Site, Calendar Year 2004*, U.S. Department of Energy-Richland Operations, Richland, Washington.

DOE/TIC-11026, 1981, *Radioactive Decay Data Tables*, D. C. Kocher, Oak Ridge National Laboratory.

ERDA 76-21, *Nuclear Air Cleaning Handbook*, C. A. Burchsted, A. B. Fuller, and J. E. Kahn, Oak Ridge National Laboratory.

HNF-3602. 1999. *Calculating Potential to Emit Releases and Doses for FEMPs and NOCs.* Fluor Daniel Hanford, Richland, Washington.

HNF-3602, Rev. 1. 2002. *Calculating Potential to Emit Releases and Doses for FEMPs and NOCs.* Fluor Hanford, Richland, Washington.

PNL-3509. 1981. *Standardized Input for Hanford Environmental Impact Statements – Part 1*, Pacific Northwest Laboratory, Richland, Washington.

PNL-3777, Rev. 0. 1982. *Hanford Dose Overview Program: Standardized Methods and Data for Hanford Environmental Dose Calculations*, Pacific Northwest Laboratory, Richland, Washington.

PNL-3777, Rev. 1. 1984. *Hanford Dose Overview Program: Standardized Methods and Data for Hanford Environmental Dose Calculations*, Pacific Northwest Laboratory, Richland, Washington.

PNL-3777, Rev. 2. 1993. *Recommended Environmental Dose Calculation Methods and Hanford-Specific Parameters*, Pacific Northwest Laboratory, Richland, Washington.

PNL-6584. 1988. *GENII — The Hanford Environmental Radiation Dosimetry Software System*, Vol. 1-3. Pacific Northwest Laboratory, Richland, Washington.

PNNL-14428. 2004. *Hanford Area 2000 Population.* Pacific Northwest National Laboratory, Richland, Washington.

PNNL-15160. 2005. *Hanford Site Climatological Summary, 2004 with Historical Data.* Pacific Northwest National Laboratory, Richland, Washington.

PNNL-15222. 2005. *Hanford Site Environmental Report for Calendar Year 2004.* Pacific Northwest National Laboratory, Richland, Washington.

WHC-SD-ER-TP-004, *Measurement of Gamma Activity from HEPA Filters*, Rev. 1, J. M. Barnett, April, 1993.

DISTRIBUTION

U.S. Environmental Protection Agency	**MSIN**
Region 10	
1200 Sixth Avenue	
Seattle, WA 98101	
J. KenKnight	OAQ-107
R. W. Poeton	OEA-095
D. Zhen	OAQ-107
K Watt	OAQ-107
Washington State Department of Health	
Air Emissions and Defense Waste Section	
Division of Radiation Protection	
7171 Cleanwater Lane, Bldg. 5	
Bldg. 5 Airdustrial	
Olympia, WA 98504-7837	
A. W. Conklin	
J. E. Erickson	
Washington State Department of Health	
Division of Radiation Protection	
Air Emissions and Defense Waste	
309 Bradley Blvd., Suite 201	
Richland, WA 99352	
F. T. Adams	
J. R. Culmer	
R. B. Evans	
E. W. Fordham	
T. P. Frazier	
G. L. Laws	
P. J. Martell	
J. W. Schmidt	
U.S. Department of Energy, Office of River Protection	
D. W. Bowser	H6-60
G. M. Neath	H6-60
U.S. Department of Energy, Richland Operations Office	
J. B. Hebdon	A5-15
T. W. Ferns	A5-15
M. F. Jarvis	A5-15
DOE-RL Public Reading Room	H2-53

DISTRIBUTION (cont)

CH2M HILL Hanford Group, Inc.	**MSIN**
L. E. Borneman	T6-03
J. D. Guberski	R1-51
J. J. Luke	H6-03
P. C. Miller	R1-51
L. L. Penn	H6-03
Fluor Hanford, Inc.	
B. M. Barnes	T4-09
J. A. Bates	H8-12
H. C. Boynton	T4-52
L. P. Diediker (15)	H8-13
B. J. Dixon	R3-32
D. L. Dyekman	H8-13
M. E. Eby	N2-57
R. H. Engelmann	H8-12
L. L. Fritz	H8-12
M. F. Hackworth	T4-55
N. A. Homan	H8-13
J. E. Hyatt	H8-40
M. T. Jansky	H8-40
R. E. Johnson	H8-13
G. J. LeBaron	S2-42
P. W. Martin	T3-28
J. K. Perry	R3-32
K. A. Peterson	H3-12
D. J. Rokkan (30)	H8-13
D. G. Saueressig	T4-04
D. E. Schoepflin	T3-28
F. M. Simmons	H8-40
R. W. Szelmeczka	S5-31
G. J. Warwick	S3-30
D. J. Watson	X3-79
J. A. Winterhalder	E6-35
Lockheed Martin Services, Inc.	
Central Files	B1-07
DPC	H6-08
EDMC (2)	H6-08

DISTRIBUTION (cont)

Pacific Northwest National Laboratory	MSIN
R. L. Aaberg	K3-54
B. G. Anderson	J2-25
E. J. Antonio	K3-54
M. Y. Ballinger	BSRC
B. C. Barfuss	J2-25
J. M. Barnett (3)	J2-25
R. L. Dirkes	K6-75
B. G. Fritz	K6-75
R. W. Hanf, Jr.	K6-75
A. K. Ikenberry	P7-79
T. M. Poston	K6-75
K. Rhoads (2)	K3-54
S. F. Snyder	K3-54
L. H. Staven (2)	K3-54
PNNL Reference Library	P8-55
Washington Closure Hanford, LLC	
J. W. Donnelly	X0-17
J. W. Golden, Jr.	L1-04
D. L. Johnson	L1-09
R. R. Nielson	X5-50
J. G. Woolard	H9-03

This page intentionally left blank.

Task# DOE-ESD-C-2006-0098

E-STARS[TM] Report
Task Detail Report
05/16/2006 0614

TASK INFORMATION			
Task#	DOE-ESD-C-2006-0098		
Subject	RESPONSE TO HANFORD SITEWIDE ACTIONS IN NOTICE OF VIOLATION AND COMPLIANCE ORDER ON EMISSION UNIT 296-S-21 AT THE 222-S LABORATORY		
Parent Task#		**Status**	Open
Reference		**Due**	05/17/2006
Originator	Forgione, Elizabeth J	**Priority**	High
Originator Phone	(509) 376-7125	**Category**	None
Origination Date	04/19/2006 0838	**Generic1**	
Remote Task#		**Generic2**	
Deliverable	None	**Generic3**	
Class	Long Term	**View Permissions**	Normal
Instructions	bcc w/ encl: ESD RDG File ESD OFF File T. L. Aldridge, PNSO-OD D.W. Bowser, ORP-ED R. F. Christensen, PNSO-OD D. T. Evans, AMRC J. B. Hebdon, ESD E. V. Hiskes, OCC M. F. Jarvis, ESD C. K. Kasch, SED M. K. Marvin, OCC F. M. Roddy, AMCP G. A. Vazquez, DOE-EH-41 B. D. Williamson, OCC W. W. Woolery, AMCP Record Note: The State of Washington Department of Health issued a Notice of Violation (NOV), dated November 17, 2005, to the DOE for the 222-S Laboratory for having incorrectly calculated the potential-to-emit (PTE) for its 296-S-21 Stack. Order No.3 of the NOV requires that DOE Contractors assess their quality assurance programs to determine whether or not adequate processes and organizational safeguards exists to ensure that PTE determinations are accurately done. DOE and FHI discussed the scope of these deliverables with WDOH to make sure they met the intent of Order No. 3 of the NOV before they were prepared. The remaining orders in the NOV are site-specific actions and are being closed by ORP. This letter of transmittal sends the completed Contractor assessments, and a revised sitewide dose factor document that now includes a section on quality assurances, as well as section on peer reviewing of PTE calculations. Submittal of this letter and its enclosures will close ESTARS Manager's Action LMSI-RLCC-ESD-2006-0019.2, which is due to WDOH on or before Wednesday, May 17, 2006.		

RECEIVED
MAY 16 2006
DOE-RL/RLCC

ROUTING LISTS

1	Final List	Active
	• Weis, Michael J - Approve - Awaiting Response *Instructions:* MW 5/16/06	
	• Klein, Keith A - Approve - Awaiting Response	

Task# DOE-ESD-C-2006-0098

	Instructions:	
2	List 2	Inactive
	• Shoop, Doug S - Approve - Approved with comments - 05/15/2006 1444 *Instructions:*	
3	List 1	Inactive
	• Jarvis, Mary F - Approve - Approved - 05/01/2006 1325 *Instructions:*	
	• Bowser, Dennis W - Approve - Approved - 04/20/2006 1441 *Instructions:*	
	• Hebdon, Joel B - Approve - Approved with comments - 04/20/2006 0910 *Instructions:*	
	• Hollowell, Betty L - Approve - Approved with comments - 04/24/2006 0653 *Instructions:*	
	• Schepens, Roy J - Approve - Withdrawn - 05/10/2006 1450 *Instructions:*	

ATTACHMENTS

Attachments	1. 06-ESD-0098 222s lab nov.doc 2. 06-ESD-0098 DOE Contractor 222-S NOV QA Assessments.pdf 3. 06-ESD-0098 DOE-RL-2006-29 draft 4-17-06.doc 4. 06-ESD-0098 NOV 222-S Nov 17 2005.tif

COLLABORATION

COMMENTS

Poster	Hebdon, Joel B (Hebdon, Joel B) - 04/20/2006 0904
	Approve
	Transmittal should be under a Shoop signature. Contact should be Hebdon.
Poster	Forgione, Elizabeth J (Forgione, Elizabeth J) - 04/20/2006 1004
	Hebdon, Joel B -- Approve
	Letter and route list changed. ejf
Poster	Hollowell, Betty L (Corbin, Peggy A) - 04/24/2006 0604
	Approve
	Approve. Ed Hiskes reviewed and concurred. BDW for BLH. 4/21/06
Poster	Shoop, Doug S (Goldsmith, Julie R) - 05/15/2006 0205
	Approve
	concurrence w/changes per DS Shoop, 5/13/06

TASK DUE DATE HISTORY

Modified	04/19/2006 0844 - Forgione, Elizabeth J (Forgione, Elizabeth J)	**New Due Date**	05/17/2006 1700

SUB TASK HISTORY

Subtask#	DOE-ESD-C-2006-0098.1
Subject	RESPONSE TO HANFORD SITEWIDE ACTIONS IN NOTICE OF VIOLATION AND COMPLIANCE ORDER ON

Task# DOE-ESD-C-2006-0098		
	EMISSION UNIT 296-S-21 AT THE 222-S LABORATORY	
Originator	Hollowell, Betty L	
	Routing List	*No Active Routing List*

-- end of report --