CRWMS/M&O

Calculation Cover Sheet

Complete only applicable items.

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1.0 Purpose

The purpose of this calculation is to document 1) the Waste Package Degradation (WAPDEG) version 3.09 (CRWMS M&O 1998b, *Software Routine Report for WAPDEG (Version 3.09)*) simulations used to analyze waste package degradation and failure under the repository exposure conditions characterized by the higher thermal loading repository design feature and, 2) post-processing of these results into tables of waste package degradation time histories suitable for use as input into the Integrated Probabilistic Simulator for Environmental Systems version 5.19.01 (RIP) computer program (Golder Associates 1998). Specifically, the WAPDEG simulations discussed in this calculation correspond to waste package emplacement conditions (repository environment and design) defined in the Total System Performance Assessment - Viability Assessment (TSPA-VA), with the exception that the higher thermal loading Design Feature (Design Feature 26) of the License Application Design Selection (LADS) analysis was analyzed.

Higher thermal loading would keep the drift temperature above the boiling point of water for a longer period of time, thereby minimizing moisture around the waste packages during a longer post-closure period. The higher thermal loading would also affect the surrounding rock, which may have adverse effects. The only failure mechanism of this feature would be if the effects on the surrounding rock were determined to be unacceptable.

As a result of the change in waste package placement relative to the TSPA-VA base-case design, different temperature and relative humidity time histories at the waste package surface are calculated (input to the WAPDEG simulations), and consequently different waste package failure histories (as calculated by WAPDEG) result.

2.0 Method

Temperature and relative humidity (RH) time histories at the waste package surface are calculated elsewhere and provided as input to this WAPDEG simulation. These histories are pre-processed into a form suitable for use as input to the WAPDEG stochastic simulation code (CRWMS M&O 1998b, *Software Routine Report for WAPDEG (Version 3.09)*) through the use of the pre-processor Mkhhistory (CRWMS M&O 1998c, *Software Routine Report for Mkhhistory (Version 1.00)*).

Based on user-supplied input, the stochastic simulation code WAPDEG is used to generate waste package failure profiles. WAPDEG's inputs include time-varying histories of the temperature and relative humidity at the waste package surface (as discussed above), various temperature and relative humidity thresholds for corrosion initiation, corrosion models, and corrosion model parameter distributions. A waste package may fail either through localized corrosion processes (pitting or crevice corrosion), leading to small pinhole perforations (generically referred to as "pits"), or through general corrosion processes leading to much larger "patch" perforations. More detailed discussions of the WAPDEG conceptual model are given elsewhere (CRWMS M&O 1998a, *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document - Chapter 5, Waste Package Degradation Modeling And Abstraction*, pp. 5-27 to 5-29). The waste package failure profiles calculated by WAPDEG consist of time-varying measures of the number of pit and patch penetrations on each failed waste package. The WAPDEG post-processor, Post308

(CRWMS M&O 1998b, *Software Routine Report for WAPDEG (Version 3.09)*, Appendix D), abstracts this information, to produce one RIP input table (Golder Associates 1998, pp. 7-22 through 7-25) per WAPDEG simulation. The RIP input table contains:

- 1) The fraction of waste packages failed versus time curve for the simulation,
- 2) The average number of pit penetrations per failed waste package versus time curve and,
- 3) The average number of patch penetrations per failed waste package versus time curve.

Post308 has two main objectives:

- a) It reformats the WAPDEG output to conform to the RIP input format and,
- b) It decreases the number of points in each of the three curves discussed above to approximately 83 (or less depending on the data being processed), through a process of time averaging.

More detailed discussions of the WAPDEG version 3.09 and Post308 codes appear elsewhere (CRWMS M&O 1998b, *Software Routine Report for WAPDEG (Version 3.09)*).

3.0 Assumptions

No assumptions are made in executing Mkhhistory. The limitations on the Mkhhistory software routine and on the validity of the resulting output are discussed in detail in Mkhhistory's Software Routine Report (CRWMS M&O 1998c, *Software Routine Report for Mkhhistory (Version 1.00)*).

For the calculations involved in attaining a post processed table for input into RIP there are two steps to consider: 1) Execution of the WAPDEG code and; 2) Post processing of WAPDEG output for creation of tables for input to RIP. There are several assumptions necessary to consider for the WAPDEG simulations. The assumptions used to model waste package degradation in this calculation are identical to those used in the TSPA-VA REV 01 base case calculation (CRWMS M&O 1998d, *Creating Input Tables from WAPDEG for RIP*) (DTN: MO9810SPA00013.000). Although WAPDEG version 3.07 (CRWMS M&O 1998j, *Software Routine Report for WAPDEG (Version 3.07)*) was used in the TSPA-VA base case calculation and WAPDEG version 3.09 is used in the present calculation, the assumptions listed in the TSPA-VA REV 01 base case calculation are applicable to the present calculation as the additional features of WAPDEG version 3.09 relative to WAPDEG version 3.07 are not used in this calculation. No additional assumptions pertaining to the use of the WAPDEG code are made as a result of considering the higher thermal loading design feature. No additional assumptions pertaining to the use of the Post308 code are made as a result of considering the higher thermal loading design feature.

4.0 Use of Computer Software

4.1. Software Approved for QA Work

Mkhhistory version 1.00 (CRWMS M&O 1998c, *Software Routine Report for Mkhhistory (Version 1.00)*) was used to pre-process the thermal hydrologic time, temperature, and relative humidity

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"histories" into a format usable by the WAPDEG code. The following information has been obtained from the Software Configuration Secretary (SCS) relative to this software:

Software Name:	Mkhistory
Software Version:	1.00
CSCI Identifier:	30080 v 1.00
Document Identifier:	30080-2999, REV 00
Media Identifier:	30080-M04-001, REV 00
Software Change Request:	LSBR 194

This software routine was obtained from the Software Configuration Manager in accordance with appropriate procedures. Mkhistory was executed on a DELL PowerEdge 2200 Workstation equipped with Dual (2) Pentium II 266 MHz processors (CRWMS M&O tag 112371) in the Windows NT 4.0 operating system. Mkhistory version 1.00 has gone through the complete verification and validation process required by AP-SI.1Q Revision 1 for a software routine and is thus a fully qualified software routine approved for use in quality affecting work. Mkhistory was used within the range of values tested and documented within its Software Routine Report (CRWMS M&O 1998c, *Software Routine Report for Mkhistory (Version 1.00)*).

Mkhistory version 1.00 is an appropriate tool for this application, because it is able to read input data and produce output files that can be used as input into WAPDEG.

4.2. Software Routines

The software used to perform the waste package degradation simulations was WAPDEG version 3.09 (CRWMS M&O 1998b, *Software Routine Report for WAPDEG (Version 3.09)*) (TBV-568) and its post processor, Post308 (CRWMS M&O 1998b, *Software Routine Report for WAPDEG (Version 3.09)*, Appendix D) (TBV-568). The following has been obtained from the Software Configuration Secretary (SCS) relative to this software routine:

Software Name:	WAPDEG
Software Version:	3.09
CSCI Identifier:	30048 v 3.09
Document Identifier:	30048-2999, REV 02
Media Identifier:	30048-M04-001, REV 02

Software Change Request:

LSBR 177

This software was obtained from the Software Configuration Manager in accordance with appropriate procedures. The WAPDEG simulations were executed on Hewlett-Packard HP-UX 20 workstations (CRWMS M&O tags 102877, 112515, 108319, 107436, 107437, 108335, 111031). The post processing was accomplished on a DELL PowerEdge 2200 Workstation equipped with Dual (2) Pentium II 266 MHz processors (CRWMS M&O tag 112371) in the Windows NT 4.0 operating system.

WAPDEG version 3.09 is an appropriate tool for this application, because it was specifically designed to calculate waste package failure profiles in a manner consistent with the information requirements of the RIP code. Although there has been a Software Routine Report (SRR) prepared for version 3.09 of the WAPDEG code (CRWMS M&O 1998b, *Software Routine Report for WAPDEG (Version 3.09)*), WAPDEG has not gone through the complete verification and validation process required by AP-SI.1Q Revision 1 so it is not to be considered qualified and has been designated "to be verified" (TBV-568). WAPDEG version 3.09 was used within the range of values tested and documented in its Software Routine Report (CRWMS M&O 1998b, *Software Routine Report for WAPDEG (Version 3.09)*).

Post308 is an appropriate tool for this application, because it is able to read WAPDEG output files and post-process them to make tables for input into RIP. Although all of the documentation necessary to fully qualify the Post308 code has been included in the WAPDEG version 3.09 SRR (CRWMS M&O 1998b, *Software Routine Report for WAPDEG (Version 3.09)*, Appendix D), since WAPDEG version 3.09 has not gone through the complete verification and validation process required by AP-SI.1Q Revision 1, Post308 is not to be considered qualified and has been designated "to be verified" (TBV-568). Post308 was used within the range of values tested and documented in its Software Routine Report (CRWMS M&O 1998b, *Software Routine Report for WAPDEG (Version 3.09)*, Appendix D).

5.0 Calculation Inputs

5.1. Description

Files containing the thermal hydrologic time, temperature, and relative humidity (RH) "histories" at the surface of waste packages in the northeast region of the repository were obtained (DTN: LL981109204242.066) and are included in the electronic media supporting this calculation (CRWMS M&O 1998i, *Supporting Media for "RIP Input Tables From WAPDEG For LA Design Selection: Higher Thermal Loading"*). These histories are organized by bin numbers and model identifiers with file names like NE_snf_mean_XX_noBF_109e1_c_j1_22_03b_data. The nomenclature of this file name reflects that the data are for the following: the Northeast (NE) region of the potential repository; spent nuclear fuel (snf) waste packages; the "mean" infiltration rate; the thermal hydrologic history file bin (XX); no backfill (noBF); long-term average climate conditions (22); and this is a data file (data). The designators "109e1", "c", and "j1" that appear in each file

name are not relevant to this calculation. These text files contain columns of ASCII numerical data. Column 1 contains the time (years), Column 2 the waste package surface temperature ($^{\circ}\text{C}$), Column 3 the relative humidity at the waste package surface (fraction), Column 4 the air mass fraction (X_{air}), Column 5 the liquid saturation in the invert (fraction), Column 6 the drift wall temperature ($^{\circ}\text{C}$), and Column 7 the drift wall relative humidity (fraction). In this calculation, a total of 13 thermal hydrologic history files are used, each distinguished by differing values of the thermal hydrologic history file bin number. Bin numbers 01, 02, 11, 12, 21, 22, 31, 32, 41, 42, 52, 62, and 72 are used in this calculation (i.e., NE_snf_mean_01_noBF_109e1_c_j1_22_03b_data, NE_snf_mean_02_noBF_109e1_c_j1_22_03b_data, . . . , etc.). Note that it was necessary to remove the designator "_data" from each thermal hydrologic file name to satisfy the 40 character Mkhhistory maximum file name length requirement.

These thermal hydrologic history files were processed by the Mkhhistory code (after the "_data" designator was removed from each thermal hydrologic history file name). The bulk (but not all) of Mkhhistory's processing is devoted to copying Columns 1, 2, and 3 (the columns containing the time, temperature and RH at the waste package surface) from the thermal hydrologic history files named in Column 1 of the Mkhhistory input file (NEsfnoBF109e1cj12203b.mk) to the file named in Column 2 of the Mkhhistory input file. Note that the first row of ASCII numerical data (corresponding to time equals 0 years) is not copied to the file named in Column 2 of the Mkhhistory input file as discussed in the Mkhhistory SRR (CRWMS M&O 1998c. *Software Routine Report for Mkhhistory (Version 1.00)*). The initial contents of the Mkhhistory input file NEsfnoBF109e1cj12203b.mk are:

```

13
NE_snf_mean_01_noBF_109e1_c_j1_22_03b_  NESf01noBF109e1cj12203b.hst
NE_snf_mean_02_noBF_109e1_c_j1_22_03b_  NESf02noBF109e1cj12203b.hst
NE_snf_mean_11_noBF_109e1_c_j1_22_03b_  NESf11noBF109e1cj12203b.hst
NE_snf_mean_12_noBF_109e1_c_j1_22_03b_  NESf12noBF109e1cj12203b.hst
NE_snf_mean_21_noBF_109e1_c_j1_22_03b_  NESf21noBF109e1cj12203b.hst
NE_snf_mean_22_noBF_109e1_c_j1_22_03b_  NESf22noBF109e1cj12203b.hst
NE_snf_mean_31_noBF_109e1_c_j1_22_03b_  NESf31noBF109e1cj12203b.hst
NE_snf_mean_32_noBF_109e1_c_j1_22_03b_  NESf32noBF109e1cj12203b.hst
NE_snf_mean_41_noBF_109e1_c_j1_22_03b_  NESf41noBF109e1cj12203b.hst
NE_snf_mean_42_noBF_109e1_c_j1_22_03b_  NESf42noBF109e1cj12203b.hst
NE_snf_mean_52_noBF_109e1_c_j1_22_03b_  NESf52noBF109e1cj12203b.hst
NE_snf_mean_62_noBF_109e1_c_j1_22_03b_  NESf62noBF109e1cj12203b.hst
NE_snf_mean_72_noBF_109e1_c_j1_22_03b_  NESf72noBF109e1cj12203b.hst

```

i.e., 13 thermal hydrologic history files are to be processed by Mkhhistory and data from NE_snf_mean_01_noBF_109e1_c_j1_22_03b_ is to be copied to NESf01noBF109e1cj12203b.hst, etc. The above are the contents of NEsfnoBF109e1cj12203b.mk before execution of Mkhhistory (several data segments are appended to this file during Mkhhistory program execution as discussed in the Mkhhistory SRR (CRWMS M&O 1998c. *Software Routine Report for Mkhhistory (Version 1.00)*). The thermal hydrologic history files before and after processing by Mkhhistory and the NEsfnoBF109e1cj12203b.mk file after execution of Mkhhistory are included in the electronic media supporting this calculation (CRWMS M&O 1998i. *Supporting Media for "RIP Input Tables From WAPDEG For LA Design Selection: Higher Thermal Loading"*) (DTN: MO9903MWDHTL62.000).

WAPDEG version 3.09 requires several input files (*.inp, *.cdf, and *.hst files, see below) (DTN: MO9903MWDHTL62.000) and creates several output files (*.aux, *.bin, *.cam, *.crm, *.out, *.pat)

(DTN: MO9903MWDHTL62.000). Post308 reads from the *.bin, *.pat, *.out files of the WAPDEG version 3.09 runs and creates several output files (*.asc, *.dat, *.rip) (DTN: MO9903MWDHTL62.000). The *.rip files can be used as input to RIP and are described in Section 6.0.

Analyzing waste package failure histories with the WAPDEG code and creating the associated RIP input tables requires the use of a number of files for the WAPDEG code to read. The following are the files required for WAPDEG:

- 1) Files containing the relative humidity (RH) and temperature histories at the surface of waste packages (the *.hst files discussed above) (DTN: MO9903MWDHTL62.000).
- 2) Cumulative distribution function (cdf) for the temperature threshold for the onset of carbon steel corrosion. This threshold is used for the outer barrier or corrosion allowance material (CAM) (file: TThresh.cdf) (CRWMS M&O 1998e, *Cumulative Distribution Functions for the Temperature Threshold for the Onset of Carbon Steel Corrosion*) (DTN: MO9810SPA00013.000).
- 3) One cdf each for the RH threshold for the onset of humid-air corrosion (file: HARH.cdf) and the transition from humid-air corrosion to aqueous corrosion (file: AQRH.cdf) for the CAM outer barrier (CRWMS M&O 1998f, *Cumulative Distribution Functions for the Relative Humidity Thresholds for the Onset of Carbon Steel Corrosion*) (DTN: MO9810SPA00013.000).
- 4) Cumulative distribution functions for the CRM general corrosion rates with no drips (CRWMS M&O 1998g, *Cumulative Distribution Functions for No Drip Corrosion Resistant Material General Corrosion Model*) at 25, 50, and 100°C (files: gnd17550.cdf, gnd27550.cdf, gnd37550.cdf) (DTN: MO9810SPA00013.000).
- 5) Cumulative distribution functions for general corrosion rates under dripping for the inner barrier corrosion resistant material (CRM) (CRWMS M&O 1998h, *Cumulative Distribution Functions for the Dripping Case of the Corrosion Resistant Material General Corrosion Model*) at 25, 50, and 100°C (files: g8415050.cdf, g8425050.cdf, g8435050.cdf) (DTN: MO9810SPA00013.000).
- 6) The above file names and other model parameters are contained in the WAPDEG input file (*.inp) for the particular simulation being executed. With the exception of the thermal hydrologic time, temperature, and relative humidity history files discussed in 1) above, the other parameters in the WAPDEG input file are identical to those discussed in the TSPA-VA REV 01 base case calculation (CRWMS M&O 1998d, *Creating Input Tables from WAPDEG for RIP*, Section 5.0) (DTN: MO9810SPA00013.000).

The input files discussed above are used by WAPDEG to produce waste package degradation profiles. The waste package degradation profiles resulting from a WAPDEG simulation are then read by the post processor, Post308, which generates a table in a format appropriate for input into RIP (Golder Associates 1998, pp. 7-22 through 7-25). The RIP input table contains:

- 1) The fraction of waste packages failed versus time curve for the simulation,
- 2) The average number of pit penetrations per failed waste package versus time curve and,
- 3) The average number of patch penetrations per failed waste package versus time curve.

5.1.1. Mkhhistory Input Files and Parameters Used

One Mkhhistory input file was used (NEsfnoBF109e1cj12203b.mk). The files with file names specified in the first column of NEsfnoBF109e1cj12203b.mk are read by Mkhhistory and the file names specified in the second column contain Mkhhistory output. The user-supplied total number of waste packages used was 1 million.

5.1.2. WAPDEG Input Files and Parameters Used

Two WAPDEG input files were used to generate the RIP input tables for the License Application Design Selection analysis of the higher thermal loading design feature: NE1a5s5f26.inp and NE0a5s6f26.inp representing the always dripping and never dripping WAPDEG simulations, respectively. These input files are included in the electronic media supporting this calculation (CRWMS M&O 1998i, *Supporting Media for "RIP Input Tables From WAPDEG For LA Design Selection: Higher Thermal Loading"*) (DTN: MO9903MWDHTL62.000).

The first two characters of the input file name indicate that the WAPDEG simulations apply to the northeast (NE) region of the repository. The next character (0 or 1) indicates respectively that a no-drip case is being simulated or that 100% of the waste package surface is subjected to dripping throughout the simulation. The next two characters (a5) indicate that the file is for the base case infiltration. The next two characters (s5 or s6) refer to the different uncertainty/variability splits and percentiles used for the mean of the CRM general corrosion rate distributions (CRWMS M&O 1998g, *Cumulative Distribution Functions for No Drip Corrosion Resistant Material General Corrosion Model*). The classifications are as follows:

Uncertainty/Variability Splitting
(0.25 Uncertainty = 0.75 Variability, etc.)

		Uncertainty		
		0.25	0.50	0.75
Percentile	5th	s1	s2	s3
	50th	s4	s5	s6
	95th	s7	s8	s9

From the above table, it is apparent that the input file NE1a5s5f26.inp uses a 50% uncertainty - 50% variability split and uses the 50th percentile for the mean of the CRM general corrosion rate distributions and the input file NE0a5s6f26.inp uses a 75% uncertainty - 25% variability split and uses the 50th percentile for the mean of the CRM general corrosion rate distributions. The next three characters in the input file name ("f26") indicate that these input files pertain to design feature 26 of the LADS study. Below is shown the input file NE1a5s5f26.inp used in the WAPDEG simulation:

NE1a5s5f26.inp

```
Design Feature 26 Thermal loading
snf, always drip, 100%
Uncertainty/Variability=50/50 drip, 50th Quantile
12/14/98 Bryan Bullard
```

START OF PARAMETERS

3.09

13

NEsf01noBF109elcj12203b.hst
88765, 0., 0.NEsf02noBF109elcj12203b.hst
50615, 0., 0.NEsf11noBF109elcj12203b.hst
22683, 0., 0.NEsf12noBF109elcj12203b.hst
345199, 0., 0.NEsf21noBF109elcj12203b.hst
1081, 0., 0.NEsf22noBF109elcj12203b.hst
189994, 0., 0.NEsf31noBF109elcj12203b.hst
1310, 0., 0.NEsf32noBF109elcj12203b.hst
104198, 0., 0.NEsf41noBF109elcj12203b.hst
819, 0., 0.NEsf42noBF109elcj12203b.hst
106075, 0., 0.NEsf52noBF109elcj12203b.hst
40276, 0., 0.NEsf62noBF109elcj12203b.hst
40442, 0., 0.NEsf72noBF109elcj12203b.hst
8548, 0., 0.

10:0, 2.0

75., 0.35

400, 964, 3100, 3100

1.0, 1.e6, 1200

1.e4, 5.e4, 1.e5, 1.e6

304058394, F, F

0.0, 0.0

180.0, 180.0

Fixed

1.0

Fixed

1.0

Fixed

0.0

Fixed

1000000.0

T, F

Fixed

0.0

1.0

[No Drip Model, CAM]

CAMGeneral+PitMultiples

B-Normal

1.5, 0.25, 1.0, 1.0e6

[No Drip Model, CRM]

CRMGeneralRateOnly

3, 1.e+6

25.0

File

gnd17550.cdf

Version number of code

Number of alternate histories

History file 1

packs/history, T std, RH std

History file 2

packs/history, T std, RH std

History file 3

packs/history, T std, RH std

History file 4

packs/history, T std, RH std

History file 5

packs/history, T std, RH std

History file 6

packs/history, T std, RH std

History file 7

packs/history, T std, RH std

History file 8

packs/history, T std, RH std

History file 9

packs/history, T std, RH std

History file10

packs/history, T std, RH std

History file11

packs/history, T std, RH std

History file12

packs/history, T std, RH std

History file13

packs/history, T std, RH std

Thickness of outer, inner barriers (cm)

% thick to fail CRM, frac variance to packs

Number of packs, patches/pack, pits/patch

Bin start time & end time (y), and # of bins

Output times (y) for cumul. pit penetrations

Random# seed, restart flag, ignore CAM variance

Max temp, RH change over a time step (C, %RH)

Angle defining top/bottom (degrees)

Distribution for fraction top seeing drips

Distribution parameter(s)

Distribution for fraction bottom seeing drips

Distribution parameter(s)

Distribution for dripping start time

Distribution parameter(s)

Distribution for dripping stop time

Distribution parameter(s)

Neutral(T/F) water initially, new water (T/F)

Distr for time range for ceramic protection

Distribution parameter(s)

Package variance share

This segment always required

CAM corrosion model for no drips

Distribution for pit multiple

Mean, StDev, Min, Max

This segment always required

CRM corrosion model for drips

Number of dists (temps °C), max CRM rate

Temp appropriate for dist #1

Distribution type for #1

Distribution parameter (s)

50.0	Temp appropriate for dist #2
File	Distribution type for #2
gnd27550.cdf	Distribution parameter (mm/yr)
100.0	Temp appropriate for dist #3
File	Distribution type for #3
gnd37550.cdf	Distribution parameter (mm/yr)
[No Drip Features]	This segment always required
File	Distr for thermal protection temperature
TThresh.cdf	Distribution parameter(s)
File	Dist type for humid-air initiation
HARH.cdf	Distribution parameter(s)
File	Dist type for humid-air/aqueous transition
AQRH.cdf	Distribution parameter(s)
1.0	RH correlation factor
0.0, 0.0	Galvanic protect depth %, % patches protected
0.0	Spalling depth as a % of thickness
Fixed	Dist for multiple for CAM corrosion rate
1.0	Distribution parameter(s)
Fixed	Dist for multiple for CRM corrosion rate
1.0	Distribution parameter(s)
1.0	Pack variance share for multiples
[Neutral Drip Model, CAM]	Required if any non-neutral drips can be seen
CAMGeneral+PitMultiples	CAM corrosion model for no drips
B-Normal	Distribution for pit multiple
1.5, 0.25, 1.0, 1.0e6	Mean, StDev, Min, Max
[Neutral Drip Model, CRM]	Required if any non-neutral drips can be seen
CRMGenrate+ArrheniusPit	CRM corrosion model for drips
3, 1.e+6	Number of dists (temps), max CRM rate
25.0	Temp appropriate for dist #1
File	Distribution type for #1
g8415050.cdf	Distribution parameter (s)
50.0	Temp appropriate for dist #2
File	Distribution type for #2
g8425050.cdf	Distribution parameter (s)
100.0	Temp appropriate for dist #3
File	Distribution type for #3
g8435050.cdf	Distribution parameter (mm/yr)
Normal	Distribution type for A (b0)
11.275, 2.4495	Distribution parameter(mm/yr)
Fixed	Distribution type for K (b1)
5.5494e+003	Distribution parameter(mm/yr)
Fixed	Distribution type for n
0.5	Distribution parameter(s)
[Neutral Drip Features]	Required if any non-neutral drips can be seen
File	Distr for thermal protection temperature
TThresh.cdf	Distribution parameter(s)
Uniform	Dist type for CRM LC T init
80.0, 100.0	Distribution parameter
File	Dist type for humid-air initiation
HARH.cdf	Distribution parameter(s)
File	Dist type for humid-air/aqueous transition
AQRH.cdf	Distribution parameter(s)
1.0	RH correlation factor
0.0, 0.0	Galvanic protect depth %, % patches protected
0.0	Spalling depth as a % of thickness
Fixed	Dist for multiple for CAM corrosion rate
1.0	Distribution parameter(s)
Fixed	Dist for multiple for CRM corrosion rate
1.0	Distribution parameter(s)
1.0	Pack variance share for multiples

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Below is shown the input file NE0a5s6f26.inp used in the WAPDEG simulation:

NE0a5s6f26.inp

Design Feature 26 Thermal loading

snf, no drip, 100%

Uncertainty/Variability=75/25, 50th Quantile

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START OF PARAMETERS

3.09

13

NEsf01noBF109elcjl2203b.hst

88765, 0., 0.

NEsf02noBF109elcjl2203b.hst

50615, 0., 0.

NEsf11noBF109elcjl2203b.hst

22683, 0., 0.

NEsf12noBF109elcjl2203b.hst

345199, 0., 0.

NEsf21noBF109elcjl2203b.hst

1081, 0., 0.

NEsf22noBF109elcjl2203b.hst

189994, 0., 0.

NEsf31noBF109elcjl2203b.hst

1310, 0., 0.

NEsf32noBF109elcjl2203b.hst

104198, 0., 0.

NEsf41noBF109elcjl2203b.hst

819, 0., 0.

NEsf42noBF109elcjl2203b.hst

106075, 0., 0.

NEsf52noBF109elcjl2203b.hst

40276, 0., 0.

NEsf62noBF109elcjl2203b.hst

40442, 0., 0.

NEsf72noBF109elcjl2203b.hst

8548, 0., 0.

10.0, 2.0

75., 0.50

400, 964, 3100, 3100

1.0, 1.e6, 1200

1.e4, 5.e4, 1.e5, 1.e6

304058394, F, F

0.0, 0.0

180.0, 180.0

Fixed

0.0

Fixed

0.0

Fixed

0.0

1.0

[No Drip Model, CAM]

CAMGeneral+PitMultiples

B-Normal

1.5, 0.25, 1.0, 1.0e6

[No Drip Model, CRM]

CRMGeneralRateOnly

Version number of code

Number of alternate histories

History file 1

packs/history, T std, RH std

History file 2

packs/history, T std, RH std

History file 3

packs/history, T std, RH std

History file 4

packs/history, T std, RH std

History file 5

packs/history, T std, RH std

History file 6

packs/history, T std, RH std

History file 7

packs/history, T std, RH std

History file 8

packs/history, T std, RH std

History file 9

packs/history, T std, RH std

History file10

packs/history, T std, RH std

History file11

packs/history, T std, RH std

History file12

packs/history, T std, RH std

History file13

packs/history, T std, RH std

Thickness of outer, inner barriers (cm)

% thick to fail CRM, frac variance to packs

Number of packs, patches/pack, pits/patch

Bin start time & end time (y), and # of bins

Output times (y) for cumul. pit penetrations

Random# seed, restart flag, ignore CAM variance

Max temp, RH change over a time step (C, %RH)

Angle defining top/bottom (degrees)

Distribution for fraction top seeing drips

Distribution parameter(s)

Distribution for fraction bottom seeing drips

Distribution parameter(s)

Distr for time range for ceramic protection

Distribution parameter(s)

Package variance share

This segment always required

CAM corrosion model for no drips

Distribution for pit multiple

Mean, StDev, Min, Max

This segment always required

CRM corrosion model for drips

3, 1.e+6	Number of dists (temps °C), max CRM rate
25.0	Temp appropriate for dist #1
File	Distribution type for #1
gnd17550.cdf	Distribution parameter (s)
50.0	Temp appropriate for dist #2
File	Distribution type for #2
gnd27550.cdf	Distribution parameter (mm/yr)
100.0	Temp appropriate for dist #3
File	Distribution type for #3
gnd37550.cdf	Distribution parameter (mm/yr)
(No Drip Features)	This segment always required
File	Distr for thermal protection temperature
TThresh.cdf	Distribution parameter(s)
File	Dist type for humid-air initiation
HARH.cdf	Distribution parameter(s)
File	Dist type for humid-air/aqueous transition
AQRH.cdf	Distribution parameter(s)
1.0	RH correlation factor
0.0, 0.0	Galvanic protect depth %, % patches protected
0.0	Spalling depth as a % of thickness
Fixed	Dist for multiple for CAM corrosion rate
1.0	Distribution parameter(s)
Fixed	Dist for multiple for CRM corrosion rate
1.0	Distribution parameter(s)
1.0	Pack variance share for multiples

One should note that the "number of packs" on the fourth input file line after the last history file name is 400 for both input files and that the sum of the "packs/history" (the first value on each line after the history file name) differs from this value (since Mkhhistory was executed with a user-supplied 1 million total number of waste packages). In the case where the "number of packs" disagrees with the sum of the "packs/history," WAPDEG normalizes the "packs/history" to the "number of packs" based on the fraction of the sum of the entered "packs/history" for all histories used (i.e., the "packs/history" are normalized so that they sum to 400 (the "number of packs")).

To gain a deeper understanding of the WAPDEG code, refer to the Software Routine Report for WAPDEG (CRWMS M&O 1998b, *Software Routine Report for WAPDEG (Version 3.09)*).

5.2. Procedure

Mkhhistory was executed in a Windows NT 4.0 MS-DOS prompt window. Mkhhistory prompts the user for a list-file name (i.e., NEsfnoBF109e1cj12203b.mk). The Mkhhistory program then prompts the user for the total number of waste packages to be considered. The user entered "1000000".

WAPDEG was executed from the Hewlett-Packard HP UX 20 command line. WAPDEG prompts the user for the WAPDEG input file name i.e., NE1a5s5f26.inp or NE0a5s6f26.inp.

The "raw" output from a WAPDEG simulation consists of six files: a *.out file, *.pat file, *.bin file, *.crm file, *.cam file, and *.aux file (where "*" is the input file name prefix). The content and format of these files are discussed in the WAPDEG version 3.09 Software Routine Report (CRWMS M&O 1998b, Section 4.1). These files are also included in the electronic media supporting this calculation (CRWMS M&O 1998i, *Supporting Media for "RIP Input Tables From WAPDEG For LA Design Selection: Higher Thermal Loading"*) (DTN: MO9903MWDHTL62.000). Only the *.out (waste

package failure curves), *.pat (cumulative number of patch penetrations for each waste package), and *.bin (cumulative number of pit penetrations for each waste package) files are used by Post308 to create the RIP input tables.

In order to create the tables for input to RIP, Post308 is executed in a Windows NT 4.0 MS-DOS prompt window within the same directory as the output files from WAPDEG (i.e., *.bin, *.pat, *.out). The program prompts the user for the particular filename prefix that is common to the WAPDEG simulation output files to be post processed. After the program post processes the WAPDEG output, it prompts the user to enter a file name for the RIP input table to be created. The RIP input tables were chosen to have the same prefix name as the corresponding WAPDEG input files with a *.rip extension. The output from the post processor consists of three files; *.asc, *.dat, and *.rip. The content and format of these files are discussed in the WAPDEG version 3.09 Software Routine Report (CRWMS M&O 1998b, Appendix D). These files are also included in the electronic media supporting this calculation (CRWMS M&O 1998i, *Supporting Media for "RIP Input Tables From WAPDEG For LA Design Selection: Higher Thermal Loading"*) (DTN: MO9903MWDHTL62.000).

6.0 Results

Since unqualified inputs were used in the development of the results presented in this section, they should be considered TBV. This document will not directly support any construction, fabrication, or procurement activity, and therefore, the inputs and outputs are not required to be procedurally controlled as TBV. However, any use of the data from this analysis for inputs into documents supporting construction, fabrication, or procurement is required to be controlled as TBV in accordance with appropriate procedures. Furthermore, this calculation makes use of software (WAPDEG version 3.09 and Post308) that are unqualified (TBV-568).

All input and output files relevant to this calculation are included in the electronic media supporting this calculation (CRWMS M&O 1998i, *Supporting Media for "RIP Input Tables From WAPDEG For LA Design Selection: Higher Thermal Loading"*) (DTN: MO9903MWDHTL62.000). For brevity, only selected files are reproduced in hardcopy form within this section.

The primary outputs of Mkhistry are the *.hst files used as input to WAPDEG. For reference the contents of NEsf01noBF109e1cj12203b.hst are:

1.0	183.25	0.257800
1.5	186.89	0.236450
2.0	191.43	0.186000
2.5	197.78	0.120060
3.0	209.11	0.067393
3.5	216.15	0.051082
4.0	222.26	0.043509
4.5	229.42	0.036058
5.0	236.61	0.030855
6.0	241.28	0.027744
7.0	245.41	0.026928
8.0	249.03	0.027718
9.0	251.56	0.028372
10.0	252.78	0.028879

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11.0	253.46	0.029323
12.0	254.25	0.029763
13.0	254.25	0.030119
15.0	251.63	0.030590
20.0	241.80	0.031313
25.0	232.09	0.032115
30.0	219.17	0.040799
35.0	212.46	0.046370
40.0	205.03	0.053909
45.0	196.16	0.064746
50.0	187.79	0.077527
51.0	185.34	0.081696
55.0	177.82	0.096498
60.0	174.02	0.112480
70.0	166.95	0.136640
80.0	160.74	0.162310
90.0	152.97	0.201980
100.0	146.08	0.249150
101.0	145.34	0.255240
105.0	142.28	0.280290
110.0	138.91	0.311230
120.0	133.51	0.365090
150.0	119.03	0.552280
180.0	113.23	0.660110
200.0	110.90	0.688870
220.0	109.42	0.706790
230.0	108.78	0.716410
260.0	107.46	0.742330
300.0	106.17	0.771180
350.0	105.11	0.791870
400.0	104.35	0.805590
450.0	103.78	0.816850
500.0	103.30	0.827110
550.0	102.89	0.836210
600.0	102.53	0.843830
700.0	101.30	0.856890
800.0	99.38	0.867570
900.0	97.23	0.875950
1000.0	95.40	0.882900
1100.0	93.67	0.887350
1200.0	91.79	0.891880
1300.0	89.99	0.896840
1400.0	88.00	0.902050
1500.0	85.87	0.906950
1600.0	84.36	0.909400
1800.0	81.37	0.913740
2000.0	78.47	0.918780
2500.0	72.85	0.924730
3000.0	69.93	0.928560
4000.0	66.29	0.932380
5000.0	63.89	0.934740
6000.0	61.91	0.937180
8000.0	57.90	0.940340
10000.0	54.66	0.942630
15000.0	47.83	0.950720
20000.0	42.69	0.958020
30000.0	34.98	0.969900
40000.0	30.85	0.976410
50000.0	28.47	0.980410
60000.0	26.84	0.984150

80000.0	24.80	0.988350
100000.0	23.62	0.990300
120000.0	23.10	0.991540
150000.0	22.46	0.993960
200000.0	21.88	0.995380
300000.0	21.43	0.996740
400000.0	21.23	0.997440
500000.0	21.12	0.997850
600000.0	21.06	0.998070
700000.0	21.01	0.998270
800000.0	20.98	0.998450
900000.0	20.96	0.998550

The other outputs of Mkhhistory are appended to the *.mk files and consist of the history file input segment (i.e., all the text in the input file lines from "13 [Number of alternate histories" to "8548, 0., 0. [packs/history, T std, RH std"), documentation of the sum of the fraction and total number of waste packages represented by each history, and a text segment that could be used to graph all of the histories processed. These files are contained in the electronic media supporting this calculation (CRWMS M&O 1998i. *Supporting Media for "RIP Input Tables From WAPDEG For LA Design Selection: Higher Thermal Loading"*).

The primary outputs of the Post308 post processor are the RIP input tables. The RIP input tables are formatted as multidimensional lookup-tables as discussed in the RIP user's guide (Golder Associates 1998, pp. 7-22 through 7-25).

For reference the RIP input table NE1a5s5f26.rip (DTN: MO9903MWDHTL62.000) is shown below.

```
! From wapdeg file: NE1a5s5f26
! From wapdeg version: 3.09
! Postprocessor: post308
! NE1a5s5f26.inp
!
! Design Feature 26 Thermal loading
! snf, always drip, 100%
! Uncertainty/Variability=50/50 drip, 50th Quantile
! 12/14/98 Bryan Bullard
!
! START OF PARAMETERS
2
3 82
1 2 3
0.0000
3310.3112
4962.6277
10258.8391
17712.3519
23464.0447
27413.6972
31274.6073
34486.6569
37375.2361
40756.0292
44680.2015
50761.8143
```

57896.3382
62381.7513
66852.1106
70797.7064
74140.8504
76736.1489
79906.8379
85125.0859
89647.0447
92791.2864
96058.5391
99427.6547
101743.6223
104717.4813
107772.3110
110282.6506
112201.8454
114158.2219
116817.3084
119538.3331
122322.7386
124451.4612
128096.1206
132588.9085
136464.3428
140445.2953
143716.6865
148777.0617
153108.7462
154881.6619
158496.3218
162181.0097
165008.8340
167880.4018
169824.3652
172785.4608
175792.3614
177827.9410
180928.5887
184077.2001
186208.7137
188364.9089
190546.0718
192752.4913
194984.4600
197242.2736
200681.4339
204173.7945
206538.0156
208929.6131
213805.6551
218776.1624
221309.4710
223872.1139
227775.5980
234433.2390
242671.7310
251199.7414
258527.7673
264549.6526

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272282.1605		
283488.8468		
295133.9620		
307281.1908		
329345.0165		
363238.4926		
414923.0970		
530122.7232		
1000000.0000		
0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0060	0.8423	0.0000
0.0168	1.3811	0.0791
0.0301	1.8301	0.3956
0.0442	2.0713	0.6697
0.0584	2.9064	0.8745
0.0719	1.3977	1.1677
0.0835	1.3567	1.3419
0.0949	3.3858	1.4391
0.1078	1.3304	1.6000
0.1184	0.9047	1.8138
0.1331	0.9688	1.9402
0.1452	1.0094	2.1284
0.1602	1.1317	2.1966
0.1707	1.9330	2.3689
0.1853	0.9936	2.4911
0.1975	1.2021	2.6063
0.2122	1.9678	2.6748
0.2198	1.8666	2.8401
0.2343	5.7446	3.1163
0.2473	0.8179	3.3398
0.2601	1.0423	3.5374
0.2696	1.8137	3.7519
0.2892	1.4231	3.9724
0.2980	0.6124	4.1190
0.3086	0.6533	4.3286
0.3235	0.7416	4.4623
0.3394	0.9667	4.5923
0.3494	4.4148	4.7082
0.3626	0.6135	4.7841
0.3754	0.6459	4.9279
0.3862	0.6538	5.0683
0.3976	0.6696	5.2823
0.4115	0.6866	5.3467
0.4172	0.7263	5.6716
0.4355	0.8150	5.9670
0.4465	0.9867	6.3564
0.4594	1.5878	6.6393
0.4705	1.3394	6.9101
0.4846	2.3451	7.3926
0.5020	2.2313	7.7797
0.5115	2.2726	7.9270
0.5226	2.6515	8.3266
0.5422	1.2865	8.6549
0.5542	2.5045	9.0679
0.5750	1.9912	9.4342
0.5779	1.3064	9.9147
0.5878	2.1543	10.4597
0.6013	2.3450	11.0805
0.6129	0.8770	11.4668

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0.6217	1.0027	12.2729
0.6440	1.2228	12.8955
0.6586	1.5297	13.4714
0.6667	1.9124	13.9831
0.6821	1.9425	14.4550
0.6869	1.8963	15.1269
0.6986	1.5781	15.6522
0.7156	1.2227	15.9899
0.7239	1.1493	16.9378
0.7426	1.5957	17.6911
0.7553	2.3236	18.2081
0.7633	1.5329	18.8595
0.7752	2.5634	20.2111
0.7997	1.1192	21.3241
0.8081	1.6922	21.9116
0.8124	2.6618	22.6611
0.8254	2.9781	23.6017
0.8358	2.4333	25.3135
0.8479	2.2107	27.5059
0.8591	1.6088	29.5510
0.8744	1.2454	31.0572
0.8871	1.4452	32.2866
0.8971	1.4645	33.9910
0.9084	4.0255	36.5795
0.9212	2.9877	39.1573
0.9325	1.9119	41.8974
0.9452	1.5801	46.9888
0.9587	1.7852	54.7426
0.9660	2.3378	66.7997
0.9808	3.1494	92.7498
0.9975	1.0251	145.9975

Presented below is a graph (derived from the NE1a5s5f26.dat file) of the first breach (by either patch or pit penetrations) curves of both the CAM (outer carbon steel) and CRM (inner Alloy 22) layers, and the first patch and first pit curves of the CRM inner layer for the dripping (NE1a5s5f26.inp) case:

Below is shown a graph of the average number of failed patches per failed waste package for the dripping case (derived from the NE1a5s5f26.asc file):

Presented below is a graph of the average number of pits failed per failed waste package for the dripping case (also derived from the NE1a5s5f26.asc file):

The first breach curve for the CRM, the average number of patch penetrations per failed waste package curve, and the average number pit penetrations per failed waste package curves are also represented in the RIP input table, NE1a5s5f26.rip.

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8.0 Attachments

N/A.