ENCLOSURE 1

RAI Volume 2, Chapter 2.1.1.7, Fourth Set, Number 6: Provide information to justify a) the data provided in Table 9.B-3, b) naval waste package misplacement probability in Section 9.B.2.3.1, and c) the probability of drift collapse followed by subsequent water ingress.

Basis: The applicant relies on data from two DOE documents that are not docketed, and since this impacts the probability of criticality in the PSA, this information is needed.

1. RESPONSE

Each of the three parts to this RAI will be addressed separately. In addition, NRC accessibility to the two DOE documents referred to in the basis as not docketed has been resolved as shown in the following discussion.

One of the DOE documents referred to in the Basis of this RAI and used to support the justifications for the PSA calculations is the *Waste Package Flooding Probability Evaluation* report. The 2008 version of the *Waste Package Flooding Probability Evaluation* (SNL 2008) was used for the license application. This report was updated in 2009 (SNL 2009). Both reports (SNL (2008) and SNL (2009)) were submitted to the NRC in conjunction with the response to RAI 3.2.2.1.2.1-4-042. The impact of the revised models in SNL (2009) on the naval probability of criticality is to increase the NNPP probability of criticality from 7.1×10^{-6} to 7.9×10^{-6} as discussed in the Part A response below.

The other DOE document referred to in the Basis of this RAI is the *Waste Package Misplacement Probability Evaluation* (BSC 2008). This report is provided with this RAI response.

Part A - Justify the data provided in Table 9.B-3

The data in *Probabilistic Safety Assessment (U),* Background, Evaluation, and Analysis Report (BEAR 9), Table 9.B-3, is based on SNL (2008). Table A-1 below presents the data based on SNL (2008) and SNL (2009) and identifies the location of the data justification in SNL (2009).

The changes from SNL (2008) to SNL (2009) result in changes to the sequence probabilities in BEAR 9, Table 9.5-1. Table A-2 below lists the sequence probabilities as calculated with SNL (2008) and SNL (2009). A comparison of the two sets of sequence probabilities shows that the probability of criticality of naval spent nuclear fuel (SNF) in the first 10,000 years following repository closure increases from the license application value of 7.1×10^{-6} to a value of 7.9×10^{-6}. Considering the contribution from non-naval SNF of 3.7×10^{-5}, the total probability of criticality for all SNF in the repository increases from 4.4×10^{-5} to 4.5×10^{-5} over 10,000 years. This represents a 2.3% increase in the total probability of criticality for all SNF in the repository.

Table A-1

Item No.	Event Description in BEAR 9 Table 9.B-3	Event Mean Probability		Justification (SNL (2009))
		SNL (2008)	SNL (2009)	
1	Drift collapse in the lithophysal zone after 300 years results in water ingress into one or more naval waste packages in 10,000 years	3.0×10^{-5}	1.57×10^{-5}	Page 19 (Update to Section B.2.4 (Case 4D)) provides the probability for the interval up to 10,000 years. It has been conservatively applied to the slightly smaller interval (300-10,000 years) used in the BEAR 9 models.
2	Large block rockfall in the nonlithophysal zone results in water ingress into one or more naval waste packages in 10,000 years	7.75×10^{-6}	7.32×10^{-4}	Page 15 (Update to Section B.2.3 (Case 3D))
3	Early drift collapse event in the lithophysal zone before 300 years results in water ingress into one or more naval waste packages and cladding failure in 10,000 years	6.96×10^{-6}	5.92×10^{-6}	Page 27 (Update to Addendum 001)
4	Misplaced drip shield results in water ingress into one or more naval waste packages (in both lithophysal and nonlithophysal zones) in 10,000 years	1.5×10^{-7}	1.59×10^{-7}	Page 10 (Update to Section B.2.2 (Case 2D))
5	Misplaced drip shield results in water ingress into one or more naval waste packages (in lithophysal zone only) in 10,000 years	1.18×10^{-7}	1.14×10^{-7}	See Table A-1 footnote below
6	Misplaced drip shield results in water ingress into one or more naval waste packages (in nonlithophysal zone only) in 10,000 years	3.44×10^{-8}	4.53×10^{-8}	

Table A-1 footnote: The methodology for computing the probability of water ingress into one or more naval waste packages due to drip shield misplacement is presented in Appendix B,

Section B.2.2 of SNL (2008), with corrections indicated in SNL (2009). The methodology is applied separately for each rock type (lithophysal and nonlithophysal) to obtain probability estimates conditional on each rock type, and the resulting two probabilities are summed to obtain a total mean probability of water ingress for the repository (1.59×10^{-7}) presented in SNL (2009), Table B-1, Case 2D, although the probabilities conditional on each rock type are not reported in SNL (2009). BEAR 9, Table 9.B-3 presents the mean probabilities separately for each rock type.

Table A-2 – Comparison of NNPP YM PSA Sequence Probabilities Based on SNL (2008) and SNL (2009)

Seq	Events and Failures Represented in Sequence		Basis	Probability	Contribution to Total Probability of Criticality
	Repository Event	Naval SNF Condition			
L-002 + NL-002	Misplaced drip shield results in water ingress into one or more naval waste packages	Naval component failure	BEAR 9 - SNL(2008)	6.17×10^{-11}	~0%
			Updated - SNL(2009)	6.55×10^{-11}	~0%
L-003 + NL-003	Misplaced drip shield results in water ingress into one or more naval waste packages	Naval SNF cladding failure results from thermal misplacement affecting a naval waste package	BEAR 9 - SNL(2008)	1.52×10^{-11}	~0%
			Updated - SNL(2009)	1.59×10^{-11}	~0%
L-004	Drift collapse in lithophysal zone in first 300 years followed by water ingress into all naval waste packages in the lithophysal zone	Naval SNF cladding failure results from insulating drift rubble accumulated during the first 300 years	BEAR 9 - SNL(2008)	6.96×10^{-6}	97.5%
			Updated - SNL(2009)	5.92×10^{-6}	75.0%
L-005	Drift collapse in lithophysal zone after first 300 years results in water ingress into one or more naval waste packages	Naval component failure	BEAR 9 - SNL(2008)	1.20×10^{-7}	1.7%
			Updated - SNL(2009)	2.55×10^{-7}	3.2%
L-006	Drift collapse in lithophysal zone after first 300 years results in water ingress into one or more naval waste packages	Naval SNF cladding failure results from thermal misplacement affecting a naval waste package	BEAR 9 - SNL(2008)	2.97×10^{-8}	0.4%
			Updated - SNL(2009)	6.31×10^{-8}	0.8%
L-007 + NL-006	Naval waste package misplaced on fault and fault event occurs	Undefined	BEAR 9 - SNL(2008)	2.16×10^{-8}	0.3%
			Updated - SNL(2009)	2.16×10^{-8}	0.3%
NL-004	Large block rockfall event in nonlithophysal zone results in water ingress into one or more naval waste packages	Naval component failure	BEAR 9 - SNL(2008)	5.65×10^{-9}	0.08%
			Updated - SNL(2009)	1.31×10^{-6}	16.6%
NL-005	Large block rockfall event in nonlithophysal zone results in water ingress into one or more naval waste packages	Naval SNF cladding failure results from thermal misplacement affecting a naval waste package	BEAR 9 - SNL(2008)	1.41×10^{-9}	0.02%
			Updated - SNL(2009)	3.20×10^{-7}	4.1%
Total NNPP PSA In-Package Probability of Criticality			BEAR 9 - SNL(2008)	**7.1×10^{-6}**	
			Updated - SNL(2009)	**7.9×10^{-6}**	

ENCLOSURE 1

Part B - Justify the naval waste package misplacement probability in Section 9.B.2.3.1

The calculation in BEAR 9, Section 9.B.2.3.1 is used to approximate the probability that one or more naval waste packages are placed on or near a fault line with the capacity to displace sufficiently to damage a naval waste package. The justification of this approximation is provided below.

The hypergeometric distribution can be used to determine the expected number of waste packages impacted by faults (see page 10, Eq. 1 of SNL (2008.) Since the ratio of n to N (see Table B-1) is small, the hypergeometric distribution approaches the binomial distribution in this case (page 353, *Risk Analysis in Engineering,* (Modarres 2006)). Therefore alternatively, the binomial distribution can be used to evaluate the probability, $P(x)$, that x number of the 400 naval waste packages are placed on a fault,

$$P(x) = \binom{n}{x} p^x (1-p)^{n-x}$$

where: $$\binom{n}{x} = \frac{n!}{x!(n-x)!}$$

n = number of fault intersections, see Table B-1
x = the number of naval waste packages that are placed on faults, see Table B-1
p = the probability a waste package is misplaced and that this waste package is a naval waste package = $P_{Misplaced\text{-}WP} * M/N$, see Table B-1

The probability that no naval waste packages are placed on any fault intersections is determined by setting x to 0:

$$P(0) = \binom{n}{0} p^0 (1-p)^n$$

The probability that one or more naval waste packages is placed on any of the faults is the complement of the above equation:

$$P(x>0) = 1 - \binom{n}{0} p^0 (1-p)^n = 1 - \left[\frac{n!}{0!(n-0)!} p^0 (1-p)^n \right] = 1 - (1-p)^n$$

$\approx np$ when $np << 1$

$P(x>0) \approx$ np = n($P_{Misplaced\text{-}WP}$)(M/N); i.e., the equation used in BEAR 9, Section 9.B.2.3.1

Evaluation of this equation for P(x>0), with the variables as defined in Table B-1, yields a probability of 3.0×10^{-5}.

Table B-1

Variable	Value	Definition	Basis
n	214	The maximum number of waste packages in the repository that are subject to fault displacement of sufficient magnitude to cause waste package damage	Of these 214 waste packages, 43 are modeled to be emplaced on currently known fault-to-drift intersections as tabulated in Table 6-60 of *Seismic Consequence Abstraction* (SNL 2007). The other 171 are modeled to be located on hypothesized yet-to-be mapped fault-to-drift intersections as described in Section 6.11.2.2 of SNL (2007). One of the emplacement loading rules (SAR Section 1.9, Table 1.9-8, footnote d) states that naval waste packages will not be emplaced in such locations as modeled for these 214 sites.
M	400	The maximum number of naval waste packages	SAR Section 1.5.1.4.1.1
N	11,162	The total number of waste packages in the repository	SNL (2009), Table 4-1.
$P_{Misplaced\text{-}WP}$	4.0×10^{-6}	The probability that a waste package is misplaced due to an error in operational handling	BSC (2008) determined (1) the probability of waste package misplacement during emplacement and (2) the probability that the emplacement location was based on incorrect thermal output. Only the first value, the probability of waste package misplacement during emplacement, is relevant to the evaluation in BEAR 9, Section 9.B.2.3.1. The probability of a single misplacement due to errors in operational handling of any waste package is 4.0×10^{-6} as provided in BSC (2008), Section 6.2.2.3. The operational misplacement evaluation examines human performance and organizational responsibilities in execution of the handling process steps from receipt of waste through placement and closure of a waste package and ending with emplacement of the waste package.

Part C - Justify the probability of drift collapse followed by subsequent water ingress

The probability of drift collapse followed by subsequent water ingress is provided in Table 9.B-3. The justification of this table is discussed in Part A of this response.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BEAR (Background, Evaluation, and Analysis Report) 9. NNPP-SNF-YMSA-09. *Probabilistic Safety Assessment (U)*, Revision Original.

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SNL 2007. *Seismic Consequence Abstraction*. MDL-WIS-PA-000003, Rev 03, Las Vegas, Nevada: Sandia National Laboratory. ACC: DOC.20070928.0011; LLR.20080414.0012; DOC.20090219.0003.

SNL (Sandia National Laboratory) 2008. *Waste Package Flooding Probability Evaluation.* CAL-DN0-NU-000002 Rev 00C AD01, Las Vegas, Nevada: Sandia National Laboratory. ACC: DOC.20080424.0001.

SNL 2009. *Waste Package Flooding Probability Evaluation.* ERD 02 to CAL-DN0-NU-000002 Rev 00C, Las Vegas, Nevada: Sandia National Laboratory. ACC: DOC.20090210.0002.

ENCLOSURE 2

RAI Volume 2, Chapter 2.1.1.7, Fourth Set, Number 7: Justify the probability of violating the restriction on placing two relatively hot waste packages next to each other in an emplacement drift (Section 9.3.2.2.2) used in the PSA.

1. RESPONSE

Waste package emplacement rules (extracted from Postclosure Parameter 05-03 in SAR Table 1.9-9) which limit thermal conditions during preclosure are as follows: (1) no waste package shall be emplaced that has a thermal power output greater than 18 kW at the time of emplacement, (2) no seven-waste-package segment that does not contain a naval waste package shall exceed a thermal line load of 2.0 kW/m at the time of emplacement, (3) the calculated thermal energy density of any seven adjacent as-emplaced waste packages shall be controlled to ensure that the temperature shall not exceed 96°C at the midpillar, (4) the seven-waste-package segment that contains a naval waste package shall not exceed a thermal line load of 1.45 kW/m at the time of emplacement, and (5) no waste package in a seven-waste-package segment that contains a naval waste package shall have a thermal output greater than 11.8 kW at the time of emplacement.

Phenomena That May Affect the Reactivity of Naval Spent Nuclear Fuel (U), Background, Evaluation, and Analysis Report (BEAR 8), phenomenon HT3, considers that nonconformance with any of the above thermal-based rules in the emplacement of any waste package (naval or non-naval) in a seven-waste-package segment that contains a naval waste package may result in thermal conditions outside of the range evaluated to assure that no thermal damage occurs to naval SNF cladding. Such thermal damage could cause the release of some of the fissile material from the naval SNF, resulting in an unanalyzed configuration of fissile material that might be critical in the presence of liquid water. Therefore, *Probabilistic Safety Assessment (U)*, Background, Evaluation, and Analysis Report (BEAR 9), Section 9.3.2.2, conservatively models naval waste packages that are placed in an unacceptable thermal location, and have liquid water ingress, as a critical configuration in the PSA (BEAR 9, Section 9.3.1.1). This concern is not limited in BEAR 9 to two waste packages placed next to each other but rather includes improper placement of two (or more) waste packages within the same seven-waste-package segment as the naval waste package.

Part A - Explicit Evaluation of Waste Package Thermal Misplacement Probability

BSC 2008 evaluated the probability that one waste package is placed in an incorrect location (BSC 2008 Section 6.2.2.4). This probability is then utilized to determine the probability that misplacement of waste packages will result in exceeding the thermal limits for a naval waste package.

1. <u>Probability that One Waste Package is Misplaced</u>

The *Waste Package Misplacement Probability* calculation (BSC 2008) determined (1) the probability of waste package misplacement during emplacement and (2) the probability that the emplacement location was based on incorrect thermal output calculations.

The probability of a misplacement due to errors in operational handling of waste packages is 4.0 $\times 10^{-6}$ per waste package to be emplaced (BSC 2008, Section 6.2.2.3). The operational misplacement evaluation examines human performance and organizational responsibilities in execution of the handling process steps from receipt of waste through emplacement of the waste package.

The probability of a misplacement due to errors in thermal calculations is 2.6×10^{-5} per waste package to be emplaced (BSC 2008, Section 6.2.2.3). The evaluation of these errors examines human performance and organizational responsibilities during performance of the thermal calculations and emplacement planning determinations that direct the handling operations.

The total probability of a misplacement that does not conform to the loading rules is 3.0×10^{-5} per waste package to be emplaced (BSC 2008, Section 6.2.2.4). This total probability is the sum of the probability for misplacement of a waste package due to errors in thermal calculations and the probability of errors in operational handling.

2. <u>Probability that Misplacement(s) Result in Exceeding Naval Waste Package Thermal Limits</u>

As stated in BSC 2008 Section 6.1.9, thermal analysis has shown that, with one exception discussed below, naval spent nuclear fuel is not adversely affected thermally by a single misplacement of a waste package. Misplacement of two waste packages within a seven waste package segment that contains a naval waste package could result in exceeding thermal limits. These situations include combinations of misplacement of one or more naval waste packages and one or more hot commercial waste packages within a seven waste package segment. The probability that two waste packages would be misplaced and the thermal limits for a naval waste package would be exceeded is 2×10^{-5} (BSC 2008, page 6 of CACN) over the entire repository. This probability is the total for the emplacement of all waste packages within the repository.

As stated in BSC 2008 Section 6.1.9, the only single misplacement that can result in exceeding the thermal limits involves loading of the first 120 meters of the first drift in the repository. Specifically, thermal limits can be exceeded if a complete loss of ventilation event occurs prior to completely loading the first 120 meters of the first drift in the repository, if a naval waste package with a decay heat of greater than 8.5kW is emplaced into a seven waste package segment that includes a commercial waste package with a decay heat of greater than 11.8 KW. Single misplacements are only a concern in the first 120 meters of the first drift since natural ventilation will be established once the first 120 meters of the first drift is filled. BSC 2008 evaluated the probability of occurrence of an arrangement that would result in exceeding the thermal limits by considering the number of opportunities for misplacements and the combinations of waste package types within the first 120 meters. As stated in BSC 2008 (page 4 of the CACN), the probability that the thermal limits in a naval waste package are exceeded by a single misplaced waste package in the first 120 meters of the first drift is 2.5×10^{-5} considering placement of all waste packages in the first 120 meters of the first drift. Since there is only one first drift, this value represents the probability for the entire repository. BSC 2008 also evaluated the repository postclosure temperatures in a drift with a single misplacement and, as a result of

the decrease in decay heat of the waste packages with time, thermal limits are not exceeded in a naval waste package due to any single misplacement.

The sum of these two probabilities (4.5×10^{-5}) represents the probability over the entire repository inventory that the thermal limits for naval waste packages are exceeded due to waste package emplacement errors.

Part B - Waste Package Thermal Misplacement Probability Used in BEAR 9

1. Confirmation of Conservatism in BEAR 9 Value

BEAR 9, Section 9.3.2.2, documents that the PSA used a thermal misplacement probability of 1×10^{-4} per naval waste package to represent the probability that the naval waste package exceeds thermal limits. This value is conservatively higher than the BSC 2008 value (4.5×10^{-5}) discussed in A.2 above. Moreover, the BSC 2008 value is the probability over the entire repository inventory that the thermal limits for naval waste packages are exceeded due to waste package emplacement errors. BEAR 9 models that each naval waste package to be emplaced has this probability. Therefore, the BEAR 9 misplacement probability value is conservative.

2. Justification of Using a Conservative Value in BEAR 9

To summarize, the NNPP probability of criticality calculations are based on a conservative probability of 1.0×10^{-4} that a naval waste package is affected by an exceedance of any of the thermal-based emplacement rules (Postclosure Parameter 05-03 in SAR Table 1.9-9). Since the sequences involving thermal misplacement (L-003, NL-003, L-006, and NL-005) cumulatively contribute only 3.8×10^{-7} to the naval probability of criticality of 7.9×10^{-6} over 10,000 years (see Table A-2 in the response to RAI 2.2.1.1.7-4-006) and 0.85% of the total repository probability of criticality of 4.5×10^{-5} over 10,000 years (Part A in response to RAI 2.2.1.1.7-4-006), the use of the conservative value has a negligible effect on the total probability of criticality for the repository and its use is justified in BEAR 9 evaluations.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BEAR (Background, Evaluation, and Analysis Report) 8. NNPP-SNF-YMSA-08. *Phenomena That May Affect the Reactivity of Naval Spent Nuclear Fuel (U)*, Revision Original.

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