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TAD Source Term and Dose Rate Evaluation

Prepared for:
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TABLES

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ACRONYMS

BSC	Bechtel SAIC Company, LLC
BWR	boiling water reactor
B&W	The Babcock & Wilcox Company
CE	Combustion Engineering
CFR	Code of Federal Regulations
CRWMS	Civilian Radioactive Waste Management System
CSNF	commercial spent nuclear fuel
DIRS	Document Input Reference System
DOE	U.S. Department of Energy
HLW	high-level (radioactive) waste
ISG	Interim Staff Guidance
NRC	U.S. Nuclear Regulatory Commission
PCSA	preclosure safety analysis
PDC	project design criteria
PWR	pressurized water reactor
SNF	spent nuclear fuel
SS	stainless steel
TAD	transport, aging, and disposal canister
WP	waste package

UNITS OF MEASURE

cm	centimeter
GWd/MTU	gigawatt days per metric ton uranium
h or hr	hour
in.	inch
kW	kilowatt
m	meter
mrem	millirem
rem	Roentgen equivalent man
yr	year

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1. PURPOSE AND SCOPE

The purpose of this report is to evaluate the radiation source term specification and associated dose rates for the transport, aging and disposal canister (TAD) in support of the repository facility design. The TAD applies to commercial spent nuclear fuel (CSNF) only, including pressurized-water-reactor (PWR) fuel and boiling-water-reactor (BWR) fuel.

The primary focus is on the source term for the shielding design, which requires more conservatism for assurance of adequacy of permanent shielding than for other applications such as worker dose assessments and offsite dose calculations for normal operations. The latter applications use the average source term specification, which is acceptable for demonstration of regulatory compliance on an annual basis.

The specific work scope includes the following items:

- Evaluate the project and regulatory requirements, criteria and/or guidance related to the content in the TAD
- Review and evaluate the existing technical products that are applicable to this work regarding the source term and resultant dose rates
- Establish the source term specification for the TAD, including the specification for the TAD containing PWR fuel as well as for the TAD containing BWR fuel
- Develop a technical report in accordance with PA-PRO-0313 [DIRS 177335] to document the results, conclusions and recommendations.

The information contained in this document was developed by the Nuclear and Radiological group and is intended solely for the use of the Engineering organization in its work regarding the repository facility shielding design. Yucca Mountain Project personnel from the Nuclear and Radiological group should be consulted before the use of the information for purposes other than those stated herein or use by individuals other than authorized personnel in the Engineering organization.

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2. QUALITY ASSURANCE

The source term specification supports the shielding design of the repository facilities, which is part of the preclosure safety analysis (PCSA). Therefore, this activity is subject to the requirements of the *Quality Assurance Requirements and Description* for related activities on performance of the PCSA (DOE 2006 [DIRS 176927], Section 2.2.2, Item C.1).

Performance of the work scope as described in Section 1, and development of the associated technical product conform to procedure PA-PRO-0313, *Technical Reports* [DIRS 177335].

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3. EVALUATION METHOD

The following approach is used to perform the evaluation:

- Identify the assumptions and software (if any) used in this evaluation (Section 4).
- Review and identify the requirements, design criteria and guidance related to the content in the TAD from the following sources (Section 5):
    - Project requirements and criteria (Section 5.1)
    - Regulatory requirements and guidance (Section 5.2)
    - Interface requirements (Section 5.3)
- Review and identify technical inputs from the existing project documents required to support the evaluation, including (Section 6):
    - Source term specification for PWR spent nuclear fuel (SNF) (Section 6.1)
    - Source term specification for BWR SNF (Section 6.2)
    - Source term specification for waste package (WP) (Section 6.3)
    - Source term specification for 21-PWR site-specific canister (Section 6.4)
    - Source term specification for aging casks or overpacks (Section 6.5)
    - Surface dose rates for 21-PWR WP (Section 6.6)
    - Surface dose rates for 44-BWR WP (Section 6.7)
    - Surface dose rates for naval long WP (Section 6.8)
    - Dose contribution by fuel assembly in 21-PWR WP (Section 6.9)
    - Canister surface dose rates (Section 6.10)
    - TAD shell material and thickness (Section 6.11)
- Perform the evaluation (Section 7) against the requirements, criteria and guidance provided in Section 5 using the assumptions in Section 4 and technical inputs in Section 6, including:
    - TAD source term variations (Section 7.1)
    - Effect of TAD on WP dose rates (Section 7.2)
    - Sensitivity of shielding to TAD source terms (Section 7.3)
    - Applicability of existing shielding calculations to TAD (Section 7.4)
    - Meeting project requirements and criteria (Section 7.5)
    - Meeting regulatory requirements and guidance (Section 7.6)
    - Impact of interface requirements (Section 7.7)
    - Establishing TAD source term specification (Section 7.8)
- Summarize key conclusions (Section 8.1), and make appropriate recommendations (Section 8.2) on the TAD source term and associated shielding calculations.

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4. ASSUMPTIONS AND SOFTWARE

4.1 ASSUMPTIONS

No assumptions are used in this evaluation.

4.2 SOFTWARE

No computer software is used in this evaluation.

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5. REQUIREMENTS, CRITERIA AND GUIDANCE

This section summarizes the requirements, criteria and guidance, which are relevant to this evaluation, including:

- Project requirements and criteria (Section 5.1)
- Regulatory requirements and guidance (Section 5.2)
- Interface requirements (Section 5.3)

5.1 PROJECT REQUIREMENTS AND CRITERIA

This section identifies and lists the project requirements and criteria related to the TAD content and its characteristics from the following controlled sources:

- *Transport, Aging and Disposal Canister System Basis of Specification Requirements Document* (BSC 2006 [DIRS 177442])
- *Project Design Criteria (PDC) Document* (BSC 2005 [DIRS 174942])

5.1.1 TAD Requirements

The TAD system basis-of-specification requirements document provides the specification on the content and its characteristics as follows:

1. <u>Content</u>

   Requirement Statement: The capacity of the TAD shall be either 21 spent fuel assemblies from a PWR or 44 spent fuel assemblies from a BWR (BSC 2006 [DIRS 177442], Section 3.8.1).

   Applicability: This requirement applies to this evaluation, as the TAD capacity affects the package source term and its resultant dose rate.

   Usage: This requirement is used in Sections 7.1 and 7.5.1 to provide the TAD capacity.

2. <u>Thermal Power Range</u>

   Requirement Statement: The thermal boundary conditions and assumptions to be used to calculate fuel pin temperatures are valid for TAD thermal power values ranging from 11.8 kW to 25 kW (BSC 2006 [DIRS 177442], Section 3.7.1).

   Applicability: This requirement applies to this evaluation for comparison of the thermal output between the shielding and thermal source terms. Note that all fuel assemblies in the TAD contribute additively to the package thermal output. However, a single fuel assembly can contribute substantially to the dose rate and dictate the shielding requirement (see Section 6.9).

Usage: This requirement is used in Sections 7.1.1, 7.1.2, 7.5.1 and 7.5.2 to provide the TAD thermal output.

3. Maximum PWR Fuel Specification

   Requirement Statement: The TAD for PWR fuel shall accept fuel assemblies with the characteristics bounded by the maximum source specification of 5% initial enrichment, 80 GWd/MTU burnup, and 5 years out-of-reactor cooling time (BSC 2006 [DIRS 177442], Section 3.6.5).

   Applicability: This requirement applies to this evaluation, as the bounding fuel parameters determine the maximum source term.

   Usage: This requirement is used in Sections 7.1.1, 7.5.1 and 7.5.2 to provide the bounding PWR fuel characteristics.

4. Maximum BWR Fuel Specification

   Requirement Statement: The TAD for BWR fuel shall accept fuel assemblies with the characteristics bounded by the maximum source specification of 5% initial enrichment, 75 GWd/MTU burnup, and 5 years out-of-reactor cooling time (BSC 2006 [DIRS 177442], Section 3.6.6).

   Applicability: This requirement applies to this evaluation, as the bounding fuel parameters determine the maximum source term.

   Usage: This requirement is used in Sections 7.1.2, 7.5.1 and 7.5.2 to provide the bounding BWR fuel characteristics.

5. TAD Shield Plug

   Requirement Statement: The TAD shall provide axial shielding (i.e., shield plug(s)) to allow limited personnel access during closure and handling operations. The combined neutron and gamma dose rate at the top surface of the loaded canister shall not exceed 80 mrem/hr (BSC 2006 [DIRS 177442], Section 3.6.4).

   Applicability: This requirement applies to this evaluation, as the TAD shield plug provides reduced facility shielding requirements in the axial direction such as concrete ceilings, making the existing shielding calculations for the non-TAD-based design conservative.

   Usage: This requirement is used in Sections 7.4.1, 7.4.3 and 7.4.4 to determine the applicability of the existing non-TAD-based shielding calculations to the TAD-based design.

5.1.2 Project Design Criteria

The *Project Design Criteria Document* provides the shielding source term criteria (BSC 2005 [DIRS 174942], Section 4.9.1.4). The criteria statement from the PDC, its applicability and usage are described below:

> *Criteria Statement*: Shielding source terms for the surface and subsurface facility design shall be based on the limiting waste form as well as the limiting waste package type.
>
> Design basis and maximum source terms shall be established to provide sufficient and bounding coverage, respectively, of the historical and projected fuel inventory for normal operations and Category 1 event sequences. The design basis source term shall cover a minimum of 95 percent of the total inventory, with provisions made available to accommodate the remaining 5 percent. The maximum source term shall represent the bounding fuel assembly in the entire inventory to be received at the repository. Use of the design basis or maximum source term shall be justified on a case-by-case basis.
>
> Minimum initial enrichment shall be established in accordance with "Interim Staff Guidance - 6. Establishing Minimum Initial Enrichment for the Bounding Design Basis Fuel Assembly(s)" (NRC 2001 [DIRS 160595]) for the selected fuel assembly used in determining the source term because lower enriched fuel irradiated to the same burnup as higher enriched fuel produces a higher source term (BSC 2005 [DIRS 174942], Section 4.9.1.4).
>
> *Applicability*: This criterion applies to this evaluation to ensure sufficient coverage of the CSNF population for meeting the shielding source term criterion.
>
> *Usage*: This criterion is used in Section 7.5.2 for compliance demonstration.

5.2 REGULATORY REQUIREMENTS AND GUIDANCE

The TAD design should comply with 10 CFR 71 [DIRS 176575] for transportation, and 10 CFR 63 [DIRS 176544] for aging and disposal at the repository. If TADs are deployed for storage at the reactor sites, additional compliance with 10 CFR 72 [DIRS 176577] needs to be included by the vendors.

This evaluation addresses compliance with 10 CFR 63 [DIRS 176544] and its associated regulatory guidance, namely, NUREG-1804 (NRC 2003 [DIRS 163274]) for repository applications only.

The following requirements are related to the TAD contents and required description to provide the associated information on the source term.

5.2.1 10 CFR 63

The 10 CFR 63 [DIRS 176544] requirements applicable to the TAD content include:

- Content of application (10 CFR 63.21)

- License specification (10 CFR 63.43)

1. 10 CFR 63.21

   Regulation Text: The Safety Analysis Report must include [10 CFR 63.21(c)]:

   > A description of the kind, amount, and specifications of the radioactive material proposed to be received and possessed at the geologic repository operations area at the Yucca Mountain site [10 CFR 63.21(c)(4)].

   Applicability: This requirement applies to this evaluation, as the TAD contains radioactive material (i.e., CSNF from PWR or BWR) for which the kind, amount, and specifications need to be described.

   Usage: This regulation is used in Section 7.6.2 to provide the regulatory requirement for describing the radioactive material to be received and possessed at the repository.

2. 10 CFR 63.43

   Regulation Text: License conditions include items in the following categories [10 CFR 63.43(b)]:

   > Restrictions as to the physical and chemical form and radioisotopic content of radioactive waste [10 CFR 63.43(b)(1)].

   Applicability: This requirement applies to this evaluation, as the required information is part of the TAD source term specification. The physical and chemical form of CSNF is a direct input to the source term generation; and radioisotopic content is the result of the source term generation.

   Usage: This regulation is used in Section 7.6.2 to provide the repository license condition on the radioactive material to be received and possessed.

5.2.2 NUREG-1804

NUREG-1804 (NRC 2003 [DIRS 163274]) is a *Yucca Mountain Review Plan*. The pertinent guidance is presented below, along with their applicability to, and usage in this evaluation.

1. Description of Spent Nuclear Fuel and High-Level Radioactive Waste Characteristics (NUREG-1804, Section 2.1.1.2.2, Review Method 4)

   > *Guidance Text*: Verify that the license application has adequately characterized the ranges of parameters that describe the spent nuclear fuel, such as:
   >
   > (1) Reactor type (e.g., boiling water, pressurized water);
   >
   > (2) Fuel assembly manufacturer and model designation;

(3) Fuel assembly physical characteristics and dimensions;

(4) Fuel cladding material (including crud deposits, oxide layer, hydride content, and extent of failure and damage);

(5) Thermal characteristics;

(6) Heat generation rate and dose rate;

(7) Radionuclide inventory;

(8) Radiochemical characteristics; and

(9) History (enrichment, burnup, and postirradiation storage)

Applicability: This guidance applies to this evaluation, as the required description is related to the source term either as an input or an output associated with the source term generation.

Usage: This guidance is used in Section 7.6.2 to provide the SNF description for compliance with the disposal regulation.

2. <u>Assessment of Calculations of Consequences to Workers and Members of the Public from Normal Operations and Category 1 Event Sequences (NUREG-1804, Section 2.1.1.5.1.2, Review Method 2)</u>

Guidance Text: Evaluate the calculation of the source term, and confirm the following:

> Characteristics of the high-level radioactive waste used in the source term calculation (e.g., enrichment, burnup, and decay time) reasonably represent or bound the range of characteristics of waste that will be handled at the geologic repository operations area, as reviewed using Section 2.1.1.2 ("Description of Structures, Systems, Components, Equipment, and Operational Process Activities") of the Yucca Mountain Review Plan.

Applicability: This guidance applies to this evaluation, as it requires specification of the bounding characteristics used in the source term calculation.

Usage: This guidance is used in Section 7.6.2 to provide the required fuel parameters for consideration in the source term calculation.

5.3 INTERFACE REQUIREMENTS

Although TADs are used for CSNF only, the interface requirements for receipt, transfer and disposal of other waste forms such as naval SNF may have implications on the TAD source term specification for the repository facility design. The following interface requirement for naval SNF canisters from the *Naval Nuclear Propulsion Program Technical Baseline Compliance Document* (McKenzie 2002 [DIRS 165219]) should be considered for its applicability to the TAD source term evaluation:

> *Requirement Text*: The SNF or HLW disposal canister (excluding the single-element-sized canister) shall not exceed a maximum surface gamma dose rate of 10^5 rem per hour and a maximum neutron dose rate of 10 rem per hour at time of shipment to the CRWMS (McKenzie 2002 [DIRS 165219], Item 21. Canister Dose Rates, p. 30).
>
> *Applicability*: This requirement applies to this evaluation, as it serves as an input for determining the bounding waste form or waste package type for shielding considerations.
>
> *Usage*: This requirement is used in Sections 6.8, 7.2 and 7.7 to determine the bounding waste form or canister.

6. TECHNICAL INPUTS

This section contains the technical inputs used in this evaluation. Direct inputs used to support the conclusions and recommendations in this report were obtained from the applicable controlled source documents. The pertinent technical inputs (direct or indirect) include the following items:

- Source term specification for PWR SNF (Section 6.1)
- Source term specification for BWR SNF (Section 6.2)
- Source term specification for WP (Section 6.3)
- Source term specification for 21-PWR site-specific canister (Section 6.4)
- Source term specification for aging casks (Section 6.5)
- Surface dose rates for 21-PWR WP (Section 6.6)
- Surface dose rates for 44-BWR WP (Section 6.7)
- Surface dose rates for naval long WP (Section 6.8)
- Dose contribution by fuel assembly in 21-PWR WP (Section 6.9)
- Canister surface dose rates (Section 6.10)
- TAD shell material and thickness (Section 6.11)

6.1 SOURCE TERM SPECIFICATION FOR PWR SNF

Technical Input: The *PWR Source Term Generation and Evaluation* document (BSC 2004 [DIRS 169061]) provides the following source term specification for PWR SNF:

Fuel assembly type: B&W Mark B (BSC 2004 [DIRS 169061], Section 5.2)

Fuel loading: 475 kg uranium (BSC 2004 [DIRS 169061], Section 5.2)

Average PWR assembly: 4.0% initial enrichment, 48 GWd/MTU burnup, and 25 years cooling (BSC 2004 [DIRS 169061], Section 5.5)

Maximum PWR assembly: 5.0% initial enrichment, 80 GWd/MTU burnup, and 5 years cooling (BSC 2004 [DIRS 169061], Section 5.5)

Average assembly thermal output: 0.601 kW/assembly (BSC 2004 [DIRS 169061], Attachment X, Files *Waste.Stream.E5.R1.B9.cut, Waste.Stream.E5.R2.B9.cut, Waste.Stream.E5.R3.B9.cut, and Waste.Stream.E5.R1.B9.cut)*

Maximum assembly thermal output: 2.475 kW/assembly (BSC 2004 [DIRS 169061], Attachment X, Files *Waste.Stream.E2.R1.B14.cut, Waste.Stream.E2.R2.B14.cut, Waste.Stream.E2.R3.B14.cut, and Waste.Stream.E2.R1.B14.cut)*

Applicability: This technical input applies to this evaluation, as it provides the source term specification for PWR SNF.

Usage: This technical input is used in Sections 6.6 and 7.1.1 to provide the PWR source terms for the 21-PWR WP and 21-PWR TAD, respectively.

6.2 SOURCE TERM SPECIFICATION FOR BWR SNF

Technical Input: The *BWR Source Term Generation and Evaluation* document (BSC 2003 [DIRS 164364]) provides the following source term specification for BWR SNF:

Fuel assembly type: General Electric 2/3 8X8 (BSC 2003 [DIRS 164364], Section 3.1)

Fuel loading: 200 kg uranium (BSC 2003 [DIRS 164364], Section 5.2)

Average BWR assembly: 3.5% initial enrichment, 40 GWd/MTU burnup, and 25 years cooling (BSC 2003 [DIRS 164364], Section 5.5.3)

Maximum BWR assembly: 5.0% initial enrichment, 75 GWd/MTU burnup, and 5 years cooling (BSC 2003 [DIRS 164364], Section 5.5.3)

Average assembly thermal output: 0.186 kW/assembly (BSC 2003 [DIRS 164364], Attachment VII, Files *3.5%.40GWd.fuel.cut, 3.5%.40GWd.bottom.cut, 3.5%.40GWd.plenum.cut, and 3.5%.40GWd.top.cut)*

Maximum assembly thermal output: 0.780 kW/assembly (BSC 2003 [DIRS 164364], Attachment VII, Files *5.0%.75GWd.fuel.cut, 5.0%.75GWd.bottom.cut, 5.0%.75GWd.plenum.cut, and 5.0%.75GWd.top.cut)*

Applicability: This technical input applies to this evaluation, as it provides the source term specification for BWR SNF.

Usage: This technical input is used in Sections 6.7 and 7.1.2 to provide the BWR source terms for the 44-BWR WP and 44-BWR TAD, respectively.

6.3 SOURCE TERM SPECIFICATION FOR WP

Technical Input: The *Subsurface Shielding Source Term Specification Calculation* document (BSC 2002 [DIRS 161120]) provides the following design basis source term specification for the waste package:

Limiting WP type: 21-PWR WP (BSC 2002 [DIRS 161120], Section 5.2)

PWR design basis fuel (BSC 2002 [DIRS 161120], Section 5.5.2):

Fuel assembly type	B&W Mark B
Initial uranium loading	475 kg/assembly
Initial enrichment	4.0%
Fuel burnup	60 GWd/MTU
Cooling time	10 years
Heat output	~1.2 kW/assembly or ~25 kW/WP

Note that this specification was used only for the shielding design associated with handling, transfer, transport and emplacement of waste packages only. No BWR design basis fuel has been specified for the 44-BWR WP, as it is bounded by the PWR design basis fuel for the 21-PWR WP.

Applicability: This technical input applies to this evaluation, as it provides the source term specification for the 21-PWR waste package without a TAD. Applicability of this specification to the waste package with a TAD is a part of this evaluation.

Usage: This technical input is used in Sections 6.4, 6.6, 7.1.1, 7.4.3 and 7.5.2 to provide the PWR design basis fuel specification for the 21-PWR WP.

6.4 SOURCE TERM SPECIFICATION FOR 21-PWR SITE-SPECIFIC CANISTER

Technical Input: The *Preliminary Shielding Calculation for the Site-Specific Canister/Basket* (BSC 2005 [DIRS 173267]) uses the following design basis source term specification for the canister (BSC 2005 [DIRS 173267], Section 5.1.6):

B&W 15x15 Mark B assembly
475 kg uranium load
4.0 wt% initial ^{235}U enrichment,
60 GWd/MTU discharge burnup,
10 years cooling time

Note that this specification is the same as for the WP source term provided in Section 6.3.

Applicability: This technical input applies to this evaluation, as it provides the source term specification for the 21-PWR waste package with a site-specific canister. Applicability of this specification to the waste package with a TAD is a part of this evaluation.

Usage: This technical input is used in Sections 7.1.1 and 7.5.2 to provide the PWR design basis fuel specification for the 21-PWR site-specific canister.

6.5 SOURCE TERM SPECIFICATION FOR AGING CASKS

Technical Input: The *Engineering Specification for the Procurement of Yucca Mountain Aging Casks – Site-specific Canisters and Overpacks* (TriVis 2005 [DIRS 175598]) provides the design input requirements with respect to fuel description for the aging casks as follows:

1. <u>Design Basis Fuel</u>

The following design basis fuel parameters shall be used in the design of the site-specific disposable canisters (TriVis 2005 [DIRS 175598], Section 3.1.3, selected applicable items only):

- Burnup of 60,000 MWd/MTU

- Cooling time of 10 years or greater out-of-reactor

- 4% initial enrichment for shielding calculations

- Heat output of 1,185 Watts per PWR assembly or 435 Watts per BWR assembly

2. Bounding Fuel Characteristics

The subcontractor shall provide information on the number of assemblies that the site-specific disposable canister can accommodate that have the following characteristics (TriVis 2005 [DIRS 175598], Section 3.1.4):

- Burnup of 80,000 MWd/MTU for PWR fuel and 75,000 MWd/MTU for BWR fuel

- Cooling time of 5 years out-of-reactor for PWR fuel and BWR fuel

- 5% initial enrichment for PWR fuel and BWR fuel

- Heat output of 2,475 Watts per PWR assembly or 780 Watts per BWR assembly

Applicability: This technical input applies to this evaluation, as it provides the source term and thermal output specification for the aging casks, and the requirement for accepting fuel assemblies with the bounding characteristics. Since aging is an element of the TAD design, applicability of this specification to the aging overpack with a TAD is a part of this evaluation.

Usage: This technical input is used in Sections 7.1.1, 7.1.2, 7.5.1 and 7.5.2 to provide the PWR and BWR design basis fuel specification and their bounding characteristics for the aging casks.

6.6 SURFACE DOSE RATES FOR 21-PWR WP

Technical Input: The *Dose Rate Calculation for 21-PWR Waste Package* (BSC 2004 [DIRS 172227]) provides the dose rates on the radial surfaces of the WP as given in Table 1 for three different sets of source terms including:

Maximum PWR assembly	5%, 80 GWd/MTU, and 5 yr (Section 6.1)
Design basis PWR assembly	4%, 60 GWd/MTU, and 10 yr (Section 6.3)
Average PWR assembly	4%, 48 GWd/MTU, and 25 yr (Section 6.1)

Note that the dose rates are for the 21-PWR WP without a TAD.

Table 1. Dose Rates on Radial Surfaces of 21-PWR WP without a TAD

Source Term	Peak Radial Dose Rate (rem/h)[a]		Reference
	WP Inner Surface	WP Outer Surface	
Maximum PWR Assembly (5%, 80 GWd/MTU & 5 yr)	66,800 (66,600 γ + 260 n)	1,520 (1,460 γ + 60 n)	BSC 2004 [DIRS 172227] Tables 6.3-1 & 6.3-2
Design Basis PWR Assembly (4%, 60 GWd/MTU & 10 yr)	27,000 (26,900 γ + 90 n)	595 (575 γ + 20 n)	BSC 2004 [DIRS 172227] Tables 6.1-6 & 6.1-7
Average PWR Assembly (4%, 48 GWd/MTU & 25 yr)	10,800 (10,800 γ + 23 n)	199 (194 γ + 5 n)	BSC 2004 [DIRS 172227] Tables 6.2-1 & 6.2-2

[a] The total dose rate may not be exactly equal to the sum of the individual components, owing to the round-off in the scientific notation used in the cited source document.

Applicability: This technical input applies to this evaluation, as it provides the WP dose rates for the different source terms for use in estimating the corresponding dose rates for the 21-PWR WP with a TAD.

Usage: This technical input is used in Section 7.2 to estimate the corresponding dose rates for the 21-PWR WP with a TAD.

6.7 SURFACE DOSE RATES FOR 44-BWR WP

Technical Input: The *Dose Rate Calculation for 44-BWR Waste Package* (BSC 2003 [DIRS 166596]) provides the dose rates on the radial surfaces of the WP as given in Table 2 for two different sets of source terms including:

Maximum BWR assembly	5%, 75 GWd/MTU, and 5 yr (Section 6.2)
Average BWR assembly	3.5%, 40 GWd/MTU, and 25 yr (Section 6.2)

Note that the dose rates are for the 44-BWR WP without a TAD. There is no design basis fuel specification for the 44-BWR WP as the 21-PWR WP is bounding. Furthermore, the maximum dose rate on the WP outer surface is slightly higher for the 44-BWR WP than the corresponding dose rate for the 21-PWR WP. This peak for the 44-BWR WP occurs only over a limited area of the surface rather than over a large area as for the 21-PWR WP. Therefore, the 21-PWR WP bounds the 44-BWR WP for shielding considerations.

Table 2. Dose Rates on Radial Surfaces of 44-BWR WP without a TAD

Source Term	Peak Radial Dose Rate (rem/h)[a]		Reference
	WP Inner Surface	WP Outer Surface	
Maximum BWR Assembly (5%, 75 GWd/MTU & 5 yr)	45,800 (45,800 γ + 58 n)	1,610 (1,600 γ + 15 n)	BSC 2003 [DIRS 166596] Tables 6.2-1 & 6.2-2
Average BWR Assembly (3.5%, 40 GWd/MTU & 25 yr)	7,510 (7,500 γ + 10 n)	128 (125 γ + 2.3 n)	BSC 2003 [DIRS 166596] Tables 6.1-6 & 6.1-7

[a] The total dose rate may not be exactly equal to the sum of the individual components, owing to the round-off in the scientific notation used in the cited source document.

Applicability: This technical input applies to this evaluation, as it provides the WP dose rates for the different source terms for use in estimating the corresponding dose rates for the 44-BWR WP with a TAD.

Usage: This technical input is used in Section 7.1.2 to indicate that PWR fuel is bounding, and in Section 7.2 to estimate the corresponding dose rates for the 44-BWR WP with a TAD.

6.8 SURFACE DOSE RATES FOR NAVAL LONG WP

Technical Input: The *Dose Rate Calculation for the Naval Long Waste Package* (BSC 2004 [DIRS 167082]) provides the dose rates on the radial surfaces of the WP as given in Table 3 for two different sets of source terms including:

Naval SNF at 2 yr after shutdown
Naval SNF at 5 yr after shutdown

Note that the dose rates are for the naval long WP loaded with a naval SNF canister. The dose contributions are virtually from gamma radiation, because of highly enriched uranium used for naval fuel, which yields a relatively small neutron source in SNF. The 2-yr-old SNF dose rate of 98,600 rem/h on the inner surface of the WP is consistent with the naval SNF canister surface dose rate specification of 100,000 rem/h (Section 5.3).

Table 3. Dose Rates on Radial Surfaces of Naval Long WP

Source Term	Peak Radial Dose Rate (rem/h)		Reference
	WP Inner Surface	WP Outer Surface	
2-yr-old Naval SNF	98,600 (98,600 γ + 0.7 n)	392 (392 γ + 0.1 n)	BSC 2004 [DIRS 167082] Tables 6.1-1 & 6.1-3
5-yr-old Naval SNF	48,325 (48,325 γ + 0.7 n[a])	179 (179 γ + 0.1 n[a])	BSC 2004 [DIRS 167082] Tables 6.1-7 & 6.1-9

[a] 2-yr-old value used, since the neutron contribution is relatively small.

Applicability: This technical input applies to this evaluation, as it provides the naval WP dose rates for comparison to the 21-PWR and 44-BWR WPs and for determination of the source term characteristics of the bounding WP type.

Usage: This technical input is used in Section 7.2 for comparison with other WP types to determine the bounding canister or WP for shielding calculations.

6.9 DOSE CONTRIBUTION BY FUEL ASSEMBLY IN 21-PWR WP

Technical Input: The *Subsurface Shielding Source Term Specification Calculation* (BSC 2002 [DIRS 161120]) provides the percent contribution to the gamma dose rate by fuel assembly loaded in the 21-PWR WP without a TAD. Note that gamma radiation is generally the principal contributor to the total dose rate, except for the case of deep penetration in concrete where neutron and secondary gamma contributions could be significant. The calculation shows that a single fuel assembly located in an outermost position of the fuel basket can make a substantial contribution to the resultant radial dose rate as follows:

On WP outer surface	~95% (BSC 2002 [DIRS 161120], Table 16)
On WP transporter outer surface	~60% (BSC 2002 [DIRS 161120], Table 16)

Hence, characteristics of a single assembly rather than the whole package can dictate the shielding design for the WP, particularly in the radial direction which is typically more controlling from a shielding perspective than the axial direction.

Applicability: This technical input applies to this evaluation, as it provides the basis for using the characteristics of the bounding fuel assembly for shielding considerations.

Usage: This technical input is used in Sections 5.1.1, 7.4.3, 7.5.1 and 7.8 to support the significance of a single fuel assembly to the external dose rates.

6.10 CANISTER SURFACE DOSE RATES

Technical Input: The *Shielding Calculation for Dry Transfer Facility, Remediation Facility, and Canister Handling Facility* (BSC 2004 [DIRS 171405]) provides the dose rates at the external surfaces of a naval canister, a high level waste (HLW) glass canister, and a single PWR SNF assembly, using a vacuum boundary conditions (i.e., no backscattering effect) (BSC 2004 [DIRS 171405], Table 20). The characteristics of the PWR assembly used for the dose rate calculation are 5% initial enrichment, 75 GWd/MTU burnup, and 5 yr cooling with a uniform burnup profile (i.e., no axial power peaking considered. Axial peaking is important only if operations involve actual fuel assemblies.). Table 4 presents the dose rates in the radial direction, which are typically more controlling from a shielding perspective than the axial dose rates. Note that the values do not include the backscattering effect.

Table 4. Radial Surface Dose Rates for Canisters and PWR Assembly

Source Type	Radial Surface Dose Rate (rem/h)		Reference
	Gamma	Neutron	
Naval SNF Canister	8.00E+04	2.43E-01	BSC 2004 [DIRS 171405], Table 20
HLW Glass Canister	6.81E+03	1.33E-01	BSC 2004 [DIRS 171405], Table 20
Single PWR SNF Assembly	1.08+05	11.18	BSC 2004 [DIRS 171405], Table 20

Applicability: This technical input applies to this evaluation, as it provides the dose rates to facilitate the selection of the TAD source term to bound all canisters.

Usage: This technical input is used in Sections 7.4.1 and 7.7 for comparison of the dose rates.

6.11 TAD SHELL MATERIAL AND THICKNESS

Technical Input: The *Yucca Mountain Project Conceptual Design Report* (DOE 2006 [DIRS 176937]) provides the TAD shell material and thickness as follows:

Material: austenitic stainless steel (DOE 2006 [DIRS 176937], Section 2.4.1.6)
Thickness: one inch (DOE 2006 [DIRS 176937], Figure 2-9)

For this evaluation, a common austenitic stainless steel material such as SS316 or SS316L (interchangeable for shielding) is used.

Applicability: This technical input applies to this evaluation, as it provides the material and thickness of the TAD shell for determining the effect of the TAD on the WP dose rates.

Usage: This technical input is used in Section 7.2 to evaluate the effect of the TAD on the WP dose rates.

Justification for Intended Use: The cited reference for this technical input is a QA: N/A document. This reference produced by the project personnel is the sole and authoritative source of information for this input. It provides the description of the repository conceptual design for project use. This input affects the dose rate or shielding calculations, but has no impact on the source term specification since the bounding SNF characteristics are specified in Section 8. A recommendation to revise the shielding calculations is included in Section 8 to address the effect of the TAD. Accordingly, this technical input is suitable for the intended use.

7. EVALUATION

This section evaluates the project requirements and criteria, regulatory requirements and guidance, and interface requirements as applied to the TAD source term specification. It includes an evaluation of the effect of the TAD source term variation on the resultant dose rate, as well as the sensitivity of the shielding requirement to the TAD source term. The evaluation leads to establishment of a recommended source term specification for the TAD for use in the repository facility shielding design.

This section is organized as follows:

- TAD source term variations (Section 7.1)
- Effect of TAD on WP dose rates (Section 7.2)
- Sensitivity of shielding to TAD source terms (Section 7.3)
- Applicability of existing shielding calculations to TAD (Section 7.4)
- Meeting project requirements and criteria (Section 7.5)
- Meeting regulatory requirements and guidance (Section 7.6)
- Impact of interface requirements (Section 7.7)
- Establishing TAD source term specification (Section 7.8)

7.1 TAD SOURCE TERM VARIATIONS

As indicated in Section 5.1.1 (Item 1), the capacity of the TAD shall be either 21 fuel assemblies from a PWR or 44 fuel assemblies from a BWR. The source terms for the 21-PWR TAD and 44-BWR TAD are separately discussed below.

7.1.1 21-PWR TAD

The 21-PWR TAD source term can vary from the average to the maximum specification, depending on the application. The average and maximum specifications are provided in Section 6.1. A design basis source specification is described in Section 6.3 for the 21-PWR WP, Section 6.4 for the 21-PWR site-specific canister, and Section 6.5 for the aging casks (or overpacks).

Table 5 summarizes the characteristics of the three different PWR source term specifications. The table includes their associated thermal outputs on a per-assembly and a per-package basis.

Table 5. 21-PWR TAD Source Term Specification

Source Term Specification	Initial Enrichment (%)	Burnup (GWd/MTU)	Cooling Time (yr)	Thermal Output (kW)		Data Source
				Per Assembly	Per Package	
Maximum	5	80	5	2.475	52	Sections 6.1 & 6.5
Design Basis	4	60	10	1.185	25	Sections 6.3 & 6.5
Average	4	48	25	0.601	12.6	Section 6.1

The maximum source specification represents the bounding PWR SNF for acceptance in the TAD, according to Item 3 of Section 5.1.1. Use of the maximum source specification for shielding design would be highly conservative, but bounding for the total PWR SNF inventory including both historical and projected discharge.

The average source specification is applicable to worker and public dose consequence analyses for normal operations. It is not suitable for the shielding design (Section 1). Therefore, no further discussion is warranted.

The design basis source specification used for the WP and aging casks has a thermal output of 25 kW per package with a 21-PWR capacity, which is the upper thermal limit provided in Item 2 of Section 5.1.1. The design basis source, which has a burnup of 60 GWd/MTU and heat output of ~1.2 kW per assembly, is more in line with the existing NRC-certified storage and transportation cask capability than the maximum source (e.g., HI-STORM 100, Holtec International 2004 [DIRS 175017], Table 2.0.1). Despite this alignment, acceptability of the 25 kW limit for the 21-PWR TAD thermal design requires further evaluation, which is beyond the scope of this report.

The maximum source specification would result in a thermal output of 52 kW per package as shown in Table 5, which is outside the valid thermal power range for the TAD (Section 5.1.1, Item 2). The PWR TAD is required to accept the maximum fuel (Section 5.1.1, Item 3) with a corresponding thermal output of ~2.5 kW per assembly (Sections 6.1 and 6.3). However, the total allowable thermal output per package needs to be separately established, based on the TAD thermal performance requirements for transportation, aging and disposal.

7.1.2 44-BWR TAD

The 44-BWR TAD source term can vary from the average to the maximum specification, depending on the application. The average and maximum specifications are provided in Section 6.2. A design basis source specification is described in Section 6.5 for the aging casks (or overpacks) containing BWR SNF. However, there is no design basis source specification for the 44-BWR WP, which is bounded by the 21-PWR WP.

Table 6 summarizes the characteristics of the three different BWR source term specifications. The table includes their associated thermal outputs on a per-assembly and a per-package basis.

Table 6. 44-BWR TAD Source Term Specification

Source Term Specification	Initial Enrichment (%)	Burnup (GWd/MTU)	Cooling Time (yr)	Thermal Output (kW)		Data Source
				Per Assembly	Per Package	
Maximum	5	75	5	0.780	34	Sections 6.2 & 6.5
Design Basis	4	60	10	0.435	19	Section 6.5
Average	3.5	40	25	0.186	8.2	Section 6.2

The maximum source specification represents the bounding BWR SNF for acceptance in the TAD (Section 5.1.1, Item 4). Since the maximum PWR fuel bounds the BWR fuel, the shielding design based on the maximum PWR fuel is adequate to cover the BWR fuel (see Section 6.7).

The average source specification is applicable to worker and public dose consequence analyses for normal operations. It is not suitable for the shielding design (Section 1). Therefore, no further discussion is warranted.

The design basis source specification used for the BWR SNF aging casks has a thermal output of 19 kW per package with a 44-BWR capacity, which is within the thermal power range provided in Item 2 of Section 5.1.1. The design basis source, which has a burnup of 60 GWd/MTU and heat output of 0.435 kW per assembly, is more in line with the existing NRC-certified storage and transportation cask capability than the maximum source (e.g., HI-STORM 100, Holtec International 2004 [DIRS 175017], Table 2.0.1). Despite this alignment, acceptability of the 25 kW limit for the 44-BWR TAD thermal design requires further evaluation, which is beyond the scope of this report.

The maximum source specification would result in a thermal output of 34 kW per package as shown in Table 6, which is outside the valid thermal power range for the TAD (Section 5.1.1). The BWR TAD is required to accept the maximum fuel (Section 5.1.1, Item 4) with a corresponding thermal output of 0.78 kW (Sections 6.2 and 6.5). However, the total allowable thermal output per package needs to be separately established, based on the TAD thermal performance requirements for transportation, aging and disposal.

7.2 EFFECT OF TAD ON WP DOSE RATES

The dose rates presented in Section 6.6 for the 21-PWR WP and Section 6.7 for the 44-BWR WP are for the WP without a TAD. These dose rates would be lower with a TAD because of attenuation by the TAD stainless steel shell, provided that the WP inner and outer barriers remain unchanged with respect to the material and thickness. With a thickness of one inch for the TAD shell (Section 6.11), Table 7 compares the dose rates for the different WP types.

Table 7. WP Dose Rate Comparison

WP Type	Source Term	Peak Radial Dose Rate (rem/h)		Comment
		WP Inner Surface	WP Outer Surface	
21-PWR WP without TAD	Maximum Source	66,800 (66,600 γ + 260 n)	1,520 (1,460 γ + 60 n)	From Table 1 (Section 6.6)
	Design Basis Source	27,000 (26,900 γ + 90 n)	595 (575 γ + 20 n)	From Table 1 (Section 6.6)
44-BWR WP without TAD	Maximum Source	45,800 (45,800 γ + 58 n)	1,610 (1,600 γ + 15 n)	From Table 2 (Section 6.7)
21-PWR WP with TAD	Maximum Source	18,700 (18,500 γ + 186 n)	449 (406 γ + 43 n)	Using SS316 attenuation factors provided below
	Design Basis Source	7,530 (7470 γ + 64 n)	174 (160 γ + 14 n)	Using SS316 attenuation factors provided below
44-BWR WP with TAD	Maximum Source	12,740 (12,700 γ + 41 n)	454 (444 γ + 11 n)	Using SS316 attenuation factors provided below
Naval Long WP	2-yr-old SNF Source	98,600 (98,600 γ + 0.7 n)	392 (392 γ + 0.1 n)	From Table 3 (Section 6.8)

The dose rate values are directly from Table 1 for the 21-PWR WP without a TAD, Table 2 for the 44-BWR WP without a TAD, and Table 3 for the naval long WP. The values with a TAD are estimated from the attenuation characteristics of stainless steel for the inner shell of the WP as provided in the *Dose Rate Calculation for the 21-PWR UCF Waste Package* (BSC 2001 [DIRS 153752], Tables 17 and 18).

This historical document is the sole source with the dose rates on both inner and outer surfaces of the WP inner shell made of SS316. It is suitable for use in determining the attenuation characteristics of stainless steel, as the source energy spectrum and geometric configuration are similar to the case considered in this evaluation. In addition, the relative change in the dose rate from the WP inner surface to the WP outer surface is consistent with that shown in Table 1. Note that the cited controlled document (BSC 2004 [DIRS 172227]) in Section 6.6 does not provide the dose rate on the outer surface of the WP inner shell.

Based on the data from this historical document, the attenuation or dose reduction factors used here for one inch of the TAD shell are estimated as follows:

WP inner shell SS316 thickness = 5 cm ≅ 2 in. (BSC 2001 [DIRS 153752], Table 1)
(suitable for use here, based on consistency with the calculations cited in Section 6.6)

Gamma attenuation (BSC 2001 [DIRS 153752], Tables 17 and 18, Segment 6)

Gamma dose rate on inner surface of inner shell = 4.6887E+04 rem/h
Gamma dose rate on outer surface of inner shell = 3.5251E+03 rem/h
Gamma dose reduction factor through ~2 in. SS316 = 13.3
Gamma dose reduction factor per in. of SS316 = $(13.3)^{1/2}$ = 3.6

Neutron attenuation (BSC 2001 [DIRS 153752], Tables 17 and 18, Segment 6)

Neutron dose rate on inner surface of inner shell = 6.8477E+01 rem/h
Neutron dose rate on outer surface of inner shell = 3.3669E+01 rem/h
Neutron dose reduction factor through ~2 in. SS316 = 2.03
Neutron dose reduction factor per in. of SS316 = $(2.03)^{1/2}$ = 1.4

For this evaluation, the dose reduction factors of 3.6 for photons and 1.4 for neutrons apply to both WP inner and outer surfaces, as the WP is only slightly shielded. Note that these factors are applicable to this evaluation only for estimating the peak dose rates on the inner and outer radial surfaces of the WP with a TAD.

On the WP inner surface, the naval long WP exhibits the highest dose rate among all the WP types included in Table 7. The dose rate of 98,600 rem/h is close to the naval SNF disposable canister surface dose rate specification of 100,000 rem/h (Section 5.3).

On the WP outer surface, the naval long WP is not bounding. The dose rate for the naval long WP is less than that for the 21-PWR or 44-BWR WP with a TAD containing the maximum fuel, but greater than that for the 21-PWR WP with a TAD containing the design basis fuel. Therefore, selection of the maximum fuel specification for the TAD would bound the naval long WP for the shielding design. Note that the larger dose reduction from the inner surface to the outer surface of the naval long WP is attributed to the fact that the gamma source energy spectrum is softer and the neutron source is smaller for naval SNF, relative to CSNF.

7.3 SENSITIVITY OF SHIELDING TO TAD SOURCE TERMS

This section evaluates the impact of the source term variation on shielding. Comparison of the dose rates on the outer surface of the 21-PWR WP with a TAD for the maximum and design basis sources shows that there is a difference by a factor of approximately 2.6 in the total dose rate. This factor is a composite of 2.5 in the gamma dose rate, and 3.0 in the neutron dose rate, as shown in Table 8. The increase in the shielding requirement external to the WP to account for the dose rate ratio is also presented in Table 8.

Table 8. Shielding Sensitivity to Source Terms for 21-PWR WP with a TAD

Contribution	Radial Dose Rate on WP Outer Surface (rem/h)		Dose Rate Ratio	Shielding Increase to Account for Dose Rate Ratio
	Maximum Source	Design Basis Source		
Gamma Dose Rate	406	160	2.5	About 1 in. of steel or 3 to 4 in. of concrete
Neutron Dose Rate	43	14	3.0	About 1 in. of hydrogenous material if steel is used for gamma shielding.
Total Dose Rate	449	174	2.6	

The difference in the dose rate between the maximum and design basis sources is translated to about one inch of gamma shielding with steel plus one inch of neutron shielding with a hydrogenous material (e.g., borated polyethylene or its equivalent). The additional steel thickness is estimated from the representative gamma attenuation characteristics provided in the *Shielding Calculations for Glovebox Subsystem and Support Area of WP Closure System* (BSC 2005 [DIRS 176872], Table 11). The neutron shielding estimate uses the attenuation data for borated polyethylene from the *MGDS Subsurface Radiation Shielding Analysis* (CRWMS M&O 1997 [DIRS 100232], Table 7.5-2). These data are suitable for use here, as they were generated with a qualified software item, and the impact of the additional neutron shielding on the weight is relatively minimal due to the low-density material used.

If concrete shielding is used, the additional thickness required for the maximum source relative to the design basis source is about 3 to 4 inches of concrete, which provides both gamma and neutron shielding. This estimate is based on the neutron and gamma attenuation characteristics of concrete provided in the *Shielding Calculations for Glovebox Subsystem and Support Area of WP Closure System* (BSC 2005 [DIRS 176872], Tables 11 and 12).

7.4 APPLICABILITY OF EXISTING SHIELDING CALCULATIONS TO TAD

Several existing shielding calculations are available to provide the shielding requirements for the surface and subsurface facilities. These calculations were performed for the design without the use of the TAD. This section discusses the applicability of the existing calculations to the TAD-based design.

7.4.1 Surface Facilities

The *Shielding Calculation for Dry Transfer Facility, Remediation Facility, and Canister Handling Facility* (BSC 2004 [DIRS 171405]) provides the shielding requirements for the surface operations associated with a single CSNF assembly, WP and various canister types. Table 9 lists the bounding source terms used to determine the shielding requirements.

Table 9. Bounding Source Terms Used for Surface Operations

Operation	Source Term Specification	Characteristics	Reference
Single CSNF Assembly	PWR maximum source	5%, 80 GWd/MTU & 5 yr	BSC 2004 [DIRS 171405], Section 5.2.2
Waste Package	21-PWR WP design basis source	4%, 60 GWd/MTU & 10 yr	BSC 2004 [DIRS 171405], Section 5.2.2
Canister (e.g., naval)	Simulated by a PWR assembly	5%, 75 GWd/MTU & 5 yr	BSC 2004 [DIRS 171405], Section 5.4.1

For transfer and staging of fuel assemblies in the Wet Handling Facility pool, the existing shielding calculation for the Wet Remediation Area (BSC 2004 [DIRS 171405], Section 5.4.3) is directly applicable. The applicable calculation includes determination of the minimum water depth required above the SNF staging rack, and the minimum water height required above the top of a single fuel assembly during in-pool transfer.

The existing shielding calculation for the WP operations is based on a WP outer radial surface dose rate of ~600 rem/h (Table 7) using the PWR design basis source. The TAD design reduces the WP surface dose rate to ~450 rem/h (Table 7), even with the maximum source. Hence, for radial shielding, the existing calculation is slightly conservative. For axial shielding, the TAD shield plug (Section 5.1.1, Item 5) and end plates provide extra shielding, which can be used to reduce the building floor and ceiling thicknesses. It should be noted that the same waste package design is used for the configurations with and without a TAD to reach this conclusion.

The canister operations use a hypothetical radiation source simulated by a PWR fuel assembly with the characteristics of 5% initial enrichment, 75 GWd/MTU, and 5 yr cooling. Without consideration of axial power peaking, this radiation source results in a gamma dose rate of 108,000 rem/h and a neutron dose rate of 11 rem/h, using a vacuum boundary (i.e., no backscattering effect included). These dose rates bound the naval SNF canister surface dose rate specification (Section 6.10).

Table 10 compares the dose rates on the surfaces of the hypothetical PWR fuel assembly and TAD. For this evaluation, the TAD surface dose rate is taken to be the same as the WP inner surface dose rate. For the TAD containing 21 PWR assemblies or 44 BWR assemblies, the gamma dose rate on the TAD outer surface is less than the value on the simulated assembly surface, but the corresponding neutron dose rate is much greater. The existing calculation with the use of a simulated source term for the canister operations needs to be validated to ensure adequacy of neutron shielding for the TAD, as the maximum neutron dose rate on the TAD outer surface is 186 rem/h (Table 10), which exceeds the dose rate of 11.2 rem/h (Table 10) from a single PWR fuel assembly used for the canister handling operations.

Table 10. Comparison of TAD and Single PWR Assembly Surface Dose Rates

Location	Source Characteristics	Gamma Dose Rate (rem/h)	Neutron Dose Rate (rem/h)	Cross Reference
21-PWR TAD Outer Surface	5%, 80 GWd/MTU & 5 yr	18,500	186	Table 7
44-BWR TAD Outer Surface	5%, 80 GWd/MTU & 5 yr	12,700	41	Table 7
PWR Assembly Outer Surface	5%, 75 GWd/MTU & 10 yr	108,000	11.2	Table 4

7.4.2 Aging Pads

The existing document on *Dose Rate Evaluations for Spent Nuclear Fuel Aging Areas* (BSC 2004 [DIRS 172499]) uses the following bases:

- TN-32 dry storage cask with a capacity of 32 PWR assemblies (BSC 2004 [DIRS 172499], Section 5.2.2)

- Radial dose rate of 60 or 20 mrem/h at 1 m from the cask surface (BSC 2004 [DIRS 172499], Section 6)

For the TAD-based design, the aging overpack will contain 21 PWR or 44 BWR fuel assemblies. With a smaller capacity, the physical size will be smaller in diameter as compared to the TN-32 cask. With respect to the configuration, the dose rate calculation for the larger TN-32 cask due to more fuel assemblies, especially for skyshine radiation, is conservative when applied to the TAD-based aging overpack.

In accordance with the TAD performance specification, the aging overpack shall limit the combined maximum neutron and gamma dose rate to less than 40 mrem/h at contact with any exterior surface of the overpack (BSC 2006 [DIRS 177442], Section 3.6.2). This surface translates to a dose rate of 17 mrem/h at 1 m from the surface (BSC 2006 [DIRS 177442], p. F-4). Linear scaling can be used to adjust the dose rates from the existing calculation to match the dose rate specification for the TAD aging overpack.

Although the existing calculation provides the dose rate results for the aging pads for scoping use or preliminary estimates, revision is recommended to account for the TAD aging overpack geometry, relocated aging pads, and new dose rate limit.

7.4.3 Subsurface Facilities

The existing shielding calculations for the subsurface facilities include the following:

- *Dose Rate Calculation for Emplacement Drift Turnout Configurations* (BSC 2003 [DIRS 165078])

- *Dose Rate Calculation for an Optimized Turnout Drift Configuration* (BSC 2005 [DIRS 172596])

- *Dose Rate Calculation for the Exhaust Main in Emplacement Panel 1* (BSC 2005 [DIRS 172750])

All these calculations use the same bases consistently as listed below:

- Bounding 21-PWR WP without a TAD (Section 6.3)
- Design basis source term (4%, 60 GWd/MTU, and 10 yr) (Section 6.3)

These existing calculations are conservative for the 21-PWR WP with a TAD, even for the maximum source term (5%, 80 GWd/MTU, and 5 yr). The conservatism is attributed to the fact that with the same WP design, the 21-PWR WP with a TAD containing the maximum fuel has a lower radial dose rate than the 21-PWR WP containing the design basis fuel without a TAD (see Table 7). Furthermore, the extra axial shielding afforded by the TAD shield plug (Section 5.1.1, Item 5) and end plates significantly reduces the axial dose rates. Further optimization of the turnout and emplacement drift configuration is recommended to take advantage of the additional axial shielding provided by the TAD.

Use of the maximum source term specification for subsurface shielding calculations is deemed to be highly conservative as SNF may be aged prior to emplacement. In addition, the dose rates of interest are generally in the axial direction from the emplaced WPs (e.g., access main and turnout), where the average of the characteristics of SNF assemblies contained in the WPs dictates the total dose contribution. This situation is different from the radial dose rates, which may be dominated by a single fuel assembly alone (Section 6.9).

Despite the conservatism with the maximum source term specification, its use can be justified and supported by the fact that it bounds other waste forms, in particular, naval SNF as demonstrated in Section 7.2.

7.4.4 Emplacement Equipment

The existing *Waste Package Transporter Shielding Design Calculation* (BSC 2004 [DIRS 167113], Section 5.1.6) uses the same bases as the subsurface shielding calculations described in Section 7.4.3, namely, 21-PWR WP with the design basis source (4%, 60 GWd/MTU, and 10 yr).

For radial shielding including the transporter sidewalls, roof and floor, the existing shielding thicknesses are adequate for the 21-PWR WP with a TAD containing the maximum fuel, as its radial dose rate is less than that from the existing calculation for 21-PWR WP with the design basis source (no TAD).

For axial shielding including the transporter door and end, the existing shielding thicknesses are more than adequate for the 21-PWR WP with a TAD containing the maximum fuel, because of the additional shielding provided by the TAD shield plug (Section 5.1.1, Item 5) and end plates.

With the redesign of the WP transporter, an opportunity exists to revise the shielding calculation to incorporate the TAD design and maximum source term specification. The revision could result in less shielding and a lighter WP transporter, despite the use of the maximum source term.

7.5 MEETING PROJECT REQUIREMENTS AND CRITERIA

7.5.1 Project Requirements

Section 5.1.1 of this report provides the TAD requirements as specified in the *Transport, Aging and Disposal Canister System Basis of Specification Requirements Document* (BSC 2006 [DIRS 177442]) with respect to the content (Item 1), thermal power (Item 2), and maximum fuel specification (Items 3 and 4). The specification on the content and maximum fuel should be directly applicable to the repository facility shielding design.

The maximum fuel specification is acceptable for shielding evaluation, since the characteristics of a single assembly loaded in an outermost position of the fuel basket can dictate the shielding design, as demonstrated in Section 6.9. Placement of the maximum fuel in every loading position would produce comparable but conservative (i.e., higher) dose rate results at peak locations relative to the contribution from a single maximum fuel assembly in an outermost position.

However, the maximum fuel specification would result in a thermal output of 52 kW (2.475 kW/assembly [Section 6.5] x 21 assemblies/TAD) for the 21-PWR TAD with the maximum fuel in every loading position. This thermal output far exceeds the upper end of the valid thermal power range (i.e., 25 kW in Section 5.1.1, Item 2). A separate source term should be developed and used for thermal evaluation. Development of the thermal source term is not included in this report, as the primary focus is on the shielding source term.

7.5.2 Project Criteria

The maximum fuel specification provided in Section 5.1.1 (Items 3 and 4) represents the bounding CSNF characteristics, which should cover 100% of the historical and projected inventory. This full coverage is conservative in relation to the project design criteria provided in Section 5.1.2 for the design basis source term, which requires a minimum coverage of 95% of the total inventory.

The design basis specification of 4%, 60 GWd/MTU, and 10 yr was previously used as the shielding source term for the WP (Section 6.3), 21-PWR site-specific canister (Section 6.4) and aging casks (Section 6.5). This specification results in a thermal output of ~25 kW per package as used in the TAD basis of specification (Section 5.1.1, Item 2).

The design basis specification would cover 97% of PWR SNF population, based on the fuel assembly thermal distribution with the 1999 design basis waste input (BSC 2002 [DIRS 161120], Section 5.5.2). As indicated in Section 5.3 of BSC 2002 [DIRS 161120], the change of the waste stream scenarios to the 2002 design basis waste input would impact the surface facility design and waste aging requirements.

Another issue with the design basis specification using the 2002 design basis waste input is that it does not meet the minimum coverage of 95% of the SNF inventory required in the PDC (Section 5.1.2), if utilities delivered the youngest fuel first beginning with 5-yr-old fuel. The coverage would only be 45% to ~60%, depending on the utility fuel selection option (BSC 2003

[DIRS 165990], Table C-4). To eliminate any uncertainties with the waste stream such as timing, quantity, fuel type, heat load, etc., it is prudent at this time to use the maximum fuel specification to bound the entire SNF population.

In accordance with ISG-6 (NRC 2001 [DIRS 160595]), the shielding source term requires a specification on the minimum initial enrichment (see Section 5.1.2 of this report) to correspond to the specified fuel burnup. For a burnup of 80 GWd/MTU, it is theoretically conceivable that an initial enrichment of lower than 5% could achieve the same burnup. Since the combination of 80 GWd/MTU and 5 yr cooling is bounding, introduction of additional conservatism with the minimum initial enrichment specification is unwarranted for the 80 GWd/MTU fuel that does not exist currently. Furthermore, there is no certainty that such fuel will ever be designed and produced in the future, or that a lower initial enrichment (<5%) could be used to achieve 80 GWd/MTU.

7.6 MEETING REGULATORY REQUIREMENTS AND GUIDANCE

This evaluation addresses repository operations only. For disposal at the Yucca Mountain repository, Section 5.2.1 provides the regulatory requirements that are applicable to the TAD content.

The regulatory guidance for compliance with these requirements is described in Section 5.2.2. One of the items specified in Section 5.2.2 is the history of the SNF including enrichment, burnup, and post-irradiation storage. The SNF history is required for determination of thermal characteristics, heat generation rate and dose rate, and radionuclide inventory identified in Section 5.2.2.

7.7 IMPACT OF INTERFACE REQUIREMENTS

As described in Section 5.3, there is an interface requirement for naval SNF canisters that needs to be considered for impact on the TAD source term. This requirement specifies that the naval SNF canister surface dose rate shall not exceed 10^5 rem/h gamma and 10 rem/h neutron.

Without the TAD-based design, the naval SNF canister surface dose rate is bounded by the dose rate from a single PWR fuel assembly with the characteristics of 5% initial enrichment, 75 GWd/MTU, and 5 yr cooling. The gamma and neutron dose rates on the external surface of this PWR fuel assembly are 108,000 rem/h and 11 rem/h, respectively (Table 4). Accordingly, simulation of the source term as represented by this PWR fuel assembly is bounding for all canister transfer and handling operations.

The dose rate on the outer surface of the naval long WP is ~400 rem/h (Table 7), which is bounded by the dose rate for the 21-PWR WP with a design basis source (no TAD). For this reason, there have been no shielding calculations performed for the naval long WP.

With the TAD design for CNSF, the use of the design basis source for the 21-PWR WP with a surface dose rate of 174 rem/h will not bound the naval long WP, as demonstrated in Table 7. To bound the naval long WP, the maximum source specification needs to be used for the TAD, based on the dose rate comparison in Table 7.

7.8 ESTABLISHING TAD SOURCE TERM SPECIFICATION

Based on the evaluation presented in Sections 7.1 through 7.7, the following source term specification is established for the TAD to support the repository facility shielding design and licensing:

- PWR: 5% initial enrichment, 80 GWd/MTU burnup, and 5 yr cooling (Section 7.1)
- BWR: 5% initial enrichment, 75 GWd/MTU burnup, and 5 yr cooling (Section 7.1)

The PWR fuel burnup of 80 GWd/MTU represents a bounding value set in Licensing Position-009 (Williams 2003 [DIRS 166132]) for the projected discharge, based on the nuclear industry trend towards higher burnup fuel.

The TAD source term specification is supported and justified as follows:

1. The characteristics of a single fuel assembly located in an outermost position of the TAD fuel basket can dictate the shielding design, because of the large contribution to the dose rate from this assembly alone (Section 6.9).

2. The TAD with the maximum source term specification provides a bounding basis for the facility shielding design to cover other canister types such as naval SNF canisters (Sections 7.2 and 7.7).

3. The TAD shielding requirement is only slightly sensitive to the source term variation from the design basis (4%, 60 GWD/MTU, and 10 yr) to the maximum specification (5%, 80 GWd/MTU, and 5 yr) (Section 7.3).

4. The existing shielding calculations for the non-TAD-based design are conservative when applied to the TAD design using the maximum source term specification, as attributed to the fact that with the same WP design, the shell, shield plug and end plates of the TAD provide dose reduction to offset the increase in the source intensity (Section 7.4).

5. The TAD source term specification will not impact the concrete structures that are controlled by the structural/seismic requirements. Any instances where the shielding prevails over the seismic/structural requirements could be individually assessed as needed to remove the conservatism from the existing calculations (Section 7.4).

6. The TAD source term specification is consistent with the project requirements, and provides 100% coverage of the historical and projected CSNF inventory, which exceeds the shielding source term criterion of 95% minimum coverage (Section 7.5). The selection of 100% coverage eliminates the need for consideration of uncertainties (timing, quantity, type, heat load, etc.) associated with the waste stream to the repository.

7. The TAD source term specification provides the key parameters for inclusion in the description of the package contents as required by 10 CFR 63 [DIRS 176544] and its accompanying regulatory guidance document (Section 7.6).

The complete physical, thermal and nuclear characteristics of the maximum PWR and BWR fuel are available in the following two documents:

- *PWR Source Term Generation and Evaluation* (BSC 2004 [DIRS 169061])
- *BWR Source Term Generation and Evaluation* (BSC 2003 [DIRS 164364])

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The following major conclusions can be drawn from this evaluation:

- The TAD source term specification for the repository shielding design should be based on the bounding characteristics of a single fuel assembly rather than the entire package, as a single assembly located in an outermost position of the TAD fuel basket can be the principal contributor to the dose rate external to the package.

- Use of the maximum source term specification (i.e., 5%, 80 GWd/MTU, and 5 yr for PWR fuel) for the TAD would bound all canister types for the repository shielding design.

- With the same WP design, the existing shielding calculations for the non-TAD-based design are conservative when applied to the TAD-based design with the maximum source specification, because of the shielding provided by the TAD shell, shield plug and end plates.

- Selection of the maximum source term specification meets the project requirements and criteria, and supports the description of the TAD contents for regulatory compliance.

8.2 RECOMMENDATIONS

As a result of this evaluation, the following recommendations are made:

1. <u>Source Term Specification</u>

   It is recommended that the maximum source term specification as provided below be used for the shielding design involving TAD operations:

   - PWR TAD: 5% initial enrichment, 80 GWd/MTU burnup, and 5 yr cooling

   - BWR TAD: 5% initial enrichment, 75 GWd/MTU burnup, and 5 yr cooling

   Since the PWR TAD bounds the BWR TAD, the shielding design provided for the PWR TAD should also be adequate for the BWR TAD.

   The recommended source term specification applies to all TAD operations. Major operations include TAD loading and transfer, loading and unloading of the shielded transfer cask, aging operations, and loading and emplacement of WPs.

2. <u>Revisions to Shielding Calculations</u>

   This evaluation concludes that the existing shielding calculations for the non-TAD-based design are conservative when applied to the TAD-based design with the maximum source specification. However, other considerations such as new facility layout, new WP design, changes in the requirements, and inclusion of the TAD effect may necessitate revisions to the existing shielding calculations. The revisions may also be required to provide referenceable supporting products for use in the Safety Analysis Report, and to comply with the current versions of the procedures.

Accordingly, it is recommended that future planning include revisions of the pertinent existing shielding calculations to support the License Application. Specifically, the following revisions are recommended:

- Validate the applicability of a single PWR fuel assembly source term for the canister operations (Section 7.4.1), or revise the source term for the canister operations if the single PWR fuel assembly source term is determined to be no longer applicable.

- Perform dose rate evaluations for the spent nuclear fuel aging areas to account for the TAD aging cask geometry and new dose rate limit (Section 7.4.2).

- Optimize the turnout and emplacement drift configuration to take advantage of the additional shielding provided by the TAD (Section 7.4.3).

- Revise the WP transporter shielding design to incorporate the TAD design and maximum source term specification (Section 7.4.4).

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