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1. PURPOSE

The objective of this calculation is to evaluate the required minimum burnup as a function of average initial boiling water reactor (BWR) assembly enrichment that would permit loading of fuel into a potential 44 BWR waste package (WP). The potential WP design is illustrated in Attachment I. The scope of this calculation covers a range of initial enrichments from 1.5 through 5.0 weight percent U-235, and a burnup range of 0 through 50 GWd/mtU.

This report is an engineering calculation supporting the development of validation reports to be used for License Application of the proposed Monitored Geologic Repository, and was performed under Administrative Procedure-3.12Q, *Calculations* (Ref. 7.35). This calculation was performed under Technical Work Plan TWP-EBS-MD-000004, *Technical Work Plan for: Waste Package Design Description for LA* (Ref. 7.15).

2. METHOD

The calculation method used to perform the reactivity calculations involves the simulation of the burnup and decay of fuel assemblies, for various initial enrichments and spent nuclear fuel (SNF) burnups, and the calculation of the effective multiplication factor (k_{eff}) for the loaded WP configuration. The calculational method used to determine the SNF isotopics consisted of using the SAS2H control sequence of the SCALE, Version 4.3, code system (Ref. 7.7) to deplete the fuel for various initial fuel enrichments and burnups. The ORIGEN-S module of the SCALE code system (Ref. 7.7) was used to decay the fuel from the SAS2H cases out to 75,000 years. The isotopic compositions calculated from SCALE were then used as input for SNF to the MCNP code (Ref. 7.12) to calculate k_{eff} for the WP loaded with the various burnup/enrichment pairs in two different configurations – intact basket and fully degraded basket. The k_{eff} calculations are based on taking credit for burnup with a subset of the total isotopes present in commercial spent nuclear fuel (SNF) known as the *Principal Isotopes* (p. 3-34, Ref. 7.10).

The k_{eff} calculations were performed using continuous-energy neutron cross-section libraries as selected in the *Selection of MCNP Cross Section Libraries* report (pp. 61-66, Ref. 7.6). The SNF from the various burnup/enrichment pairs were simulated, and the results reported from the MCNP calculations were the combined average values of k_{eff} from three estimates (collision, absorption, and track length) listed in the final generation summary in the MCNP output. Each of the WP configurations was modeled in detail using specifications for the General Electric (GE) 8x8 fuel assembly (p. 5, Ref. 7.3 and Sections A and C, Ref. 7.16), and WP dimensions from the 44 BWR WP sketch as shown in Attachment I. In order to determine if a burnup/enrichment pair has a potential for criticality, a worst case scenario was evaluated. This worst case scenario is based on having the waste package breached and filled with moderator at the same time that the spent fuel is peaking in fissile nuclide inventory with certain fission product absorbers having been decayed away.

As fuel is burned in a reactor, the burnup of the fuel becomes distributed axially. The profile of this axial distribution attains a flattened cosine shape with time, although the exact profile can vary significantly with operating history and other effects unique to the individual reactor. Axial profiles from the Quad Cities Unit 2 reactor were used as representative of typical BWR fuel assemblies. The development of the profiles and reactor operating parameters are discussed in Section 5.

The control of the electronic management of data was accomplished in accordance with methods specified in Reference 7.15.

3. ASSUMPTIONS

3.1 It was assumed that the use of information from Reference 7.26 for the development of correlations relating power to moderator void fraction is representative of typical BWR fuel assemblies for relative axial power shapes and moderator void history profiles. The rationale for this assumption is that this information comes directly from actual reactor operating history data. This assumption was used in Section 5.

3.2 A critical limit (CL) of 0.979 was used in this calculation. The rationale for this assumption is that an example calculation estimated a value of 0.979 for a distribution free tolerance limit with no trend variable based on benchmark experiment results (p. 23, Ref. 7.31). This assumption was used in Sections 5 and 6.

3.3 It was assumed that a 58 volume percent (vol%) settled iron oxide configuration, with intact fuel assembly arrays, is the most limiting fully degraded configuration. The rationale for this assumption is that Reference 7.23 (p. 48) evaluated various configurations for the 21 PWR waste package and identified the 58 vol% settled oxide configuration as the bounding case for the fully degraded basket configuration of the viability assessment (VA) waste package design. This assumption was used in Section 5.

3.4 It was assumed that the degraded basket corrosion product mixture is similar to that listed on page 14 of Reference 7.22. The rationale for this assumption is that the basket materials for the current waste package design in this evaluation and the one from Reference 7.22 are sufficiently similar. This assumption was used in Section 5.

3.5 It was assumed that increasing the Hematite volume proportionally with the ratio of carbon steel present in the 44 BWR waste package to the 21 PWR waste package listed on page 16 of Reference 7.25, would result in an accurate amount of Hematite corrosion product for the 44 BWR WP. The rationale of this assumption is that page 29 of Reference 7.25 indicates that the corrosion of A516 (carbon steel) is the primary constituent of the Hematite production. This assumption is used in Section 5.

3.6 It was assumed that increasing the Ni_2SiO_4 volume proportionally with the ratio of Neutronit present in the 44 BWR waste package to the 21 PWR waste package listed on page 16 of Reference 7.25, would result in an accurate amount of Ni_2SiO_4 corrosion product for the 44 BWR WP. The rationale of this assumption is that page 29 of Reference 7.25 indicates that the corrosion of borated stainless steel (Neutronit) is the primary constituent of the Ni_2SiO_4 production. This assumption is used in Section 5.

3.7 It was assumed that the omission of spacer grids during the depletion calculation would have a negligible impact on the spent fuel material composition. The rationale for this assumption is that SAS2H is limited in the heterogeneity that may be modeled. The spacer grids would need to be homogenized with the in-channel moderator over the entire length of the fuel. The volume fraction that the spacers would occupy is small (< 5%). Therefore the omission of the grids should have a minimal impact on the calculated isotopics. This assumption is used in Section 5.

3.8 It was assumed that the development of correlations relating burnable poison rods to initial enrichment were representative of typical BWR fuel loadings. The rationale for this assumption is that these correlations were based on existing uranium-gadolinia loadings (Table 5, Ref. 7.26). This assumption is used in Section 5.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE

4.1.1 SCALE (SAS2H Module)

The SAS2H control module of the SCALE, Version 4.3, modular code system (Ref. 7.7) was used to perform the fuel assembly depletion calculations required for this evaluation. The software specifications are as follows:

- Program Name: SCALE (SAS2H of the SCALE Modular Code System)
- Version/Revision Number: Version 4.3
- Computer Software Configuration Item (CSCI) Number: 30011 V4.3
- Computer Type: Hewlett Packard (HP) 9000 Series Workstations
- Computer Processing Unit (CPU) number: 700887

The input and output files for the various SAS2H calculations were documented in the attachments to this calculation as described in Sections 5 and 8, such that an independent repetition of the software use could be performed. The SAS2H software used was: (a) appropriate for the application of commercial fuel assembly depletion, (b) used only within the range of validation as documented in References 7.1 and 7.2, and (c) obtained from the Software Configuration Manager in accordance with appropriate procedures.

4.1.2 SCALE (ORIGEN-S Module)

The ORIGEN-S functional module of the SCALE, Version 4.3, modular code system (Ref. 7.7) was used to extend the fuel assembly decay calculations required for this evaluation. The software specifications are as follows:

- Program Name: SCALE (ORIGEN-S of the SCALE Modular Code System)
- Version/Revision Number: Version 4.3
- Computer Software Configuration Item (CSCI) Number: 30011 V4.3
- Computer Type: Hewlett Packard (HP) 9000 Series Workstations
- Computer Processing Unit (CPU) number: 700887

The input and output files for the various ORIGEN-S calculations were documented in the attachments to this calculation as described in Sections 5 and 8, such that an independent repetition of the software use could be performed. The ORIGEN-S software used was: (a) appropriate for the application of spent nuclear fuel decay, (b) used only within the range of validation as documented in References 7.1 and 7.2, and (c) obtained from the Software Configuration Manager in accordance with appropriate procedures.

4.1.3 MCNP

The MCNP code (Ref. 7.12) was used to calculate k_{eff} for the various configurations. The software specifications are as follows:

- Program Name: MCNP
- Version/Revision Number: Version 4B2LV
- CSCI Number: 30033 V4B2LV
- Computer Type: HP 9000 Series Workstations
- CPU number: 700887

The input and output files for the various MCNP calculations are documented in the attachments to this calculation file as described in Sections 5 and 8, such that an independent repetition of the software use may be performed. The MCNP software used was: (a) appropriate for the application of k_{eff} neutron spectrum calculations, (b) used only within the range of validation as documented throughout References 7.4 and 7.5, and (c) obtained from the Software Configuration Manager in accordance with appropriate procedures.

4.1.4 Ft71v01

- Program Name: Ft71v01 (Ref. 7.37)
- Version/Revision Number: Version 01
- Software Tracking Number: 10493-01-00
- Computer Type: HP 9000 Series Workstations
- CPU number: 700887

This software application reads the binary files written to the ft71f001 file by ORIGEN-S and processes them into an ASCII format. The binary files that are read and the ASCII text files that it generates are provided in the attachments to this calculation file as described in Sections 5 and 8, such that an independent repetition of the software use may be performed.

4.2 MODELS

None.

5. CALCULATION

This report evaluates the minimum required burnup of an assembly, for a specific average initial enrichment, at which the calculated k_{eff} is equal to the critical limit (CL). The CL is the value of k_{eff} at which the configuration is potentially critical, and accounts for the criticality analysis methodology bias and uncertainty. A series of computer calculations were performed in order to develop a set of curves which show k_{eff} versus burnup for different initial enrichments, and the minimum burnup required to reach the CL.

5.1 TIME PERIODS

5.1.1 Preclosure

The process for calculating criticality potential during the preclosure time period (0-300 yrs) follows that described in Reference 7.14 (pp. 8, 22, and 23). During the preclosure time period it is currently required that the system be designed such that the calculated k_{eff} be sufficiently below unity to show at least a 5 percent margin after allowance for the bias in the method of calculation, and the uncertainty in the experiments used to validate the method of calculation (p. 16, Ref. 7.11).

As specified in Reference 7.14 (p. 22 and Appendix A), a loading curve is developed based on calculations made to determine acceptable enrichment and burnup pairs that can be loaded into a disposal container. There may be different disposal containers for different classes of enrichment/burnup pairs. Acceptable pairs are those combinations that yield a k_{eff} less than the upper subcritical limit (USL), which is yet to be defined. The difference between the CL and the USL is the additional 5 percent margin. For the purpose of this evaluation, the USL will be 0.929, which is the CL with the required additional 5% margin (see Assumption 3.2).

5.1.2 Postclosure

During the postclosure time period (>300 yrs), the process for calculating criticality potential follows that discussed in Reference 7.10. The CL is defined as the value of k_{eff} at which the configuration is potentially critical, and accounts for the criticality analysis methodology bias and uncertainty. Acceptable burnup/enrichment pairs that can be loaded into the disposal container would yield a k_{eff} less than the CL. Critical limits are established during the model validation process, but for the purpose of this evaluation, an example CL for commercial fuel of 0.979 was used (see Assumption 3.2).

The postclosure time period evaluates configurations that provide the highest k_{eff} values. Curves are generated for these configurations at different decay times in order to determine which burnup/enrichment pairs have a potential to go critical. This analysis evaluates two possible configurations – intact basket configuration and fully degraded basket configuration. Although a loading curve is applicable at the time of waste package loading, it must be demonstrated that for a given burnup/enrichment, the probability that k_{eff} will exceed the CL, will be less than 10^{-4} in any year for the first 10,000 years (p. 1-4, Ref. 7.10). This includes all degraded WP internal configurations.

5.2 FUEL DEPLETION

The method of calculation is based upon the calculation of isotopic constituents of irradiated fuel using the SAS2H sequence of the SCALE computer code system. The SAS2H sequence provides the isotopics present in the fuel when it is discharged from the reactor, and at specified times after discharge. The ORIGEN-S sequence provides the ability to have isotopics listed at numerous specific decay times. A five-year decay time after discharge was the minimum time used for the criticality evaluations in this analysis. This value is based on the required minimum cooling time of spent fuel stated in §961.11 of Reference 7.8. Isotope concentrations from extended decay time periods up to 100,000 years were also provided to facilitate analyses as a function of decay. The assembly average initial enrichments evaluated in this report range from 1.5 wt% U-235 through 5.0 wt% U-235, with burnups ranging from 0 GWd/mtU through 50 GWd/mtU.

The SAS2H control sequence accesses five functional modules of the SCALE code system for performing fuel depletion and decay calculations. The five modules include BONAMI, NITAWL-II, XSDRNPM, COUPLE, and ORIGEN-S. Each of the modules has a specific purpose in the sequence to perform the fuel depletion and decay calculations. The following provides a brief description of what each module does with a more detailed description being provided in Reference 7.1.

- BONAMI – applies the Bondarenko method of resonance self-shielding to nuclides for which Bondarenko data is available.
- NITAWL-II – performs Nordheim resonance self-shielding corrections for nuclides that have resonance parameter data available.
- XSDRNPM – performs a one-dimensional (1-D) neutron transport calculation on a specified geometry to facilitate production of cell-weighted cross sections for fuel depletion calculations.
- COUPLE – updates all cross section constants included on an ORIGEN-S working nuclear data library with data from the cell-weighted cross section library obtained from the XSDRNPM calculation. Additionally, the weighting spectrum produced by XSDRNPM is applied to update all nuclides in the ORIGEN-S working library which were not included in the XSDRNPM calculation.
- ORIGEN-S – performs point depletion, buildup, and decay calculations for the specified assembly irradiation history. Additionally, it can be run as a stand alone case to provide isotopic concentrations at various decay times.

The SAS2H control module uses ORIGEN-S to perform a point depletion calculation for the fuel assembly section described in the SAS2H input file. The ORIGEN-S module uses cell-weighted cross sections based on 1-D transport calculations performed by XSDRNPM. One-dimensional transport calculations are performed on two models, Path A and Path B, to calculate energy dependent spatial neutron flux distributions necessary to perform cross section cell-weighting calculations. A detailed description of the calculations used to produce time-dependent cross sections by SAS2H is documented in Section S2.2.4 of Volume 1, Rev. 5 in Reference 7.1.

The Path A model is simply a unit cell of the fuel assembly lattice containing a fuel rod. In the Path A model, the fuel pellet, gap, and clad are modeled explicitly. The only modification required to develop the Path A model is the conversion of the fuel assembly's square lattice unit cell perimeter to a radial perimeter conserving moderator volume within the unit cell (exterior to the fuel rod cladding). A 1-D transport calculation is performed on the Path A model for each energy group, and the spatial flux distributions for each energy group are used to calculate cell-weighted cross sections for the fuel.

The Path B model is a larger representation of the assembly than the Path A model. The Path B model approximates spectral effects due to heterogeneity within the fuel assembly such as water gaps, burnable poison rods, control rods, axial power shaping rods, etc. The structure of the Path B model is based on a uniform distribution of non-fuel lattice cells. In reality, most fuel assemblies do not have uniformly distributed non-fuel lattice cells, but the approximation of uniformly distributed non-fuel lattice cells is considered acceptable within the fidelity of these calculations as documented in Section S2.2.3.1 of Volume 1, Rev. 5 in Reference 7.1.

In SAS2H, the duration of a depletion calculation may be separated into a number of time steps of variable length in order to update the cross section libraries as fuel isotopics change. The duration of each time step was specified such that a maximum of 80 days of irradiation was not exceeded between cross section updates, with the exception of the 50 GWd/mtU burnup cases. Due to SAS2H limitations a 90 day time period was required for these cases. The 80 day irradiation time step limit should assure that the changes in isotopic concentrations of the system (primarily fuel) did not alter the neutron spectrum radically enough to cause a time step of the depletion calculation to be performed without the availability of cross sections which have been properly weighted with an appropriate neutron spectrum and spatial flux.

5.2.1 SAS2H Fuel Material Specification

The material specification section defines the UO_2 fresh fuel composition for the axial node to which the SAS2H calculation pertains. The UO_2 fresh fuel composition is characterized by the fuel density, fuel temperature, and weight percentages of U-234, U-235, U-236, and U-238. For fresh fuel SAS2H cases, a number of additional isotopes are specified in trace amounts in the fuel composition to assure that their buildup and decay is tracked during the depletion calculation. Table 1 contains a listing of the trace isotopes which are specified as each having a concentration of 1E-21 atoms/b-cm in the fresh fuel composition. The fresh fuel compositions for each U-235 enrichment used in this evaluation are specified in Table 2, and were calculated using Equation 1 (p. 20, Ref. 7.19) for each isotope based on the U-235 weight percent.

Table 1. Trace Isotopes Specified in Fresh Fuel Compositions

kr-83	kr-85	sr-90	y-89	mo-95	zr-93	zr-94
zr-95	nb-94	tc-99	rh-103	rh-105	ru-101	ru-106
pd-105	pd-108	ag-109	sb-124	xe-131	xe-132	xe-135
xe-136	cs-134	cs-135	cs-137	ba-136	la-139	ce-144
nd-143	nd-145	pm-147	pm-148	nd-147	sm-147	sm-149
sm-150	sm-151	sm-152	gd-155	eu-153	eu-154	eu-155

Table 2. SAS2H Fresh Fuel Compositions

Enrichment (wt% U-235)	wt% U-234	wt% U-235	wt% U-236	wt% U-238
1.5	0.0120	1.5000	0.0069	98.4811
2.0	0.0164	2.0000	0.0092	97.9744
2.5	0.0209	2.5000	0.0115	97.4676
3.0	0.0254	3.0000	0.0138	96.9608
3.5	0.0300	3.5000	0.0161	96.4539
4.0	0.0347	4.0000	0.0184	95.9469
4.5	0.0395	4.5000	0.0207	95.4398
5.0	0.0442	5.0000	0.0230	94.9328

$$U^{234}\ wt\% = (0.007731) * (U^{235}\ wt\%)^{1.0837}$$

$$U^{236}\ wt\% = (0.0046) * (U^{235}\ wt\%)$$

$$U^{238}\ wt\% = 100 - U^{234}\ wt\% - U^{235}\ wt\% - U^{236}\ wt\%$$

(Eq. 1)

5.2.2 Fuel Assembly Trajectory through Life

In order to compute the input variables to SAS2H for a specific fuel assembly enrichment, the process illustrated in Figure 1 must be followed. The parameters listed in Table 3 are the general BWR parameters used for the development of the SAS2H inputs, and calculations throughout Section 5.2.

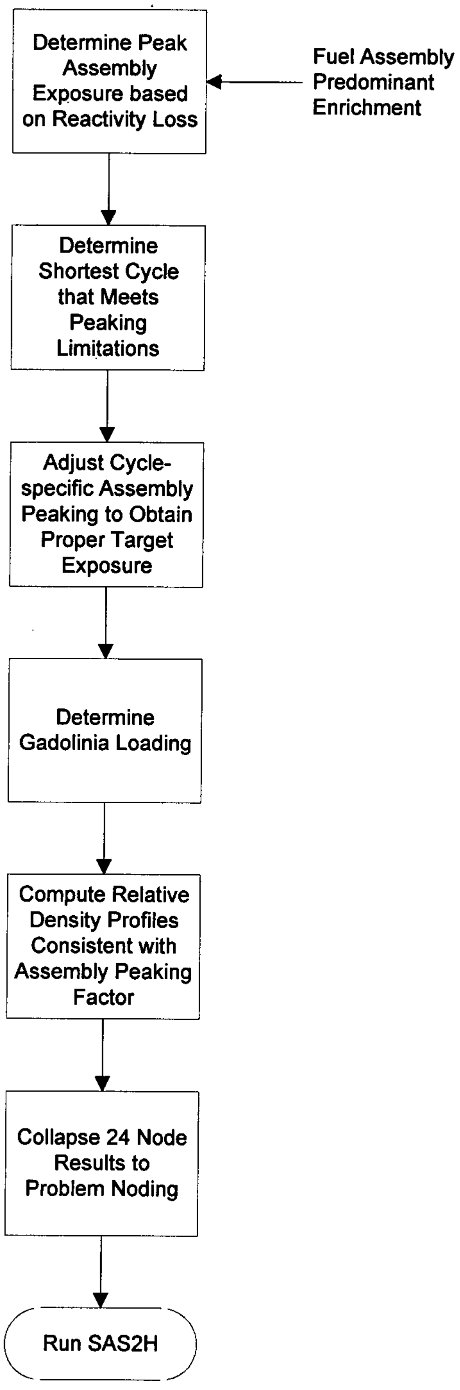


Figure 1. Flowchart for Specifying Input Parameters for SAS2H

Table 3. General BWR Parameters

Symbol	Description	Value	Units	Reference/Justification
PRATED	Rated Thermal Power	2511	MW_{th}	p. 3, Ref. 7.3
NA	Number of Fuel Assemblies	724	n/a	p. 3, Ref. 7.3
AAP	Average Power of Assembly	3.4682	MW_{th}	= PRATED/NA
EIC9	Cycle 9 Core Exposure Increment	6212.4	MWd/stU	p. 18, Ref. 7.3
EFPD9	Cycle 9 Core EFPD[d]	348.44	d (days)	p. 18, Ref. 7.3
CMST	Core Mass (Heavy Metal)	140.84	st (short ton)	= PRATED*EFPD9/EIC9
CMMT	Core Mass (Heavy Metal)	127.77	mt (metric ton)	= CMST/(1.1023 st/mt)
AFAM	Average Fuel Assembly Mass	0.1765	mt	= CMMT/NA
EGC9	Cycle 9 Energy Generated	874.9	GWd	= EIC9*CMST/1000
AAEC9	Assembly-Averaged Energy in Cycle 9	1.208	GWd	= EGC9/NA
EXPOSE	Exposure values	0	GWd/mtU	Selected range of application
		10		
		20		
		30		
		40		
		50		
ENRICH	Enrichment values	1.50	w/o	Selected range of application
		2.00		
		2.50		
		3.00		
		3.50		
		4.00		
		4.50		
		5.00		
AAPF1	Average Assembly Peaking Factor for Cycle 1	1.412	n/a	Table 6
AAPF2	Average Assembly Peaking Factor for Cycle 2	1.210	n/a	Table 6
AAPF3	Average Assembly Peaking Factor for Cycle 3	1.212	n/a	Table 6
AAPF4	Average Assembly Peaking Factor for Cycle 4	0.876	n/a	Table 6
LAAPF	Life-averaged Assembly Peaking Factor	1.177	n/a	AVERAGE(AAPF1,AAPF2, AAPF3, AAPF4)
POD	Fuel Pellet Diameter	1.0414	cm	p. 5, Ref. 7.3
CID	Cladding Inner Diameter	1.06426, 2.4561[c]	cm	p. 5, Ref. 7.3
COD	Cladding Outer Diameter	1.2268, 2.6187[c]	cm	p. 5, Ref. 7.3
AFL	Active Fuel Length	368.91	cm	p. 5, Ref. 7.3
NRODS	Fuel Rods per Fuel Assembly	60	n/a	Representative assembly specification
assempitch	Assembly pitch	15.24	cm	p. 5, Ref. 7.3
hlfbldthk	Half blade thickness	0.39624	cm	p. A-9, Ref. 7.16[a]
bldlnth	Blade length	24.36876	cm	p. A-9, Ref. 7.16[b]
rodpitch	Fuel rod pitch	1.6256	cm	p. 5, Ref. 7.3
inwidth	Inner width of channel	13.4061	cm	p. 5, Ref. 7.3
Cthickness	Channel thickness	0.2032	cm	p. 5, Ref. 7.3
outwidth	Outer width of channel	13.8125	cm	Inwidth+2*Cthickness

NOTES: [a] Calculated and converted to cm as half the blade thickness of 0.312 in.
[b] Calculated as follows: bldlnth = 4.875 in. + (4.875 in. – 0.5*0.312 in.) and converted to cm
[c] Dimension for 4 pin water rod
[d] EFPD = Effective Full Power Days

5.2.3 BWR Fuel Assembly Specification

This is a representative evaluation for a typical BWR fuel assembly following typical exposure and void history trajectories through life. The typical fuel assembly geometry chosen is an 8x8 design that is the bulk of discharged BWR assemblies. The specific fuel assembly geometric design chosen was a GE 8x8 design which incorporated a large central water rod that displaces four central fuel rods. This was selected since the 8x8 assembly design is well represented among the candidate fuel assemblies for the proposed repository. The typical assembly being represented has a single enrichment zone with six-inch natural uranium ends. Integral burnable absorber inventories will vary with enrichment but will be consistent with the lattice-averaged enrichments chosen for construction of the loading curve. This axial enrichment scheme is representative of the earlier population of 8x8 fuel assemblies. While later 8x8 fuel assemblies incorporated more sophisticated axial enrichment schemes with more axial zones, the variations were generally intended to meet thermal limit restrictions and cold shutdown margin requirements and have a second order effect on enrichment distribution.

The Quad Cities units are 724 assembly BWRs (p. 3, Reference 7.3) that are typical of domestic BWR's. During the cycles for which data are available, the core was operated in a "Control Cell Core (CCC) Operation" strategy, which was typical after its introduction in the 1970's. In this strategy only a fixed set of a few control blades are used during the cycle and those blades are surrounded by fuel assemblies in the third and fourth cycles of irradiation to mitigate challenges to fuel thermal-mechanical performance. The fuel assembly selected as representative of typical BWR spent fuel was one that resided in the core for four cycles and spent its last cycle in a location where a control blade was inserted rather than in a low-power peripheral location, thus maximizing its exposure and the plutonium bred into the assembly as a result of "spectral shift" operation.

5.2.4 Range of Corresponding Peaking Factors and Enrichment Ranges

For an 8x8 BWR fuel assembly the achievable exposure is limited by its initial enrichment, integral burnable absorber inventory (i.e., gadolinia loading), and thermal-hydraulic and thermal-mechanical limitations of the fuel rods – hereafter collectively referred to as the "thermal limits." To determine a valid range of target exposures for enrichments ranging from 1.5 wt% U-235 to 5.0 wt% U-235, fuel assembly peaking factors from cycle 9 of the Quad Cities Unit 2 core were considered. These peaking factors reflect the underlying thermal limits and restrict the target exposure that may be obtained for a given enrichment. While the energy that may be generated by an individual fuel assembly is limited by exhaustion of its fissile inventory, this effect has not been considered in the present evaluation.

For Cycle 9, the incremental exposures for an eighth of the core are shown in Figure 2 and the total energy generated by each fuel assembly is shown in Figure 3. The values listed in Figure 2 were computed by averaging the Quad Cities Unit 2, cycle 9 information reported in Tables 1 and 2 of Reference 7.26. The conversion between the exposure units and the energy was performed according to Equation 2. From the energy generated and the known rated thermal power of the core, the fuel assembly power peaking factors were generated as shown in Figure 4 (this value is computed by dividing the cycle energy for a cycle by the assembly-averaged energy for the core – AAEC9 in Table 3). Since the average cycle exposure for such fuel is about 6000 GWd/stU, the peaking factors were grouped into values consistent with fuel batches to obtain peaking factors as a function of fuel assembly cycle. These are illustrated in Figures 5 through 9.

$$\text{Energy}_{\text{Assembly}} = \frac{\text{Exposure}_{\text{Assembly}} \cdot \text{CMST}}{\text{NA} \cdot 1000(\text{MWd}/\text{GWd})} \quad \text{(Eq. 2)}$$

where

$\text{Exposure}_{\text{Assembly}}$ = assembly burnup (GWd/stU)
CMST = core mass in stU (see Table 3)
NA = number of assemblies in the core (see Table 3)

These values were grouped together according to the putative assembly cycle of residence and the location of the assembly as shown in Table 4. These values are used to establish an effective assembly peaking factor over four cycles for the "typical" assembly as shown in Table 6.

Table 4. Grouped Assembly Peaking Factors

	Total			Non-peripheral			Peripheral			Non-CCC[a]			CCC		
Cycle	AAPF[b]	s[c]	n[d]	AAPF	s	n	AAPF	s	n	AAPF	s	n	AAPF	s	n
1	1.412	0.051	19	1.412	0.051	19	n/a	n/a	n/a	1.412	0.051	19	n/a	n/a	0
2	1.197	0.158	25	1.197	0.158	25	n/a	n/a	n/a	1.210	0.155	19	1.021	0.140	3
3	1.075	0.144	18	1.075	0.144	18	n/a	n/a	n/a	1.212	0.064	6	1.012	0.126	11
4	0.660	0.273	26	0.725	0.244	22	0.301	0.017	4	0.745	0.276	11	0.876	0.112	6
5	0.295	0.117	8	0.534	n/a	1	0.261	0.072	7	0.534	n/a	1	n/a	n/a	n/a

NOTES: [a] Peripheral assemblies, if any, were not included
[b] AAPF = Average assembly peaking factor
[c] s = Standard deviation about the mean
[d] n = Number of peaking factors used in calculation of the average

In Figures 5 through 9 the distinction between the four different assembly groups are as follows:

- Non-peripheral – assemblies not in the following positions: (1,11); (1,12); (1,13); (1,14); (1,15); (2,10); (3,7); (3,8); (3,9); (4,6); or (5,5)

- Peripheral – Assemblies in the following positions: (1,11); (1,12); (1,13); (1,14); (1,15); (2,10); (3,7); (3,8); (3,9); (4,6); or (5,5)

- Non-CCC – Assemblies not within a four-box darkened border region

- CCC – Assemblies within a four-box darkened region

	5	6	7	8	9	10	11	12	13	14	15
1							1180	1552	1763	1948	1969
2						1814	2522	3023	3351	3855	3782
3			1222	1799	2512	3315	4330	4925	5261	6102	5190
4		1511	2394	3240	4011	5067	6501	7124	7436	7475	6395
5	1576	2597	3137	5507	5665	7103	6742	8676	8288	9032	8064
6		3685	5446	6431	8054	8710	8766	7625	9307	7672	8696
7			5405	5365	7735	8764	6997	6984	8428	8835	5866
8				5891	8812	8366	7008	7119	9212	8150	5778
9					8502	9226	7641	8879	7890	9032	7956
10						8002	8415	7915	8258	7602	8748
11							5477	5507	7840	8647	6742
12								5415	8396	7652	6671
13									7441	8195	8044
14										7461	8418
15											6027

Figure 2. Incremental Exposures for Cycle 9 of Quad Cities Unit 2 (MWd/stU)

	5	6	7	8	9	10	11	12	13	14	15
1							0.230	0.302	0.343	0.379	0.383
2						0.353	0.491	0.588	0.652	0.750	0.736
3			0.238	0.350	0.489	0.645	0.842	0.958	1.023	1.187	1.010
4		0.294	0.466	0.630	0.780	0.986	1.265	1.386	1.447	1.454	1.244
5	0.307	0.505	0.610	1.071	1.102	1.382	1.312	1.688	1.612	1.757	1.569
6		0.717	1.059	1.251	1.567	1.694	1.705	1.483	1.810	1.492	1.692
7			1.051	1.044	1.505	1.705	1.361	1.359	1.639	1.719	1.141
8				1.146	1.714	1.627	1.363	1.385	1.792	1.585	1.124
9					1.654	1.795	1.486	1.727	1.535	1.757	1.548
10						1.557	1.637	1.540	1.606	1.479	1.702
11							1.065	1.071	1.525	1.682	1.312
12								1.053	1.633	1.488	1.298
13									1.447	1.594	1.565
14										1.451	1.637
15											1.172

Figure 3. Fuel Assembly Energy Generated by Cycle 9 of Quad Cities Unit 2 (GWd)

	5	6	7	8	9	10	11	12	13	14	15
1							0.190	0.250	0.284	0.313	0.317
2						0.292	0.406	0.487	0.539	0.620	0.609
3			0.197	0.290	0.404	0.534	0.697	0.793	0.847	0.982	0.835
4		0.243	0.385	0.521	0.646	0.816	1.046	1.147	1.197	1.203	1.029
5	0.254	0.418	0.505	0.886	0.912	1.143	1.085	1.397	1.334	1.454	1.298
6		0.593	0.877	1.035	1.296	1.402	1.411	1.227	1.498	1.235	1.400
7			0.870	0.864	1.245	1.411	1.126	1.124	1.357	1.422	0.944
8				0.948	1.418	1.347	1.128	1.146	1.483	1.312	0.930
9					1.368	1.485	1.230	1.429	1.270	1.454	1.281
10						1.288	1.355	1.274	1.329	1.224	1.408
11							0.882	0.886	1.262	1.392	1.085
12								0.872	1.352	1.232	1.074
13									1.198	1.319	1.295
14										1.201	1.355
15											0.970

Figure 4. Assembly Power Peaking Factors

	5	6	7	8	9	10	11	12	13	14	15
1											
2											
3											
4											
5								1.397		1.454	
6					1.296	1.402	1.411		1.498		1.400
7						1.411				1.422	
8					1.418				1.483		
9						1.485		1.429		1.454	
10							1.355				1.408
11										1.392	
12									1.352		
13											
14											1.355
15											

Figure 5. Peaking Factors for First-cycle Assemblies

	5	6	7	8	9	10	11	12	13	14	15
1											
2											
3										0.982	
4							1.046	1.147	1.197	1.203	
5				0.886		1.143			1.334		1.298
6			0.877	1.035							
7			0.870		1.245				1.357		
8						1.347				1.312	
9					1.368						1.281
10						1.288		1.274	1.329		
11									1.262		
12										1.232	
13										1.319	1.295
14											
15											

Figure 6. Peaking Factors for Second-cycle Assemblies

	5	6	7	8	9	10	11	12	13	14	15
1											
2											
3								0.793			
4											
5							1.085				
6								1.227		1.235	
7							1.126	1.124			
8				0.948			1.128	1.146			0.930
9							1.230		1.270		
10										1.224	
11							0.882				1.085
12								0.872			1.074
13											
14											
15											0.970

Figure 7. Peaking Factors for Third-cycle Assemblies

	5	6	7	8	9	10	11	12	13	14	15
1									0.284	0.313	0.317
2							0.406	0.487	0.539	0.620	0.609
3				0.290			0.697		0.847		0.835
4			0.385	0.521	0.646	0.816					1.029
5		0.418	0.505		0.912						
6		0.593									
7				0.864							0.944
8											
9											
10											
11								0.886			
12											
13									1.198		
14										1.201	
15											

Figure 8. Peaking Factors for Fourth-cycle Assemblies

	5	6	7	8	9	10	11	12	13	14	15
1							0.190	0.250			
2						0.292					
3			0.197		0.404	0.534					
4		0.243									
5	0.254										
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											

Figure 9. Peaking Factors for Fifth-cycle Assemblies

For a given target exposure and cycle length, the necessary average assembly peaking factor may be computed as shown in Table 5. These values for the assumed constraints are shown in Table 6. Comparing the values from Table 6 with those from the Table 5, the maximum assembly peaking factor averaged over the four cycles of operation may be obtained. This is shown in Figure 10. Referring to that figure, only target exposures that are below the average peaking factor line meet thermal limits and are permitted.

Table 5. Assembly Peaking Factors to Reach Target Exposures

Target Exposure (GWd/mtU)	Target Energy (GWd)[a]	Average Fuel Assembly Power (MWth)[b]					Relative Average Fuel Assembly Power[c]				
		9 Months	12 Months	15 Months	18 Months	24 Months	9 Months	12 Months	15 Months	18 Months	24 Months
TEXP	TE	AFAP 9	AFAP 12	AFAP 15	AFAP 18	AFAP2 4	RAFAP 9	RAFAP 12	RAFAP 15	RAFAP 18	RAFAP 24
15	2.6471	2.416	1.812	1.449	1.208	0.906	0.697	0.522	0.418	0.348	0.261
20	3.5295	3.221	2.416	1.933	1.611	1.208	0.929	0.697	0.557	0.464	0.348
25	4.4119	4.026	3.020	2.416	2.013	1.510	1.161	0.871	0.697	0.580	0.435
30	5.2942	4.832	3.624	2.899	2.416	1.812	1.393	1.045	0.836	0.697	0.522
35	6.1766	5.637	4.228	3.382	2.818	2.114	1.625	1.219	0.975	0.813	0.609
40	7.0590	6.442	4.832	3.865	3.221	2.416	1.857	1.393	1.114	0.929	0.697
45	7.9413	7.247	5.436	4.348	3.624	2.718	2.090	1.567	1.254	1.045	0.784
50	8.8237	8.053	6.040	4.832	4.026	3.020	2.322	1.741	1.393	1.161	0.871
55	9.7061	8.858	6.643	5.315	4.429	3.322	2.554	1.916	1.532	1.277	0.958
60	10.5885	9.663	7.247	5.798	4.832	3.624	2.786	2.090	1.672	1.393	1.045

NOTES: [a] Values are calculated as TEXP*AFAM
[b] Values are calculated as TE*1000/(4*n*365.25/12), where "n" is the number of months
[c] Values are calculated as AFAPn/AAP, where "n" is the number of months of the individual

Table 6. Relative Average Assembly Peaking Factors

Cycle	Relative Peaking Factor (RPF)
1	1.412
2	1.210
3	1.212
4	0.876
Life-Averaged Peaking Factor	1.177

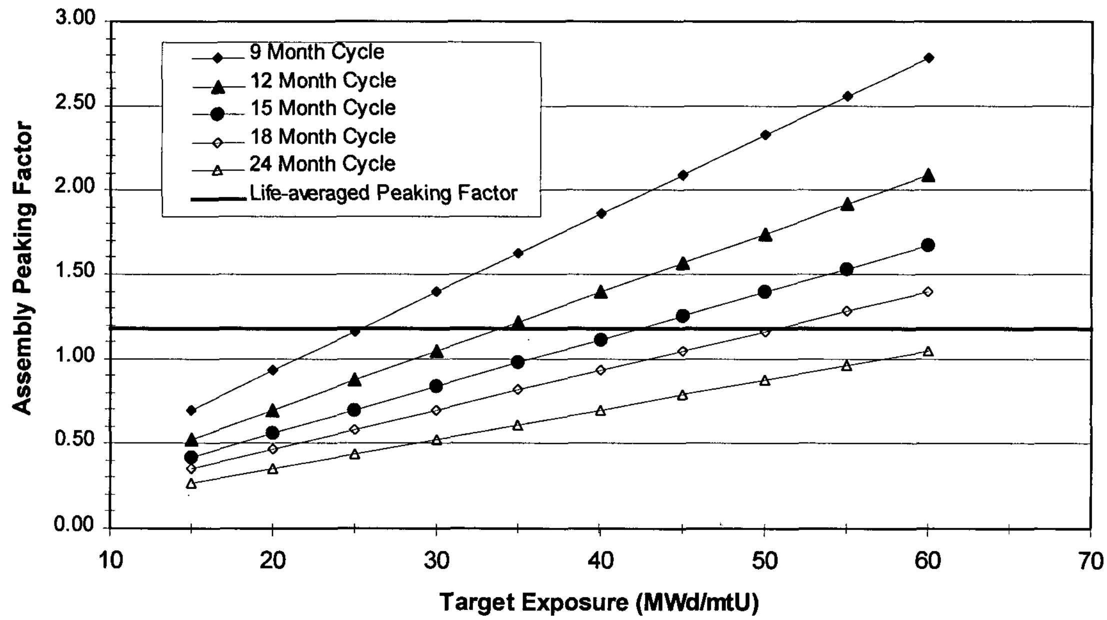


Figure 10. Assembly Peaking to Obtain Target Exposure

5.2.5 SAS2H Cladding, GDR, and Control Blade (CB) Materials

The fuel rod cladding material composition was given a temperature of 620 K, which is a typical fuel clad temperature during core operation. The fuel rod cladding and water rods were made up of Zircaloy-2 and the channel Zircaloy-4. Due to SAS2H limitations these were each represented as Zircaloy-4. The burnable absorber material was gadolinia, and the CBs were made up of B_4C granules inside of stainless steel 304 tubes and sheath (p. A-9, Ref. 7.16). The Zircaloy-4 cladding specifications used in the SAS2H input are presented in Table 7.

Table 7. SAS2H Zircaloy-4 Composition

Element	Composition ID	Wt%
Cr	24000	0.10
Fe	26000	0.21
O	8016	0.125
Sn	50000	1.45
Zr	40000	98.115
Density = 6.56 g/cm^3		

Source: Ref. 7.28

For a given initial enrichment, the corresponding gadolinia loading must be defined. To do this, known lattices deployed in the Quad Cities Units 1 and 2 core were surveyed and the lattice-averaged gadolinia concentration correlated with the linear fissile loading for the lattices. The inputs for the correlation are provided in Table 8 and are illustrated in Figure 11. The lattice averaged enrichment and corresponding GDR loading come from Table 5 of Reference 7.26. The trend was fit to a linear function in a least-squares sense and the results for the coefficients are shown in Table 9. While examination of Figure 11 suggests that a higher-dimension function may be more appropriate, the linear function was adequate for illustrative purposes.

Table 8. Gadolinia Loadings Used for Loading Functions

Lattice-averaged Enrichment (w/o)	Lattice Dimens-ionality	Total Number of Fuel Rods	Fuel Pellet Diameter (in)	Linear Loading U-235 (g/cm)	Total Number of Gadolinia-bearing Fuel Rods	Number of Gadolinia Fuel Rods	Gadolinia Concentration (w/o)	Lattice-averaged Gadolinia Concentration (w/o)
2.12	7	49	0.488	11.240	3	2 1	3.00 0.50	0.133
2.12	7	49	0.488	11.240	2	2	3.00	0.122
2.30	7	49	0.488	12.195	3	3	2.50	0.153
2.50	8	63	0.410	12.030	4	4	1.50	0.095
3.02	8	62	0.410	14.303	6	6	3.00	0.290
2.83	8	62	0.410	13.403	6	6	2.00	0.194
3.18	8	62	0.410	15.061	7	7	4.00	0.452
3.19	8	62	0.410	15.108	7	7	3.00	0.339
2.82	8	62	0.410	13.355	6	2	2.00	0.065
2.82	8	62	0.410	13.355	6	6	3.00	0.290
3.02	8	62	0.410	14.303	7	7	4.00	0.452
3.01	8	62	0.410	14.256	7	7	3.00	0.339
3.19	8	62	0.410	15.108	7	7	4.00	0.452
3.19	8	60	0.410	14.621	7	7	4.00	0.467

Table 8. Gadolinia Loadings Used for Loading Functions

Lattice-averaged Enrichment (w/o)	Lattice Dimens-ionality	Total Number of Fuel Rods	Fuel Pellet Diameter (in)	Linear Loading U-235 (g/cm)	Total Number of Gadolinia-bearing Fuel Rods	Number of Gadolinia Fuel Rods	Gadolinia Concentration (w/o)	Lattice-averaged Gadolinia Concentration (w/o)
3.20	8	60	0.410	14.667	9	9	4.00	0.600
2.82	8	62	0.410	13.355	6	6	3.00	0.290
3.20	8	60	0.410	14.667	9	9	3.00	0.450
3.37	8	60	0.410	15.446	7	7	4.00	0.467
3.34	8	60	0.410	15.309	7	7	3.00	0.350
3.50	8	60	0.410	16.042	9	2 7	4.00 3.00	0.483
3.50	8	60	0.410	16.042	7	7	3.00	0.350
3.34	8	60	0.410	15.309	7	7	3.00	0.350
3.22	8	60	0.410	14.759	9	9	3.00	0.450
3.37	8	60	0.410	15.446	11	2 9	4.00 3.00	0.583
3.37	8	60	0.410	15.446	9	9	3.00	0.450
3.22	8	60	0.410	14.759	9	9	3.00	0.450
3.20	8	60	0.410	14.667	9	3 6	3.00 2.00	0.350
3.20	8	60	0.410	14.667	6	6	2.00	0.200
2.78	8	60	0.410	12.741	7	4 3	4.00 3.00	0.417
2.90	8	60	0.410	13.291	7	4 3	4.00 3.00	0.417
2.78	8	60	0.410	12.741	7	4 3	4.00 3.00	0.417
2.77	8	60	0.410	12.695	7	7	3.00	0.350
2.88	8	60	0.410	13.200	9	2 7	4.00 3.00	0.483
2.88	8	60	0.410	13.200	7	7	3.00	0.350
2.77	8	60	0.410	12.695	7	7	3.00	0.350
3.06	8	60	0.410	14.025	7	7	3.00	0.350
3.24	8	60	0.410	14.850	7	7	3.00	0.350
3.06	8	60	0.410	14.025	7	7	3.00	0.350
3.06	8	60	0.410	14.025	7	7	3.00	0.350
3.24	8	60	0.410	14.850	9	2 7	4.00 3.00	0.483
3.24	8	60	0.410	14.850	7	7	3.00	0.350
3.06	8	60	0.410	14.025	7	7	3.00	0.350
3.24	8	60	0.410	14.850	7	7	3.00	0.350
3.39	8	60	0.410	15.538	7	7	3.00	0.350
3.39	8	60	0.410	15.538	7	3 4	4.00 3.00	0.400
3.34	8	60	0.410	15.309	7	7	3.00	0.350
3.50	8	60	0.410	16.042	7	7	3.00	0.350
3.34	8	60	0.410	15.309	7	7	3.00	0.350
3.32	8	60	0.410	15.217	10	8 2	4.00 3.00	0.633
3.48	8	60	0.410	15.951	10	8 2	4.00 3.00	0.633
3.32	8	60	0.410	15.217	10	8 2	4.00 3.00	0.633
3.36	8	60	0.410	15.401	7	7	3.00	0.350
3.54	8	60	0.410	16.226	7	1 6	4.00 3.00	0.367
3.36	8	60	0.410	15.401	7	3 4	4.00 3.00	0.400
3.41	8	60	0.410	15.630	8	8	3.00	0.400
3.57	8	60	0.410	16.363	8	6 2	4.00 3.00	0.500
3.41	8	60	0.410	15.630	8	6 2	4.00 3.00	0.500

Source: Table 5, Ref. 7.26

Table 9. Correlation Coefficients for Lattice Gadolinia Loading

Order	Lattice-Averaged Gadolinia Concentration	Average Number of Gadolinia-Bearing Fuel Rods
0	-0.46700	-4.92330
1	0.05845	0.83834

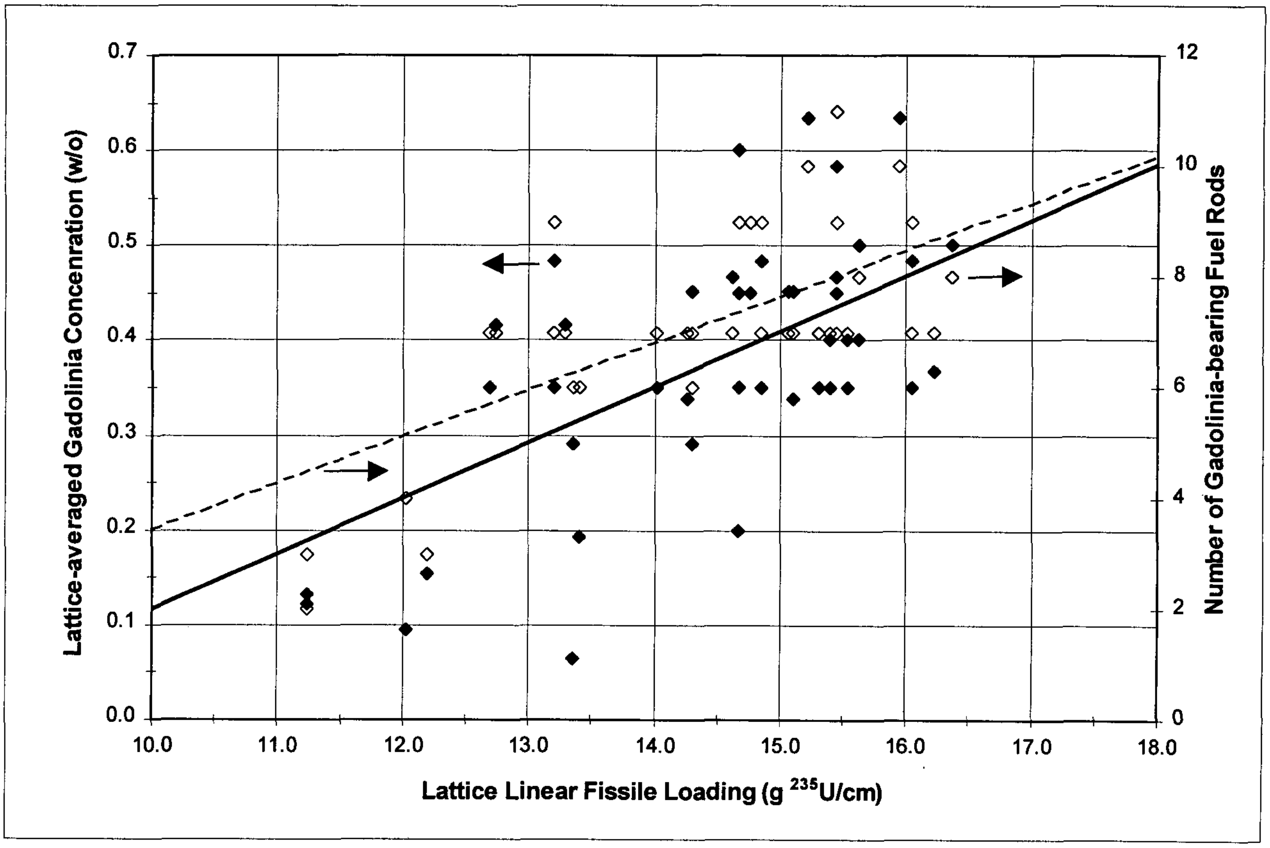


Figure 11. Typical Gadolinia Lattice Loading

Representation of the control blade in SAS2H requires it to be homogenized. The homogenized CB consisted of the amount of blade that a single fuel assembly would actually "see", as illustrated in Figure 12. The specifications for the CB come from page A-9 and C-9 of Reference 7.16 and are provided in Table 10. In order to determine the homogenized mixture composition for the SAS2H input, volume fractions of the represented CB were calculated using derived Equations 3 through 7.

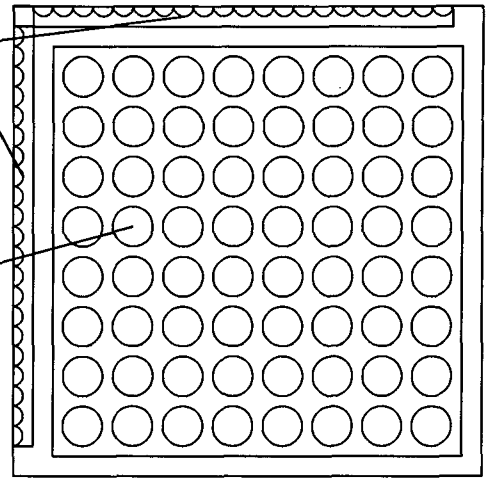


Figure 12. Cross Section of Fuel Assembly and Control Blade It "Sees"

Table 10. Control Rod Description

Description	Specifcation
Control material	B_4C granules in Type-304 stainless steel tubes and sheath
Material density	70% of theoretical
Number of control material tubes per rod	84
B_4C outer diameter	0.188 in. (0.47752 cm)
Tube wall thickness	0.025 in. (0.0635 cm)
Control blade span	4.875 in. (12.3825 cm)
Control blade full thickness	0.312 in. (0.79248 cm)
Sheath thickness	0.056 in. (0.14224 cm)
Central structure wing length	0.7815 in. (1.98501 cm)
CBVOL	9.65588 cm^2
B_4CVOL	2.026445 cm^2
CBHDWVOL	4.75879 cm^2
H_2OVOL	2.870642 cm^2
VF stainless steel 304 in CB	0.49284
VF B_4C in CB	0.20987
VF water in CB	0.29729
B_4C density	2.52 g/cm^3 (Ref. 7.34); (70% of theoretical = 1.764 g/cm^3)
Water density	0.7396 g/cm^3

The CB areal volume was calculated as follows:

$$CBVOL = hlfbldthk*bldlnth \qquad \text{(Eq. 3)}$$

where

hlfbldthk and *bldlnth* come from Table 3

The areal volume for the B_4C was calculated as follows:

$$B_4CVOL = \frac{\pi * AbsOD^2}{4} * 21$$

(Eq. 4)

where

AbsOD = B_4C outer diameter
21 = 42 half tubes

The areal volume for the blade hardware was calculated as follows:

$$CBHDWVOL = CBVOL - B_4CVOL - CWA$$

(Eq. 5)

where

CWA = the central structure wing area

The areal volume of the water inside the CB was calculated as follows:

$$H_2OVOL = CBVOL - CBHDWVOL - B_4CVOL$$

(Eq. 6)

The corresponding volume fractions for the materials that make up the CB were calculated as follows:

$$VF_i = \frac{VOL_i}{CBVOL}$$

(Eq. 7)

where

i is the component (e.g., stainless steel)

The values from Equations 3 through 7 used in derived Equations 8 through 10 were presented in Table 10. The base constituent materials – stainless steel 304 and B_4C – are presented in Table 11, and the homogenized composition for use in the SAS2H input are presented in Table 12.

$$\rho_{homogenized} = \sum_{m}^{M} [(\rho)_m (VF)_m]$$

(Eq. 8)

where

$\rho_{homogenized}$ = homogenized material density
m = a single component material of the homogenized material
M = total number of component materials in the homogenized material
ρ = the mass density of the component material
VF = volume fraction in homogenized material

$$(MF_m) = \left[\frac{(\rho)_m (VF)_m}{\rho_{homogenized}}\right]$$

(Eq. 9)

where

MF_m = mass fraction of component material in homogenized material

$$(WP_{homogenized}) = (MF_m)(WP_m)$$

(Eq. 10)

where

$WP_{homogenized}$ = weight percent of component material constituent in homogenized material
WP_m = weight percent of component material constituent in component material

Table 11. Base Constituent CB Materials

Stainless steel 304[a]		B_4C[b]	
Element/Isotope	**Wt%**	**Element/Isotope**	**Wt%**
C	0.08	C	21.737
N	0.1	B-10	14.425
Si	1.0	B-11	63.838
P	0.045	Density (g/cm^3)	2.52
S	0.030		
Cr	19.0		
Mn	2.0		
Fe	68.495		
Ni	9.25		
Density (g/cm^3)	7.94		

NOTES: [a] Values are from Reference 7.33
[b] Density comes from Reference 7.34, and material was only considered to be composed of natural B and carbon based on isotopic abundance and masses from page 18 of Reference 7.24.

Table 12. CB Homogenized Material Composition

Element/Isotope	Wt%	Element/Isotope	Wt%
C	1.85649	Fe	59.5197
N	0.0869	Ni	8.03792
Si	0.86896	H	0.54638
P	0.0391	O	4.33633
S	0.02607	B-10	1.18586
Cr	16.51032	B-11	5.24804
Mn	1.73793	Homogenized Density	4.50322 g/cm^3

5.2.6 Path B Input

The Path B model for the fuel assembly configuration is provided to the SAS2H control module. The primary concern in the development of the Path B model for PWR assemblies is the conservation of the fuel-to-moderator and the fuel-to-absorber mass ratios. The Path B model used in this evaluation is for a GE 8x8 fuel assembly with varied gadolinia burnable poison rods.

Figures 13 and 14 illustrate general diagrams (without radial dimensions) of the Path B models required to describe the different types of nodes. In the figures, R_n refers to the radial dimensions. The general model described in Figure 13 is used for all nodes that have no Gd_2O_3 (gadolinia) fuel rods (GDRs) present. Figure 14 shows the general Path B model for all nodes containing GDRs. In Figures 13 and 14, the control blade region is represented as bypass moderator during cycles with no control blade insertion. A listing of the equations used in the development of the radial dimensions in each of the Path B models is provided in Equations 11 through 17. Fuel pellet dimensions are equivalent for fuel rod and GDR calculations. For SAS2H modeling requirements unique to BWRs, fuel rod and GDR pellet dimensions were increased to the dimensions of the inner clad diameter and the material density was adjusted (smeared) accordingly. The control blade region (R_6-R_7) contains bypass moderator at a density of 0.7396 g/cm^3 (p. 5, Ref. 7.3) in nonbladed nodes and a homogenized control blade mixture for bladed nodes.

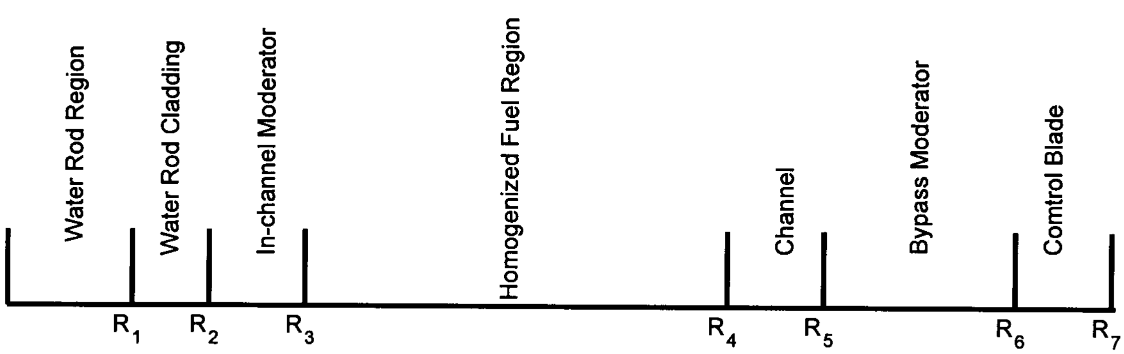


Figure 13. SAS2H General Path B Model for Nodes That Do Not Contain GDRs

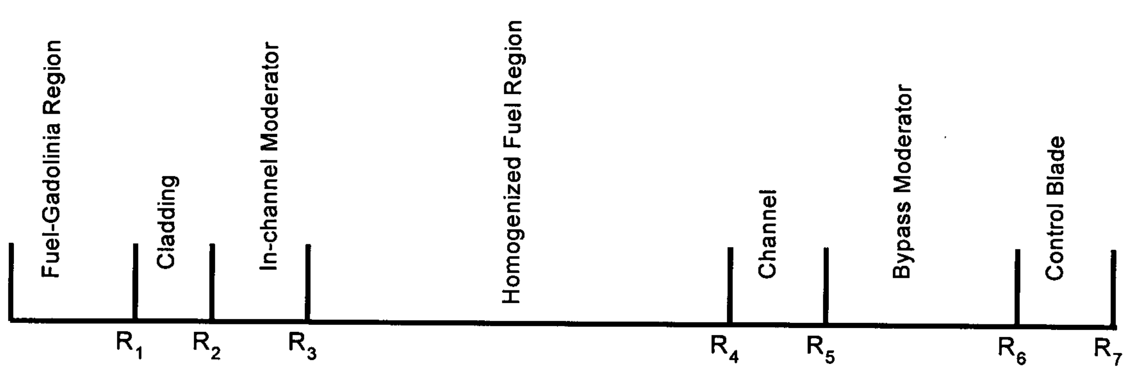


Figure 14. SAS2H General Path B Model for Nodes That Contain GDRs

The equations listed below were derived. All distance dimensions are in centimeters. All area dimensions are in square centimeters. All other parameters are dimensionless.

$$R_1 = \frac{CID}{2}$$

(Eq. 11)

where

R_1 = the radius of the center or first Path B zone
CID = the inner diameter of the cladding of either the GDR or the water rod

$$R_2 = \frac{COD}{2}$$

(Eq. 12)

where

R_2 = the radius of the second Path B zone
COD is the outer diameter of the cladding for either the water rod or GDR

$$R_3 = \sqrt{\frac{\#\,waterrods * rodpitch^2}{\pi}}$$

(Eq. 13)

where

R_3 = the radius of the third Path B zone
#waterrods = 4 for the current water rod model, and 1 for the GDR model
rodpitch = the fuel rod pitch of the assembly

$$R_4 = \sqrt{R_3^2 + \frac{(\#\,fuelrods - \#\,gdrods) * rodpitch^2}{\#\,gdrods * \pi}}$$

(Eq. 14)

where

R_3 = the radius of the third Path B zone
R_4 = the radius of the fourth Path B zone
#fuelrods = the total number of fuel and GDRs in the assembly
#gdrods = the number of GDRs in the assembly (note: in nodes that contain no GDRs the *#gdrods* term is completely removed from the above equation leaving only the *#fuelrods* term)
rodpitch = the fuel rod pitch of the assembly

$$R_5 = \sqrt{R_4^2 + \left[\frac{(outwidth^2 - inwidth^2)}{\pi} * \frac{1}{\#\,gdrods}\right]}$$

(Eq. 15)

where

R_4 = the radius of the fourth Path B zone
R_5 = the radius of the fifth Path B zone
#gdrods = the number of GDRs in the assembly (note: in nodes that contain no GDRs the *#gdrods* term is completely removed from the above equation)
outwidth = the outer width of the assembly channel
inwidth = the inner width of the assembly channel.

$$R_6 = \sqrt{\frac{[assempitch^2 - (hlfbldthk * bldlnth)]}{\pi} * \frac{1}{\# gdrods}}$$

(Eq. 16)

where

R_6 = the radius of the sixth Path B zone
#gdrods = the number of GDRs in the assembly (note: in nodes that contain no GDRs the *#gdrods* term is completely removed from the above equation)
assempitch = the assembly pitch of the Quad Cities 2 reactor
hlfbldthk = the half blade thickness of the control blade
bldlnth = the blade length "seen" by the assembly

$$R_7 = \sqrt{\frac{assempitch^2}{\pi} * \frac{1}{\# gdrods}}$$

(Eq. 17)

where

R_7 = the radius of the seventh Path B zone
#gdrods = the number of GDRs in the assembly (note: in nodes that contain no GDRs the *#gdrods* term is completely removed from the above equation)
assempitch = the assembly pitch of the Quad Cities 2 reactor

The constants used in Equations 11 through 17 to determine the Path B radii were presented in Table 3. The Path B radii and corresponding information used for each initial enrichment in this analysis are presented in Table 13. The U-235 linear loading was calculated using Equation 18, and used in conjunction with a linear fit whose coefficients are listed in Table 9 to determine the gadolinia loading. Ten axial nodes were used to represent the fuel assemblies.

$$Linear\ Fissile\ Loading = U235 * \rho * \frac{CID^2}{4} * \pi * NRODS$$

(Eq. 18)

where

U235 = weight percent of U-235 in the UO_2 matrix
ρ = smeared density of the UO_2 (g/cm^3)[a]

CID = inner diameter of the cladding (cm) as provided in Table 3
NRODS = number of fuel rods for the given assembly as given in Table 3

NOTE: [a] The smeared density is calculated based on multiplying the ratio of POD^2:CID^2 to 94% of theoretical density for UO_2 (10.97 g/cm^3 [p. 296, Ref. 7.18]), which results in a pellet density of 10.3 g/cm^3, and a smeared density of 9.86227 g/cm^3.

Table 13. SAS2H Path B Model Input Values

Initial Enrichment (Wt% U-235)[a]	Node	# Water Rods	Average Gadolinia Concentration (w/o)	Calculated Avg # of Gd rods	Path B Radii (cm)
2.0 U-235 Linear Loading = 9.2802 g/cm	1 & 10	4	N/A	N/A	R1 = 1.2281 R2 = 1.3094 R3 = 1.8343 R4 = 7.3372 R5 = 7.5733 R6 = 8.4176 R7 = 8.5983
	2 through 9	1	1.51	3	R1 = 0.5321 R2 = 0.6134 R3 = 0.9172 R4 = 4.1016 R5 = 4.2423 R6 = 4.8599 R7 = 4.9642
2.5 U-235 Linear Loading = 11.6001 g/cm	1 & 10	4	N/A	N/A	R1 = 1.2281 R2 = 1.3094 R3 = 1.8343 R4 = 7.3372 R5 = 7.5733 R6 = 8.4176 R7 = 8.5983
	2 through 9	1	2.53	5	R1 = 0.5321 R2 = 0.6134 R3 = 0.9172 R4 = 3.1771 R5 = 3.2861 R6 = 3.7645 R7 = 3.8453
3.0 U-235 Linear Loading = 13.9201 g/cm	1 & 10	4	N/A	N/A	R1 = 1.2281 R2 = 1.3094 R3 = 1.8343 R4 = 7.3372 R5 = 7.5733 R6 = 8.4176 R7 = 8.5983
	2 through 9	1	2.97	7	R1 = 0.5321 R2 = 0.6134 R3 = 0.9172 R4 = 2.6851 R5 = 2.7772 R6 = 3.1816 R7 = 3.2498

Table 13. SAS2H Path B Model Input Values

Initial Enrichment (Wt% U-235)[a]	Node	# Water Rods	Average Gadolinia Concentration (w/o)	Calculated Avg # of Gd rods	Path B Radii (cm)
3.5 U-235 Linear Loading = 16.2400 g/cm	1 & 10	4	N/A	N/A	R1 = 1.2281 R2 = 1.3094 R3 = 1.8343 R4 = 7.3372 R5 = 7.5733 R6 = 8.4176 R7 = 8.5983
	2 through 9	1	3.21	9	R1 = 0.5321 R2 = 0.6134 R3 = 0.9172 R4 = 2.3681 R5 = 2.4493 R6 = 2.8059 R7 = 2.8661
4.0 U-235 Linear Loading = 18.5598 g/cm	1 & 10	4	N/A	N/A	R1 = 1.2281 R2 = 1.3094 R3 = 1.8343 R4 = 7.3372 R5 = 7.5733 R6 = 8.4176 R7 = 8.5983
	2 through 9	1	3.37	11	R1 = 0.5321 R2 = 0.6134 R3 = 0.9172 R4 = 2.1420 R5 = 2.2155 R6 = 2.5380 R7 = 2.5925
4.5 U-235 Linear Loading = 20.8796 g/cm	1 & 10	4	N/A	N/A	R1 = 1.2281 R2 = 1.3094 R3 = 1.8343 R4 = 7.3372 R5 = 7.5733 R6 = 8.4176 R7 = 8.5983
	2 through 9	1	3.77	12	R1 = 0.5321 R2 = 0.6134 R3 = 0.9172 R4 = 2.0508 R5 = 2.1211 R6 = 2.4300 R7 = 2.4821
5.0 U-235 Linear Loading = 23.1994 g/cm	1 & 10	4	N/A	N/A	R1 = 1.2281 R2 = 1.3094 R3 = 1.8343 R4 = 7.3372 R5 = 7.5733 R6 = 8.4176 R7 = 8.5983

Table 13. SAS2H Path B Model Input Values

Initial Enrichment (Wt% U-235)[a]	Node	# Water Rods	Average Gadolinia Concentration (w/o)	Calculated Avg # of Gd rods	Path B Radii (cm)
	2 through 9	1	4.44	12	R1 = 0.5321
					R2 = 0.6134
					R3 = 0.9172
					R4 = 2.0508
					R5 = 2.1211
					R6 = 2.4300
					R7 = 2.4821

NOTE: [a] Nodes 1 & 10 are natural uranium (pp. 13-15, Ref. 7.3)

5.2.7 Axial Profiles

The axial relative power in each of the four cycles for which the fuel assembly is loaded in the core were obtained from arbitrary assemblies in cycle 9 of the Quad Cities Unit 2 core and are shown in Table 14 and illustrated in Figure 15. The values listed in Table 14 were calculated using Equation 19 along with information from Tables 1 and 2 of Reference 7.26. The core map index locations for the arbitrary assemblies selected from Reference 7.26 correspond as follows: 1 cycle burn (J6, I13); 2 cycle burn (J10, I12); 3 cycle burn (J5, I11); and 4 cycle burn (J3, I15).

$$RAP_i = \frac{EXPEOC9_i - EXPBOC9_i}{\left[\frac{\sum_{i=1}^{24} (EXPEOC9 - EXPBOC9)_i}{24} \right]}$$

(Eq. 19)

where

i = axial node
RAP_i = relative axial power for node i
$EXPEOC9i$ = assembly exposure at end of cycle (EOC) 9 for node i
$EXPBOC9i$ = assembly exposure at beginning of cycle (BOC) 9 for node i

Table 14. Relative Axial Power Profiles by Cycle of Exposure

Axial Node	Cycle 1	Cycle 2	Cycle 3	Cycle 4
24	0.1859	0.2504	0.2721	0.3161
23	0.4940	0.6164	0.6244	0.8008
22	0.6691	0.8019	0.8042	1.0004
21	0.8083	0.9167	0.9263	1.1114
20	0.9013	0.9856	1.0008	1.1649
19	0.9616	1.0295	1.0454	1.1899
18	1.0026	1.0602	1.0738	1.2021
17	1.0335	1.0843	1.0952	1.2095
16	1.0593	1.1044	1.1147	1.2155
15	1.0828	1.1215	1.1331	1.2187
14	1.1056	1.1358	1.1506	1.2171
13	1.1284	1.1468	1.1677	1.2089
12	1.1519	1.1545	1.1856	1.1928
11	1.1771	1.1592	1.1996	1.1680
10	1.2048	1.1611	1.2087	1.1345
9	1.2349	1.1678	1.2123	1.0937
8	1.2643	1.1791	1.2090	1.0481
7	1.2950	1.1941	1.1968	0.9991
6	1.3237	1.2075	1.1739	0.9491
5	1.3322	1.2042	1.1340	0.9035
4	1.3042	1.1686	1.0725	0.8673
3	1.1755	1.0664	0.9701	0.8293
2	0.8670	0.8364	0.7762	0.7217
1	0.2372	0.2474	0.2528	0.2376

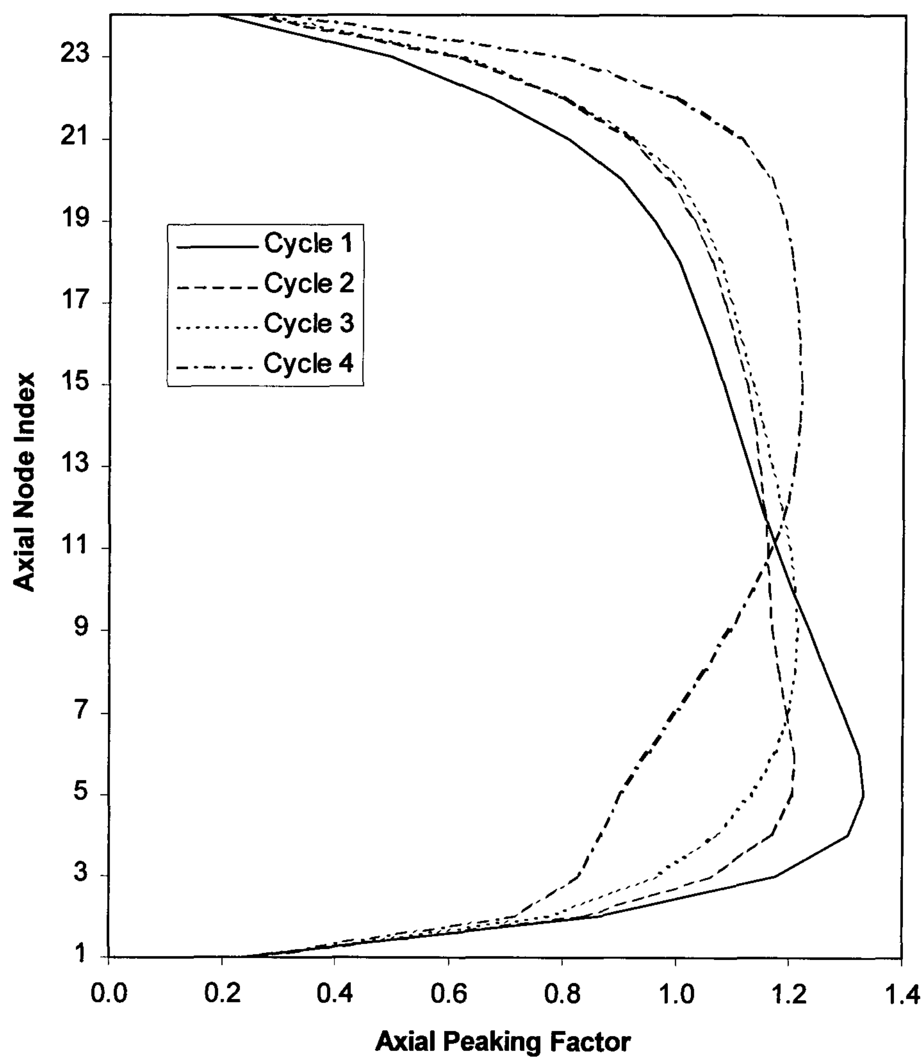


Figure 15. Cycle-specific Relative Axial Power Profiles

While these relative profiles are independent of the absolute fuel assembly power, the axial density profile within the fuel assembly is not. To provide a correlation relating the expected density profile to the axial power profile, several fuel assemblies from Cycle 9 of Quad Cities Unit 2 were examined. Since the density at any location axially up the channel is dependent on not only the power at that location but also on the power at lower locations, a correlation was developed as a function of the integrated relative power. Plots of density values as a function of integrated relative power are shown in Figure 16 for non-rodded locations and Figure 17 for rodded locations. The variation with channel integrated relative power is well fit as a quintic polynomial and the divergence with assembly relative power is addressed with an additive term that is linear with node index. The function form of this fit is shown in Equation 20 and the calculated coefficients and constants are presented in Table 15. The reference power and moderator densities correlated for come from Tables 1 through 4 of Reference 7.26. The nodal powers and corresponding average densities come from the following assembly positions:

(J2,I11); (J2,I14); (J3,I13); (J3,I14); (J4,I14); (J5,I15); (J6,I15); (J6,I13); (J3,I11); (J12,I12); (J8,I8); (J4,I15); and (J7,I12), where the nodal power was calculated using Equation 19 and the density per node was the average for that node.

$$\rho_{Relative} = \rho_{Ref} + \left[\sum_{i} C_i \cdot (IAPF_i - IAPF_{min})^i\right] + b \cdot n_z \cdot RPF \qquad (IAPF_i > IAPF_{min})$$

$$\rho_{Relative} = \rho_{Ref} \quad (IAPF_i \leq IAPF_{min})$$

(Eq. 20)

IAPF is the integrated channel power for axial node "n_z" and is computed as shown in Equation 21, where APF is the nodal relative power from the cycle-specific profile. $IAPF_{min}$ is a value below which the density is slowly varying and not well represented by the correlation; and RPF is the assembly relative peaking factor.

$$IAPF_i = \sum_{1}^{k} APF_k$$

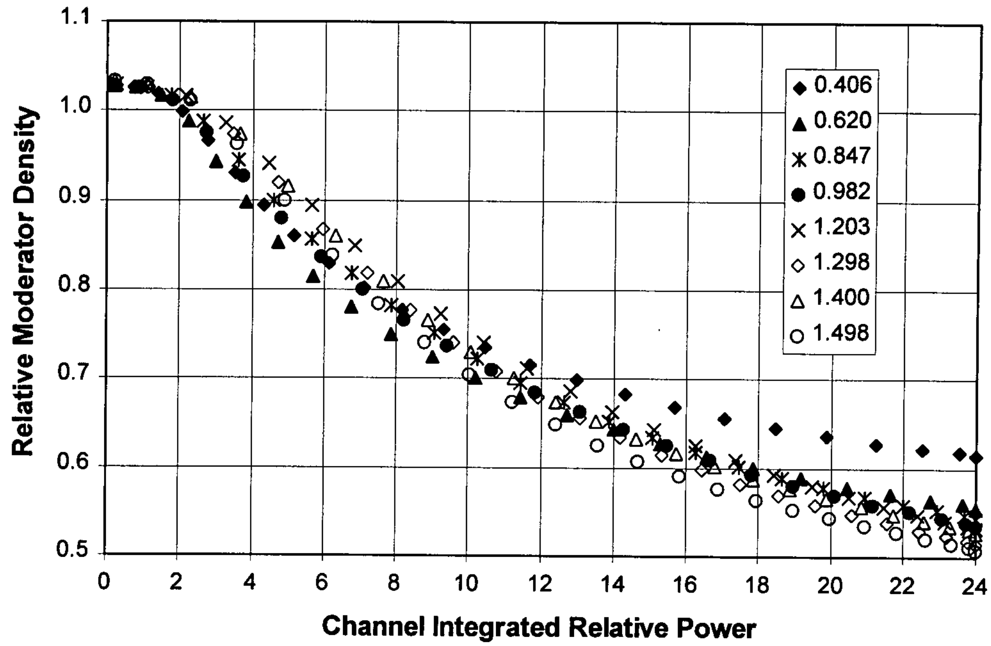
(Eq. 21)

where

k = number of nodes below current node i

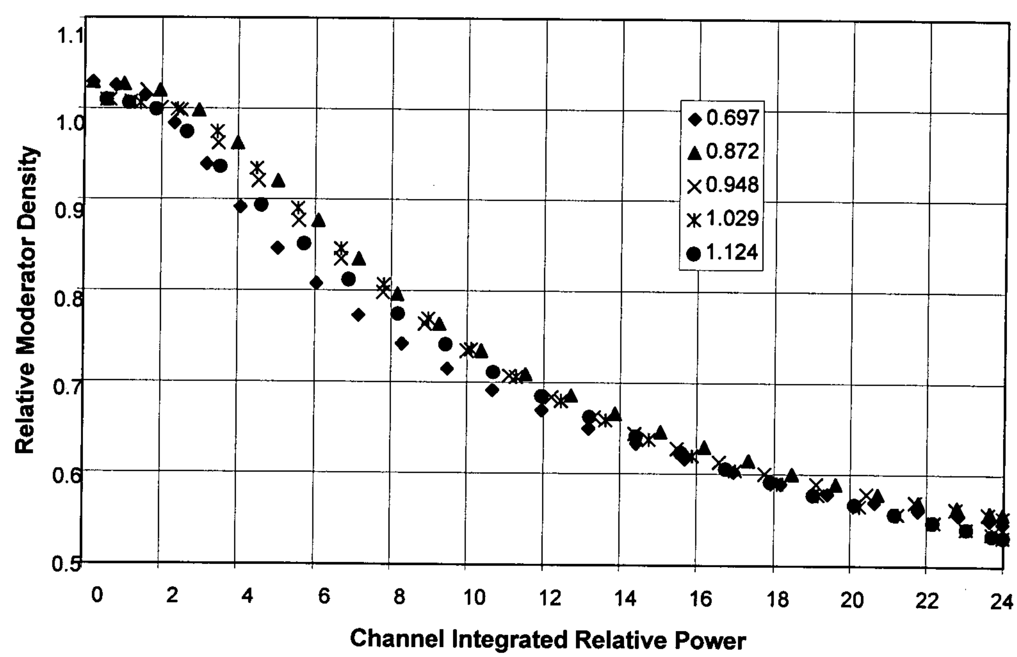
Table 15. Data and Constants for Determining Axial Moderator Density Profiles

Reference Moderator Density (g/cm^3)	$IAPF_{min}$	C_1	C_2	C_3	C_4	C_5	b
0.7396	2	-0.0558685	0.00386552	-0.00020915	7.32565E-06	-1.09444E-07	-2.41383E-03



NOTE: the legend represents the assembly relative power peaking factor

Figure 16. Moderator Density Profiles for Non-rodded Assemblies



NOTE: the legend represents the assembly relative power peaking factor

Figure 17. Moderator Density Profiles for Rodded Assemblies

5.2.8 Computation of Nodal Powers, Relative Water Densities, and Fuel Temperatures

5.2.8.1 Determination of Relative Peaking Factors

Tables 16 through 20 were used to determine the burn history for a given target burnup. The purpose of these calculations was to determine relative peaking factors (RPF's) (based on the given, typical peaking factors) that would allow for a given cycle length and target burnup. The typical representative assembly sees four cycles in a reactor, with the four RPF's shown in Table 6: 1.412, 1.21, 1.212, and 0.876. First, a required factor is determined for each cycle length, such that when multiplied by all of the RPF's, it would yield the required RPF for each cycle so that the target burnup could be reached with the given length of cycle. These factors are then multiplied by the original RPF's to determine new RPF's. From these new RPF's, a set is chosen based on the criteria that the RPF should not go below one for the first three cycles, and that as many of the four cycles were to be modeled as possible. In some cases, where there are more than one set of appropriate peaking factors, the set that is closest to the original RPF's is used. The RPF's chosen for each burnup are highlighted in Tables 16 through 20. To determine the required factor for each cycle length, and for the different possible number of cycles Equation 22 was used.

$$factor = \frac{(EXPOSE, \frac{MWd}{mtU})(NA)(AFAM, mtU)}{\sum_{\#ofcycles}(RPF_i * (PRATED, MW) * (Length_{cycle}, days))}$$

(Eq. 22)

where

parameters in Equation 22 come from Table 3.

In addition, for later use, cycle weighting factors were determined from the burnup achieved in each cycle. These weighting factors were determined only for burn histories that have more than one cycle. The factors were used to calculate cycle averaged moderator densities and fuel temperatures. These weighting factors were calculated by taking the burnup achieved in the cycle divided by the total burnup.

Table 16. Burnup History for 10,000 MWd/mtU Burnup

4 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	0.4002	0.3001	0.2401	0.2001	0.1501
3 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	0.4916	0.3687	0.2950	0.2458	0.1844
2 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	0.7189	0.5391	0.4313	0.3594	0.2696
1 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	1.3349	1.0012	0.8009	0.6674	0.5006
New RPF's					
4 Cycle Case	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	
9 month	0.5650	0.4842	0.4850	0.3506	
12 month	0.4238	0.3632	0.3638	0.2629	
15 month	0.3390	0.2905	0.2910	0.2103	
18 month	0.2825	0.2421	0.2425	0.1753	
24 month	0.2119	0.1816	0.1819	0.1315	
3 Cycle Case					
9 month	0.6942	0.5948	0.5958		
12 month	0.5206	0.4461	0.4469		
15 month	0.4165	0.3569	0.3575		
18 month	0.3471	0.2974	0.2979		
24 month	0.2603	0.2231	0.2234		
2 Cycle Case					
9 month	1.0150	0.8698			
12 month	0.7613	0.6524			
15 month	0.6090	0.5219			
18 month	0.5075	0.4349			
24 month	0.3806	0.3262			
1 Cycle Case					
9 month	1.8848				
12 month	1.4136				
15 month	1.1309				
18 month	0.9424				
24 month	0.7068				

Cycle Weighting Factors		
Cycle	**Burnup in Cycle (MWd/mtU)**	**Weighting Factor**
1	10000	1.00000
Total burnup	10000	1.00000

Table 17. Burnup History for 20,000 MWd/mtU Burnup

4 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	0.8004	0.6003	0.4802	0.4002	0.3001
3 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	0.9832	0.7374	0.5899	0.4916	0.3687
2 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	1.4377	1.0783	0.8626	0.7189	0.5391
1 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	2.6697	2.0023	1.6018	1.3349	1.0012
New RPF's					
4 Cycle Case	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	
9 month	1.1301	0.9684	0.9700	0.7011	
12 month	0.8476	0.7263	0.7275	0.5258	
15 month	0.6781	0.5811	0.5820	0.4207	
18 month	0.5650	0.4842	0.4850	0.3506	
24 month	0.4238	0.3632	0.3638	0.2629	
3 Cycle Case					
9 month	1.3883	1.1897	1.1917		
12 month	1.0412	0.8923	0.8937		
15 month	0.8330	0.7138	0.7150		
18 month	0.6942	0.5948	0.5958		
24 month	0.5206	0.4461	0.4469		
2 Cycle Case					
9 month	2.0300	1.7396			
12 month	1.5225	1.3047			
15 month	1.2180	1.0438			
18 month	1.0150	0.8698			
24 month	0.7613	0.6524			
1 Cycle Case					
9 month	3.7697				
12 month	2.8272				
15 month	2.2618				
18 month	1.8848				
24 month	1.4136				
Cycle Weighting Factors					
Cycle	**Burnup in Cycle (MWd/mtU)**	**Weighting Factor**			
1	7366	0.36828			
2	6312	0.31560			
3	6322	0.31612			
Total burnup	20000	1.00000			

Table 18. Burnup History for 30,000 MWd/mtU Burnup

4 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	1.2005	0.9004	0.7203	0.6003	0.4502
3 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	1.4748	1.1061	0.8849	0.7374	0.5531
2 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	2.1566	1.6174	1.2939	1.0783	0.8087
1 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	4.0046	3.0035	2.4028	2.0023	1.5017
New RPF's					
4 Cycle Case	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	
9 month	1.6951	1.4526	1.4550	1.0517	
12 month	1.2714	1.0895	1.0913	0.7887	
15 month	1.0171	0.8716	0.8730	0.6310	
18 month	0.8476	0.7263	0.7275	0.5258	
24 month	0.6357	0.5447	0.5456	0.3944	
3 Cycle Case					
9 month	2.0825	1.7845	1.7875		
12 month	1.5618	1.3384	1.3406		
15 month	1.2495	1.0707	1.0725		
18 month	1.0412	0.8923	0.8937		
24 month	0.7809	0.6692	0.6703		
2 Cycle Case					
9 month	3.0451	2.6094			
12 month	2.2838	1.9571			
15 month	1.8270	1.5657			
18 month	1.5225	1.3047			
24 month	1.1419	0.9785			
1 Cycle Case					
9 month	5.6545				
12 month	4.2409				
15 month	3.3927				
18 month	2.8272				
24 month	2.1204				

Cycle Weighting Factors		
Cycle	**Burnup in Cycle (MWd/mtU)**	**Weighting Factor**
1	8994	0.29979
2	7707	0.25690
3	7720	0.25732
4	5580	0.18599
Total burnup	30000	1.00000

Table 19. Burnup History for 40,000 MWd/mtU Burnup

4 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	1.6007	1.2005	0.9604	0.8004	0.6003
3 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	1.9664	1.4748	1.1799	0.9832	0.7374
2 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	2.8754	2.1566	1.7252	1.4377	1.0783
1 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	5.3395	4.0046	3.2037	2.6697	2.0023

New RPF's				
4 Cycle Case	**Cycel 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
9 month	2.2602	1.9369	1.9401	1.4022
12 month	1.6951	1.4526	1.4550	1.0517
15 month	1.3561	1.1621	1.1640	0.8413
18 month	1.1301	0.9684	0.9700	0.7011
24 month	0.8476	0.7263	0.7275	0.5258
3 Cycle Case				
9 month	2.7766	2.3794	2.3833	
12 month	2.0825	1.7845	1.7875	
15 month	1.6660	1.4276	1.4300	
18 month	1.3883	1.1897	1.1917	
24 month	1.0412	0.8923	0.8937	
2 Cycle Case				
9 month	4.0601	3.4792		
12 month	3.0451	2.6094		
15 month	2.4360	2.0875		
18 month	2.0300	1.7396		
24 month	1.5225	1.3047		
1 Cycle Case				
9 month	7.5393			
12 month	5.6545			
15 month	4.5236			
18 month	3.7697			
24 month	2.8272			

Cycle Weighting Factors		
Cycle	**Burnup in Cycle (MWd/mtU)**	**Weighting Factor**
1	11991	0.29979
2	10276	0.25690
3	10293	0.25732
4	7439	0.18599
Total burnup	40000	1.00000

Table 20. Burnup History for 50,000 MWd/mtU Burnup

4 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	2.0009	1.5007	1.2005	1.0004	0.7503
3 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	2.4580	1.8435	1.4748	1.2290	0.9218
2 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	3.5943	2.6957	2.1566	1.7971	1.3478
1 Cycle Case					
length of cycles (months):	9	12	15	18	24
length of cycles (days):	270	360	450	540	720
needed factor:	6.6743	5.0058	4.0046	3.3372	2.5029

New RPF's				
4 Cycle Case	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
9 month	2.8252	2.4211	2.4251	1.7528
12 month	2.1189	1.8158	1.8188	1.3146
15 month	1.6951	1.4526	1.4550	1.0517
18 month	1.4126	1.2105	1.2125	0.8764
24 month	1.0595	0.9079	0.9094	0.6573
3 Cycle Case				
9 month	3.4708	2.9742	2.9792	
12 month	2.6031	2.2307	2.2344	
15 month	2.0825	1.7845	1.7875	
18 month	1.7354	1.4871	1.4896	
24 month	1.3015	1.1153	1.1172	
2 Cycle Case				
9 month	5.0751	4.3491		
12 month	3.8063	3.2618		
15 month	3.0451	2.6094		
18 month	2.5376	2.1745		
24 month	1.9032	1.6309		
1 Cycle Case				
9 month	9.4242			
12 month	7.0681			
15 month	5.6545			
18 month	4.7121			
24 month	3.5341			

Cycle Weighting Factors		
Cycle	**Burnup in Cycle (MWd/mtU)**	**Weighting Factor**
1	14989	0.29979
2	12845	0.25690
3	12866	0.25732
4	9299	0.18599
Total burnup	50000	1.00000

5.2.8.2 Node Height and APF Determination

Table 21 illustrates the nodal collapsing scheme utilized to collapse the original 24 axial nodes down to ten. The purpose for collapsing the nodes was for decreasing the amount of computer time required to process the information for the generation of eigenvalues. This was done by deciding where the node breaks would be based on Table 14 and Figure 15, and then collapsing the axial peaking factors (APF) for each node by performing a length weighted average of the APF's being collapsed into one node. The formula used was as follows:

$$APF_{collapsed} = \frac{\sum_{i=1}^{\#nodes} height_i * APF_i}{height_{collapsed}}$$

(Eq. 23)

where

$height_i$ = node height (cm)
APF_i = nodal axial peaking factor
$height_{collapsed}$ = total height of nodes being collapsed into one (cm)

Table 21. Relative Axial Power Profiles by Cycle of Exposure

Node	Node height (cm)	Cycle 1	Cycle 2	Cycle 3	Cycle 4	New nodes
24	15.24	0.1859	0.2504	0.2721	0.3161	10
23	15.24	0.4940	0.6164	0.6244	0.8008	9
22	16.29	0.6691	0.8019	0.8042	1.0004	
21	16.29	0.8083	0.9167	0.9263	1.1114	
20	16.29	0.9013	0.9856	1.0008	1.1649	
19	15.24	0.9616	1.0295	1.0454	1.1899	8
18	15.24	1.0026	1.0602	1.0738	1.2021	
17	15.24	1.0335	1.0843	1.0952	1.2095	
16	15.24	1.0593	1.1044	1.1147	1.2155	7
15	15.24	1.0828	1.1215	1.1331	1.2187	
14	15.24	1.1056	1.1358	1.1506	1.2171	
13	15.24	1.1284	1.1468	1.1677	1.2089	6
12	15.24	1.1519	1.1545	1.1856	1.1928	
11	15.24	1.1771	1.1592	1.1996	1.168	
10	15.24	1.2048	1.1611	1.2087	1.1345	5
9	15.24	1.2349	1.1678	1.2123	1.0937	
8	15.24	1.2643	1.1791	1.209	1.0481	4
7	15.24	1.2950	1.1941	1.1968	0.9991	
6	15.24	1.3237	1.2075	1.1739	0.9491	
5	15.24	1.3322	1.2042	1.134	0.9035	3
4	15.24	1.3042	1.1686	1.0725	0.8673	
3	15.24	1.1755	1.0664	0.9701	0.8293	2
2	15.24	0.867	0.8364	0.7762	0.7217	
1	15.24	0.2372	0.2474	0.2528	0.2376	1

Collapsed Axial Power Profiles by Cycle of Exposure

Collapsed Nodes	Node height (cm)	Cycle 1	Cycle 2	Cycle 3	Cycle 4
10	15.24	0.1859	0.2504	0.2721	0.3161
9	64.11	0.7218	0.8337	0.8424	1.0230
8	45.72	0.9992	1.0580	1.0715	1.2005
7	45.72	1.0826	1.1206	1.1328	1.2171
6	45.72	1.1525	1.1535	1.1843	1.1899
5	30.48	1.2199	1.1645	1.2105	1.1141
4	45.72	1.2943	1.1936	1.1932	0.9988
3	30.48	1.3182	1.1864	1.1033	0.8854
2	30.48	1.0213	0.9514	0.8732	0.7755
1	15.24	0.2372	0.2474	0.2528	0.2376

5.2.8.3 Axial Moderator Density Profiles

The determination of the axial moderator density profiles are presented in Tables 22 through 26. The profiles were calculated based on Equation 20 with the coefficients shown in Table 15, and the relative peaking factors for cycles and selected burnup values derived in Tables 16 through 20. The reference fluid density was determined by interpolation from page 654 of Reference 7.18. The cycle averaged moderator density profiles used in the SAS2H input are presented in Table 27 and were calculated using Equation 24.

$$\rho_{avg} = \sum_{\# of\ cycles} W_i * \rho_i$$

(Eq. 24)

where

W = cycle weighting factor
ρ = relative density

Table 22. Axial Moderator Density Profile for 10,000 MWd/mtU Burnup

Cycle 1				
Node	APF	IAPF	$IAPF-IAPF_{min}$	Relative Density (g/cm^3)
10	0.1859	9.2328	7.2328	0.4424
9	0.7218	9.0469	7.0469	0.4501
8	0.9992	8.3251	6.3251	0.4713
7	1.0826	7.3259	5.3259	0.5016
6	1.1525	6.2433	4.2433	0.5379
5	1.2199	5.0908	3.0908	0.5812
4	1.2943	3.8710	1.8710	0.6337
3	1.3182	2.5767	0.5767	0.6984
2	1.0213	1.2585	-	0.7396
1	0.2372	0.2372	-	0.7396

Table 23. Axial Moderator Density Profile for 20,000 MWd/mtU Burnup

Cycle 1					Cycle 2			
Node	APF	IAPF	$IAPF-IAPF_{min}$	Relative density (g/cm^3)	APF	IAPF	$IAPF-IAPF_{min}$	Relative density (g/cm^3)
10	0.1859	9.2328	7.2328	0.4430	0.2504	9.1593	7.15933	0.4495
9	0.7218	9.0469	7.0469	0.4507	0.8337	8.9089	6.90893	0.4583
8	0.9992	8.3251	6.3251	0.4718	1.0580	8.0753	6.07528	0.4821
7	1.0826	7.3259	5.3259	0.5021	1.1206	7.0173	5.01728	0.5144
6	1.1525	6.2433	4.2433	0.5383	1.1535	5.8967	3.89672	0.5526
5	1.2199	5.0908	3.0908	0.5816	1.1645	4.7432	2.74322	0.5972
4	1.2943	3.8710	1.8710	0.6339	1.1936	3.5788	1.57877	0.6488
3	1.3182	2.5767	0.5767	0.6986	1.1864	2.3852	0.38520	0.7100
2	1.0213	1.2585	-	0.7396	0.9514	1.1988	-	0.7396
1	0.2372	0.2372	-	0.7396	0.2474	0.2474	-	0.7396

Cycle 3				
Node	APF	IAPF	$IAPF-IAPF_{min}$	Relative density (g/cm^3)
10	0.2721	9.1360	7.1360	0.4500
9	0.8424	8.8639	6.8639	0.4593
8	1.0715	8.0215	6.0215	0.4834
7	1.1328	6.9500	4.9500	0.5163
6	1.1843	5.8172	3.8172	0.5552
5	1.2105	4.6329	2.6329	0.6014
4	1.1932	3.4224	1.4224	0.6559
3	1.1033	2.2292	0.2292	0.7184
2	0.8732	1.1260	-	0.7396
1	0.2528	0.2528	-	0.7396

Table 24. Axial Moderator Density Profile for 30,000 MWd/mtU Burnup

	Cycle 1				Cycle 2			
Node	APF	IAPF	IAPF-$IAPF_{min}$	Relative density (g/cm^3)	APF	IAPF	IAPF-$IAPF_{min}$	Relative density (g/cm^3)
10	0.1859	9.2328	7.2328	0.4458	0.2504	9.1593	7.15933	0.4519
9	0.7218	9.0469	7.0469	0.4532	0.8337	8.9089	6.90893	0.4604
8	0.9992	8.3251	6.3251	0.4740	1.0580	8.0753	6.07528	0.4840
7	1.0826	7.3259	5.3259	0.5040	1.1206	7.0173	5.01728	0.5161
6	1.1525	6.2433	4.2433	0.5400	1.1535	5.8967	3.89672	0.5540
5	1.2199	5.0908	3.0908	0.5830	1.1645	4.7432	2.74322	0.5984
4	1.2943	3.8710	1.8710	0.6350	1.1936	3.5788	1.57877	0.6497
3	1.3182	2.5767	0.5767	0.6994	1.1864	2.3852	0.38520	0.7108
2	1.0213	1.2585	-	0.7396	0.9514	1.1988	-	0.7396
1	0.2372	0.2372	-	0.7396	0.2474	0.2474	-	0.7396
	Cycle 3				Cycle 4			
Node	APF	IAPF	IAPF-$IAPF_{min}$	Relative density (g/cm^3)	APF	IAPF	IAPF-$IAPF_{min}$	Relative density (g/cm^3)
10	0.2721	9.1360	7.1360	0.4524	0.3161	8.9579	6.9579	0.4639
9	0.8424	8.8639	6.8639	0.4615	1.0230	8.6418	6.6418	0.4735
8	1.0715	8.0215	6.0215	0.4854	1.2005	7.6189	5.6189	0.5021
7	1.1328	6.9500	4.9500	0.5180	1.2171	6.4184	4.4184	0.5395
6	1.1843	5.8172	3.8172	0.5567	1.1899	5.2013	3.2013	0.5828
5	1.2105	4.6329	2.6329	0.6026	1.1141	4.0114	2.0114	0.6318
4	1.1932	3.4224	1.4224	0.6568	0.9988	2.8973	0.8973	0.6848
3	1.1033	2.2292	0.2292	0.7191	0.8854	1.8985	-	0.7396
2	0.8732	1.1260	-	0.7396	0.7755	1.0131	-	0.7396
1	0.2528	0.2528	-	0.7396	0.2376	0.2376	-	0.7396

Table 25. Axial Moderator Density Profile for 40,000 MWd/mtU Burnup

	Cycle 1				Cycle 2			
Node	APF	IAPF	IAPF-$IAPF_{min}$	Relative density (g/cm^3)	APF	IAPF	IAPF-$IAPF_{min}$	Relative density (g/cm^3)
10	0.1859	9.2328	7.2328	0.4437	0.2504	9.1593	7.15933	0.4501
9	0.7218	9.0469	7.0469	0.4514	0.8337	8.9089	6.90893	0.4589
8	0.9992	8.3251	6.3251	0.4724	1.0580	8.0753	6.07528	0.4826
7	1.0826	7.3259	5.3259	0.5026	1.1206	7.0173	5.01728	0.5148
6	1.1525	6.2433	4.2433	0.5387	1.1535	5.8967	3.89672	0.5530
5	1.2199	5.0908	3.0908	0.5819	1.1645	4.7432	2.74322	0.5975
4	1.2943	3.8710	1.8710	0.6342	1.1936	3.5788	1.57877	0.6490
3	1.3182	2.5767	0.5767	0.6988	1.1864	2.3852	0.38520	0.7102
2	1.0213	1.2585	-	0.7331	0.9514	1.1988	-	0.7396
1	0.2372	0.2372	-	0.7363	0.2474	0.2474	-	0.7396
	Cycle 3				**Cycle 4**			
Node	**APF**	**IAPF**	**IAPF-$IAPF_{min}$**	**Relative density (g/cm^3)**	**APF**	**IAPF**	**IAPF-$IAPF_{min}$**	**Relative density (g/cm^3)**
10	0.2721	9.1360	7.1360	0.4506	0.3161	8.9579	6.9579	0.4626
9	0.8424	8.8639	6.8639	0.4599	1.0230	8.6418	6.6418	0.4723
8	1.0715	8.0215	6.0215	0.4840	1.2005	7.6189	5.6189	0.5011
7	1.1328	6.9500	4.9500	0.5168	1.2171	6.4184	4.4184	0.5386
6	1.1843	5.8172	3.8172	0.5556	1.1899	5.2013	3.2013	0.5821
5	1.2105	4.6329	2.6329	0.6018	1.1141	4.0114	2.0114	0.6311
4	1.1932	3.4224	1.4224	0.6561	0.9988	2.8973	0.8973	0.6843
3	1.1033	2.2292	0.2292	0.7186	0.8854	1.8985	-	0.7396
2	0.8732	1.1260	-	0.7396	0.7755	1.0131	-	0.7396
1	0.2528	0.2528	-	0.7396	0.2376	0.2376	-	0.7396

Table 26. Axial Moderator Density Profile for 50,000 MWd/mtU Burnup

	Cycle 1				Cycle 2			
Node	APF	IAPF	IAPF-IAPF$_{min}$	Relative density (g/cm^3)	APF	IAPF	IAPF-IAPF$_{min}$	Relative density (g/cm^3)
10	0.1859	9.2328	7.2328	0.4424	0.2504	9.1593	7.15933	0.4490
9	0.7218	9.0469	7.0469	0.4501	0.8337	8.9089	6.90893	0.4578
8	0.9992	8.3251	6.3251	0.4713	1.0580	8.0753	6.07528	0.4817
7	1.0826	7.3259	5.3259	0.5017	1.1206	7.0173	5.01728	0.5140
6	1.1525	6.2433	4.2433	0.5379	1.1535	5.8967	3.89672	0.5523
5	1.2199	5.0908	3.0908	0.5813	1.1645	4.7432	2.74322	0.5969
4	1.2943	3.8710	1.8710	0.6337	1.1936	3.5788	1.57877	0.6486
3	1.3182	2.5767	0.5767	0.6984	1.1864	2.3852	0.38520	0.7099
2	1.0213	1.2585	-	0.7396	0.9514	1.1988	-	0.7396
1	0.2372	0.2372	-	0.7396	0.2474	0.2474	-	0.7396
	Cycle 3				Cycle 4			
Node	APF	IAPF	IAPF-IAPF$_{min}$	Relative density (g/cm^3)	APF	IAPF	IAPF-IAPF$_{min}$	Relative density (g/cm^3)
10	0.2721	9.1360	7.1360	0.4495	0.3161	8.9579	6.9579	0.4618
9	0.8424	8.8639	6.8639	0.4589	1.0230	8.6418	6.6418	0.4716
8	1.0715	8.0215	6.0215	0.4830	1.2005	7.6189	5.6189	0.5004
7	1.1328	6.9500	4.9500	0.5160	1.2171	6.4184	4.4184	0.5380
6	1.1843	5.8172	3.8172	0.5549	1.1899	5.2013	3.2013	0.5815
5	1.2105	4.6329	2.6329	0.6012	1.1141	4.0114	2.0114	0.6307
4	1.1932	3.4224	1.4224	0.6557	0.9988	2.8973	0.8973	0.6840
3	1.1033	2.2292	0.2292	0.7182	0.8854	1.8985	-	0.7396
2	0.8732	1.1260	-	0.7396	0.7755	1.0131	-	0.7396
1	0.2528	0.2528	-	0.7396	0.2376	0.2376	-	0.7396

Table 27. Cycle Averaged Moderator Density Profiles

Node	10,000 MWd/mtU	20,000 MWd/mtU	30,000 MWd/mtU	40,000 MWd/mtU	50,000 MWd/mtU
10	0.4424	0.4472	0.4524	0.4507	0.4495
9	0.4501	0.4558	0.4610	0.4594	0.4583
8	0.4713	0.4787	0.4847	0.4833	0.4824
7	0.5016	0.5105	0.5173	0.5161	0.5153
6	0.5379	0.5482	0.5558	0.5548	0.5541
5	0.5812	0.5928	0.6011	0.6002	0.5996
4	0.6337	0.6456	0.6537	0.6530	0.6525
3	0.6984	0.7085	0.7149	0.7144	0.7141
2	0.7396	0.7396	0.7396	0.7376	0.7396
1	0.7396	0.7396	0.7396	0.7386	0.7396

5.2.8.4 Axial Fuel Temperature Profiles

The fuel temperature corresponding to the nodal power was computed from the nodal power in accordance with Equations 25 through 32 using the constants shown in Table 28. Specific approximations inherent in that treatment are as follows:

- heat transfer between the outer surface of the fuel rod and the coolant was assumed to be completely efficient (i.e., there is no temperature jump across the boundary layer) -- this is a reasonable assumption for boiling heat transfer and should have an acceptably small effect on fuel temperature;

- the fuel conductivity is assumed to be invariant with radial temperature distribution and fuel exposure–since the fuel temperature is lumped in the SAS2H depletion model, this is acceptable.

The axial fuel temperature profiles are presented in Tables 29 through 33. The cycle averaged axial fuel temperature profiles used in the SAS2H inputs are presented in Table 34 and were calculated based on assuming constant fuel conductivity, thus the average fuel temperature is the simple average of the surface and centerline temperatures. In Tables 29 through 33, the LHGR is in units of kW/cm; heat flux at pellet surface is in units of kW/cm^2, and all T values are in units of K. T_{avg} is the average temperature between the surface and centerline temperatures of the fuel pellet.

Table 28. Constants for Axial Fuel Temperature Profile Calculations

Constant	Value used	Reference
D_G, cm	1.0528	Calculated
Effective gap thickness, cm	0.01153	Calculated (Equation 28)
Operating moderator temperature (K)[a]	559.1	p. 654, Ref. 7.18
Stefan-Boltzman constant (kW/(cm^2*K^4))	5.67E-15	p.634, Ref. 7.18
Fuel conductivity (kW/cm*K)	3.17E-05	p. 29, Ref. 7.20
Clad conductivity (kW/cm*K)	1.64E-04	p. 219, Ref. 7.20
Fuel emissivity	0.7993	p. 48, Ref. 7.20
Clad emissivity	0.325	p. 230, Ref. 7.20
k_G (kW/cm*K)[b]	3.00E-06	p. 334 , Ref. 7.18
h_G (kW/cm^2*K)[c]	2.4225E-04	Calculated (Equation 29)

NOTES: [a] Interpolated based on reference moderator density of 0.7396 g/cm^3 (T_{Bulk} in Equation 31)
[b] Helium conductivity at a temperature of 780 K
[c] Calculated based on T_S of 900 K

The linear heat generation rate (LHGR) ($\dot{q}$) for a single fuel rod is computed as shown in Equation 25.

$$\dot{q} = \frac{(PRATED \cdot RPF \cdot APF)}{(NA \cdot N_{rod} \cdot AFL)}$$

(Eq. 25)

where

PRATED = rated power
RPF = relative power factor (the relative assembly power)
APF = axial peaking factor (the relative nodal power for a given assembly)
NA = the number of assemblies in the core
N_{rod} = the number of fuel rods in a lattice
AFL = the active length of the core.

The heat flux at the surface of the fuel pellet ($\ddot{q}$) is calculated as shown in Equation 26.

$$\ddot{q} = \frac{\dot{q}}{\pi \cdot D_P}$$

(Eq. 26)

where D_P = the diameter of the fuel pellet.

The temperature change across the cladding (ΔT_C) is calculated as shown in Equation 27 (p. 312, Ref. 7.18)

$$\Delta T_C = \frac{\ddot{q} \cdot \delta_C}{k_C}$$

(Eq. 27)

where

δ_C = the thickness of the cladding
k_C = the cladding conductivity

The effective gap thickness (δ_{eff}) is estimated as shown in Equation 28 (p. 334, Ref. 7.18)

$$\delta_{eff} = \delta_G + \delta_{jump1} + \delta_{jump2}$$

(Eq. 28)

where

δ_G is the geometrical gap thickness
δ_{jump1} and δ_{jump2} are corrections for temperature discontinuities near the surfaces. (At atmospheric pressure, the sum of the last two terms is known to be 10 μm for helium.

The gap conductance (h_G) is calculated as follows (p. 334, Ref. 7.18):

$$h_G = \frac{k_G}{\delta_{eff}} + \frac{\sigma \cdot T_S^3}{\frac{1}{\varepsilon_F} + \frac{1}{\varepsilon_C - 1}}$$

(Eq. 29)

where

T_S = the fuel pellet surface temperature
k_G = the thermal conductivity of the gas in the gap
s = the Stefan-Boltzman constant
ε_F and ε_C = the emissivities of the fuel and cladding, respectively

For the fuel/cladding gap without gap closure, the temperature jump is given as follows (p. 336, Ref. 7.18):

$$\Delta T_G = \frac{\dot{q}}{\pi \cdot D_G \cdot h_G}$$

(Eq. 30)

where

D_G = the gap mean diameter
h_G = the gap conductance (this conductance is computed as shown in Equation 29).

Assuming excellent heat transfer due to boiling and given the bulk temperature in the coolant (T_{Bulk}) the surface temperature of the fuel pellet may be computed as follows:

$$T_S = T_{Bulk} + \Delta T_C + \Delta T_G$$

(Eq. 31)

The surface temperature of the fuel pellet and the LHGR were used to determine the centerline temperature of the fuel as shown in Equation 32 (p. 336, Ref. 7.18).

$$T_{CL} = \frac{\dot{q}}{4 \cdot \pi \cdot k_f} + T_S$$

(Eq. 32)

where

T_{CL} = Fuel centerline temperature (maximum fuel temperature)
k_f = Fuel thermal conductivity of 3.17E-05 kW/cm*K based on 93.4 % of theoretical density and an average temperature of 1071 K (p. 29, Ref. 7.20)

Table 29. Axial Fuel Temperature Profile for 10,000 MWd/mtU Burnup

Cycle 1								
Node	**Axial power profiles**	**LHGR**	**Heat flux at pellet surface**	**ΔT_C**	**ΔT_G**	**T_S**	**T_{CL}**	**T_{avg}**
10	0.1859	0.0412	0.0126	6.2376	51.3906	616.7282	720.0931	668.4106
9	0.7218	0.1599	0.0489	24.2203	199.5488	782.8692	1184.2335	983.5513
8	0.9992	0.2213	0.0676	33.5276	276.2302	868.8578	1424.4560	1146.6569
7	1.0826	0.2398	0.0733	36.3237	299.2671	894.6908	1496.6243	1195.6575
6	1.1525	0.2553	0.0780	38.6691	318.5904	916.3595	1557.1591	1236.7593
5	1.2199	0.2702	0.0826	40.9300	337.2180	937.2480	1615.5144	1276.3812
4	1.2943	0.2867	0.0876	43.4292	357.8083	960.3375	1680.0184	1320.1780
3	1.3182	0.2920	0.0892	44.2300	364.4061	967.7360	1700.6875	1334.2117
2	1.0213	0.2262	0.0691	34.2663	282.3166	875.6829	1443.5228	1159.6029
1	0.2372	0.0525	0.0161	7.9588	65.5721	632.6309	764.5199	698.5754

Table 30. Axial Fuel Temperature Profile for 20,000 MWd/mtU Burnup

Node	Axial power profiles			LHGR		
Node	Cycle 1	Cycle 2	Cycle 3	Cycle 1	Cycle 2	Cycle 3
10	0.1859	0.2504	0.2721	0.0404	0.0467	0.0508
9	0.7218	0.8337	0.8424	0.1570	0.1554	0.1573
8	0.9992	1.0580	1.0715	0.2174	0.1972	0.2001
7	1.0826	1.1206	1.1328	0.2355	0.2089	0.2115
6	1.1525	1.1535	1.1843	0.2507	0.2150	0.2211
5	1.2199	1.1645	1.2105	0.2654	0.2171	0.2260
4	1.2943	1.1936	1.1932	0.2816	0.2225	0.2228
3	1.3182	1.1864	1.1033	0.2867	0.2212	0.2060
2	1.0213	0.9514	0.8732	0.2222	0.1774	0.1630
1	0.2372	0.2474	0.2528	0.0516	0.0461	0.0472
	Heat flux at pellet surface			ΔT_C		
Node	Cycle 1	Cycle 2	Cycle 3	Cycle 1	Cycle 2	Cycle 3
10	0.0124	0.0143	0.0155	6.1259	7.0710	7.6967
9	0.0480	0.0475	0.0481	23.7869	23.5413	23.8295
8	0.0664	0.0603	0.0612	32.9275	29.8767	30.3078
7	0.0720	0.0638	0.0647	35.6736	31.6435	32.0427
6	0.0766	0.0657	0.0676	37.9770	32.5735	33.4994
5	0.0811	0.0663	0.0691	40.1975	32.8827	34.2405
4	0.0861	0.0680	0.0681	42.6519	33.7049	33.7521
3	0.0876	0.0676	0.0630	43.4384	33.5025	31.2068
2	0.0679	0.0542	0.0498	33.6530	26.8664	24.6982
1	0.0158	0.0141	0.0144	7.8164	6.9863	7.1508
	ΔT_G			T_S		
Node	Cycle 1	Cycle 2	Cycle 3	Cycle 1	Cycle 2	Cycle 3
10	50.4708	58.2572	63.4123	615.6968	624.4282	630.2090
9	195.9774	193.9543	196.3283	778.8642	776.5956	779.2578
8	271.2864	246.1506	249.7028	863.3139	835.1272	839.1106
7	293.9109	260.7071	263.9964	888.6845	851.4506	855.1391
6	312.8884	268.3693	275.9983	909.9654	860.0428	868.5977
5	331.1826	270.9169	282.1042	930.4801	862.8996	875.4447
4	351.4044	277.6911	278.0802	953.1563	870.4960	870.9323
3	357.8841	276.0237	257.1098	960.4225	868.6262	847.4166
2	277.2638	221.3494	203.4855	870.0168	807.3158	787.2837
1	64.3985	57.5592	58.9144	631.3149	623.6455	625.1652
	T_{CL}			T_{avg}		
Node	Cycle 1	Cycle 2	Cycle 3	Cycle 1	Cycle 2	Cycle 3
10	717.2117	741.6043	757.7538	666.4542	683.0163	693.9814
9	1173.0451	1166.7073	1174.1444	975.9547	971.6515	976.7011
8	1408.9682	1330.2244	1341.3525	1136.1411	1082.6758	1090.2315
7	1479.8449	1375.8262	1386.1305	1184.2647	1113.6384	1120.6348
6	1539.2963	1399.8297	1423.7294	1224.6308	1129.9362	1146.1636
5	1596.6071	1407.8106	1442.8574	1263.5436	1135.3551	1159.1511
4	1659.9567	1429.0324	1430.2514	1306.5565	1149.7642	1150.5919
3	1680.2558	1423.8089	1364.5567	1320.3391	1146.2176	1105.9867
2	1427.6938	1252.5289	1196.5662	1148.8553	1029.9224	991.9249
1	760.8434	739.4178	743.6633	696.0792	681.5316	684.4143

Table 31. Axial Fuel Temperature Profile for 30,000 MWd/mtU Burnup

	Axial power profiles				**LHGR**			
Node	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
10	0.1859	0.2504	0.2721	0.3161	0.0370	0.0427	0.0465	0.0391
9	0.7218	0.8337	0.8424	1.0230	0.1438	0.1423	0.1441	0.1264
8	0.9992	1.0580	1.0715	1.2005	0.1991	0.1806	0.1832	0.1484
7	1.0826	1.1206	1.1328	1.2171	0.2157	0.1913	0.1937	0.1504
6	1.1525	1.1535	1.1843	1.1899	0.2296	0.1969	0.2025	0.1470
5	1.2199	1.1645	1.2105	1.1141	0.2430	0.1988	0.2070	0.1377
4	1.2943	1.1936	1.1932	0.9988	0.2578	0.2038	0.2040	0.1234
3	1.3182	1.1864	1.1033	0.8854	0.2626	0.2025	0.1886	0.1094
2	1.0213	0.9514	0.8732	0.7755	0.2034	0.1624	0.1493	0.0958
1	0.2372	0.2474	0.2528	0.2376	0.0473	0.0422	0.0432	0.0294
	Heat flux at pellet surface				ΔT_C			
Node	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
10	0.0113	0.0131	0.0142	0.0119	5.6101	6.4755	7.0483	5.9176
9	0.0440	0.0435	0.0440	0.0386	21.7839	21.5586	21.8218	19.1504
8	0.0608	0.0552	0.0560	0.0453	30.1549	27.3604	27.7544	22.4741
7	0.0659	0.0585	0.0592	0.0460	32.6697	28.9784	29.3431	22.7849
6	0.0702	0.0602	0.0619	0.0449	34.7792	29.8300	30.6771	22.2757
5	0.0743	0.0608	0.0633	0.0421	36.8127	30.1132	31.3558	20.8567
4	0.0788	0.0623	0.0624	0.0377	39.0604	30.8662	30.9085	18.6976
3	0.0803	0.0619	0.0577	0.0334	39.7807	30.6808	28.5777	16.5753
2	0.0622	0.0496	0.0456	0.0293	30.8193	24.6036	22.6174	14.5179
1	0.0144	0.0129	0.0132	0.0090	7.1582	6.3979	6.5483	4.4480
	ΔT_G				T_S			
Node	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
10	46.2210	53.3506	58.0698	48.7544	610.9311	618.9261	624.2181	613.7720
9	179.4754	177.6189	179.7878	157.7779	760.3593	758.2775	760.7096	736.0282
8	248.4431	225.4191	228.6655	185.1620	837.6980	811.8794	815.5199	766.7361
7	269.1625	238.7496	241.7548	187.7223	860.9323	826.8280	830.1979	769.6072
6	286.5420	245.7664	252.7456	183.5270	880.4212	834.6965	842.5228	764.9027
5	303.2958	248.0995	258.3371	171.8358	899.2085	837.3127	848.7928	751.7925
4	321.8149	254.3031	254.6521	154.0471	919.9753	844.2693	844.6606	731.8447
3	327.7489	252.7762	235.4485	136.5618	926.6296	842.5570	823.1261	712.2370
2	253.9171	202.7067	186.3420	119.6111	843.8365	786.4103	768.0594	693.2289
1	58.9759	52.7114	53.9509	36.6468	625.2341	618.2093	619.5993	600.1948
	T_{CL}				T_{avg}			
Node	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
10	703.8981	726.2333	741.0173	711.8347	657.4146	672.5797	682.6177	662.8034
9	1121.3487	1115.5328	1122.3273	1053.3761	940.8540	936.9052	941.5185	894.7022
8	1337.4062	1265.2781	1275.4482	1139.1632	1087.5521	1038.5788	1045.4840	952.9497
7	1402.3148	1307.0392	1316.4537	1147.1841	1131.6235	1066.9336	1073.3258	958.3957
6	1456.7601	1329.0210	1350.8849	1134.0415	1168.5907	1081.8587	1096.7038	949.4721
5	1509.2452	1336.3298	1368.4014	1097.4161	1204.2268	1086.8212	1108.5971	924.6043
4	1567.2605	1355.7641	1356.8575	1041.6888	1243.6179	1100.0167	1100.7591	886.7667
3	1585.8503	1350.9806	1296.6975	986.9117	1256.2400	1096.7688	1059.9118	849.5744
2	1354.5550	1194.1263	1142.8600	933.8097	1099.1957	990.2683	955.4597	813.5193
1	743.8559	724.2309	728.1140	673.9047	684.5450	671.2201	673.8566	637.0498

Table 32. Axial Fuel Temperature Profile for 40,000 MWd/mtU Burnup

	Axial power profiles				LHGR			
Node	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
10	0.1859	0.2504	0.2721	0.3161	0.0395	0.0456	0.0496	0.0417
9	0.7218	0.8337	0.8424	1.0230	0.1534	0.1518	0.1536	0.1348
8	0.9992	1.0580	1.0715	1.2005	0.2123	0.1926	0.1954	0.1583
7	1.0826	1.1206	1.1328	1.2171	0.2300	0.2040	0.2066	0.1604
6	1.1525	1.1535	1.1843	1.1899	0.2449	0.2100	0.2160	0.1569
5	1.2199	1.1645	1.2105	1.1141	0.2592	0.2120	0.2208	0.1469
4	1.2943	1.1936	1.1932	0.9988	0.2750	0.2173	0.2176	0.1317
3	1.3182	1.1864	1.1033	0.8854	0.2801	0.2160	0.2012	0.1167
2	1.0213	0.9514	0.8732	0.7755	0.2170	0.1732	0.1592	0.1022
1	0.2372	0.2474	0.2528	0.2376	0.0504	0.0450	0.0461	0.0313
	Heat flux at pellet surface				ΔT_C			
Node	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
10	0.0121	0.0139	0.0152	0.0127	5.9838	6.9070	7.5178	6.3123
9	0.0469	0.0464	0.0470	0.0412	23.2351	22.9952	23.2756	20.4275
8	0.0649	0.0589	0.0597	0.0484	32.1638	29.1835	29.6033	23.9730
7	0.0703	0.0624	0.0632	0.0490	34.8462	30.9094	31.2979	24.3045
6	0.0748	0.0642	0.0660	0.0479	37.0962	31.8178	32.7208	23.7613
5	0.0792	0.0648	0.0675	0.0449	39.2651	32.1198	33.4446	22.2476
4	0.0841	0.0664	0.0665	0.0402	41.6626	32.9230	32.9676	19.9445
3	0.0856	0.0660	0.0615	0.0357	42.4309	32.7253	30.4815	17.6807
2	0.0663	0.0530	0.0487	0.0312	32.8725	26.2431	24.1241	15.4861
1	0.0154	0.0138	0.0141	0.0096	7.6351	6.8242	6.9846	4.7447
	ΔT_G				T_S			
Node	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
10	49.3002	56.9057	61.9383	52.0060	614.3841	622.9126	628.5561	617.4182
9	191.4319	189.4547	191.7648	168.3004	773.7671	771.5499	774.1404	747.8279
8	264.9942	240.4401	243.8987	197.5108	856.2580	828.7237	832.6020	780.5838
7	287.0940	254.6590	257.8600	200.2419	881.0402	844.6683	848.2579	783.6463
6	305.6313	262.1434	269.5830	195.7668	901.8275	853.0611	861.4038	778.6281
5	323.5012	264.6318	275.5469	183.2959	921.8663	855.8517	868.0915	764.6436
4	343.2540	271.2489	271.6165	164.3209	944.0166	863.2718	863.6841	743.3654
3	349.5834	269.6202	251.1335	145.6693	951.1142	861.4455	840.7150	722.4500
2	270.8330	216.2143	198.7557	127.5882	862.8055	801.5574	781.9798	702.1743
1	62.9049	56.2239	57.5450	39.0908	629.6400	622.1481	623.6296	602.9355
	T_{CL}				T_{avg}			
Node	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
10	713.5445	737.3704	753.1362	722.0209	663.9643	680.1415	690.8462	669.7195
9	1158.8054	1152.6113	1159.8483	1086.3404	966.2862	962.0806	966.9943	917.0842
8	1389.2565	1312.3350	1323.1697	1177.8488	1122.7573	1070.5293	1077.8858	979.2163
7	1458.4893	1356.8789	1366.9069	1186.4046	1169.7647	1100.7736	1107.5824	985.0255
6	1516.5617	1380.3255	1403.6319	1172.3855	1209.1946	1116.6933	1132.5178	975.5068
5	1572.5434	1388.1213	1422.3153	1133.3175	1247.2049	1121.9865	1145.2034	948.9805
4	1634.4236	1408.8507	1410.0023	1073.8736	1289.2201	1136.0613	1136.8432	908.6195
3	1654.2519	1403.7484	1345.8346	1015.4434	1302.6831	1132.5970	1093.2748	868.9467
2	1407.5478	1236.4420	1181.7488	958.7999	1135.1766	1018.9997	981.8643	830.4871
1	756.1642	735.2345	739.3733	681.5612	692.9021	678.6913	681.5014	642.2484

Table 33. Axial Fuel Temperature Profile for 50,000 MWd/mtU Burnup

	Axial power profiles				LHGR			
Node	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 1	Cycle 2	Cycle 3	Cycle 4
10	0.1859	0.2504	0.2721	0.3161	0.0411	0.0475	0.0517	0.0434
9	0.7218	0.8337	0.8424	1.0230	0.1598	0.1581	0.1601	0.1405
8	0.9992	1.0580	1.0715	1.2005	0.2212	0.2007	0.2036	0.1649
7	1.0826	1.1206	1.1328	1.2171	0.2396	0.2125	0.2152	0.1671
6	1.1525	1.1535	1.1843	1.1899	0.2551	0.2188	0.2250	0.1634
5	1.2199	1.1645	1.2105	1.1141	0.2700	0.2209	0.2300	0.1530
4	1.2943	1.1936	1.1932	0.9988	0.2865	0.2264	0.2267	0.1372
3	1.3182	1.1864	1.1033	0.8854	0.2918	0.2250	0.2096	0.1216
2	1.0213	0.9514	0.8732	0.7755	0.2260	0.1805	0.1659	0.1065
1	0.2372	0.2474	0.2528	0.2376	0.0525	0.0469	0.0480	0.0326
	Heat flux at pellet surface				ΔT_C			
Node	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 1	Cycle 2	Cycle 3	Cycle 4
10	0.0126	0.0145	0.0158	0.0133	6.2331	7.1946	7.8310	6.5756
9	0.0488	0.0483	0.0489	0.0429	24.2032	23.9529	24.2454	21.2798
8	0.0676	0.0613	0.0622	0.0504	33.5039	30.3990	30.8368	24.9732
7	0.0732	0.0650	0.0658	0.0511	36.2980	32.1967	32.6020	25.3185
6	0.0780	0.0669	0.0688	0.0499	38.6417	33.1430	34.0841	24.7527
5	0.0825	0.0675	0.0703	0.0468	40.9011	33.4576	34.8382	23.1758
4	0.0876	0.0692	0.0693	0.0419	43.3984	34.2942	34.3412	20.7766
3	0.0892	0.0688	0.0641	0.0372	44.1987	34.0883	31.7515	18.4184
2	0.0691	0.0552	0.0507	0.0326	34.2421	27.3361	25.1292	16.1322
1	0.0160	0.0143	0.0147	0.0100	7.9532	7.1084	7.2756	4.9426
	ΔT_G				T_S			
Node	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 1	Cycle 2	Cycle 3	Cycle 4
10	51.3542	59.2757	64.5191	54.1757	616.6874	625.5703	631.4501	619.8513
9	199.4077	197.3453	199.7550	175.3221	782.7109	780.3982	783.1004	755.7019
8	276.0348	250.4541	254.0611	205.7512	868.6387	839.9531	843.9979	789.8243
7	299.0554	265.2652	268.6042	208.5962	894.4534	856.5619	860.3061	793.0147
6	318.3650	273.0613	280.8156	203.9344	916.1067	865.3043	873.9997	787.7871
5	336.9794	275.6534	287.0280	190.9432	936.9805	868.2110	880.9662	773.2191
4	357.5552	282.5460	282.9338	171.1765	960.0536	875.9402	876.3751	751.0531
3	364.1483	280.8495	261.5974	151.7468	967.4470	874.0378	852.4489	729.2652
2	282.1168	225.2193	207.0372	132.9113	875.4589	811.6555	791.2664	708.1435
1	65.5257	58.5656	59.9427	40.7218	632.5789	624.7740	626.3183	604.7644
	T_{CL}				T_{avg}			
Node	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 1	Cycle 2	Cycle 3	Cycle 4
10	719.9792	744.7951	761.2211	728.8181	668.3333	685.1827	696.3356	674.3347
9	1183.7913	1177.3303	1184.8795	1108.3375	983.2511	978.8643	983.9899	932.0197
8	1423.8438	1343.7063	1355.0060	1203.6637	1146.2412	1091.8297	1099.5019	996.7440
7	1495.9611	1390.1054	1400.5655	1212.5765	1195.2072	1123.3336	1130.4358	1002.7956
6	1556.4530	1414.5285	1438.8207	1197.9725	1236.2799	1139.9164	1156.4102	992.8798
5	1614.7671	1422.6490	1458.2826	1157.2745	1275.8738	1145.4300	1169.6244	965.2468
4	1679.2255	1444.2417	1445.4566	1095.3506	1319.6396	1160.0910	1160.9158	923.2018
3	1699.8799	1438.9270	1378.6152	1034.4825	1333.6634	1156.4824	1115.5321	881.8739
2	1442.8972	1264.6524	1207.6925	975.4758	1159.1781	1038.1539	999.4795	841.8097
1	764.3746	742.5703	746.8847	686.6705	698.4768	683.6722	686.6015	645.7174

Table 34. Cycle Averaged Fuel Temperature Profiles

Burnup/ Node	10,000 MWd/mtU	20,000 MWd/mtU	30,000 MWd/mtU	40,000 MWd/mtU	50,000 MWd/mtU
10	668.41	680.39	668.80	676.11	680.98
9	983.55	974.85	931.43	956.24	972.79
8	1146.66	1104.77	1039.11	1071.10	1092.43
7	1195.66	1141.88	1067.79	1101.68	1124.29
6	1236.76	1169.96	1087.06	1122.24	1145.70
5	1276.38	1190.11	1097.45	1133.32	1157.25
4	1320.18	1207.79	1103.60	1139.88	1164.08
3	1334.21	1197.65	1089.12	1124.43	1147.99
2	1159.60	1061.73	981.09	1009.21	1027.97
1	698.58	687.81	669.54	676.90	681.81

NOTE: Values are in degrees K and calculated from Equation 33

$$T_{Cycle\ Average} = \sum_{i=1}^{\#\ of\ cycles} W_i * T_i \qquad \text{(Eq. 33)}$$

where

W_i = Cycle weighting factor derived in Tables 16 through 20
T_i = Average cycle temperature derived in Tables 29 through 33

5.2.8.5 Nodal Power Calculation

Part of the SAS2H input is the nodal power. This was calculated based on the following equation:

$$Nodal\ power = \frac{(PRATED)*(RPF)*(APF)}{(NA)(AFL)} * node\ height \qquad \text{(Eq. 34)}$$

The values used for the SAS2H inputs are provided in Tables 35 through 39 for each burnup range.

Table 35. Nodal Powers for 10,000 MWd/mtU Burnup

Cycle 1			
Node	**APF**	**Node height (cm)**	**Nodal power (MW)**
10	0.1859	15.24	0.0376
9	0.72185	64.11	0.6149
8	0.99923	45.72	0.6071
7	1.08257	45.72	0.6577
6	1.15247	45.72	0.7001
5	1.21985	30.48	0.4941
4	1.29433	45.72	0.7863
3	1.3182	30.48	0.5339
2	1.02125	30.48	0.4136
1	0.2372	15.24	0.0480

Table 36. Nodal Powers for 20,000 MWd/mtU Burnup

Node	Node height (cm)	Cycle 1		Cycle 2	
		APF	Node power (MW)	APF	Node power (MW)
10	15.24	0.186	0.0370	0.250	0.0427
9	64.11	0.722	0.6038	0.834	0.5978
8	45.72	0.999	0.5961	1.058	0.5411
7	45.72	1.083	0.6458	1.121	0.5731
6	45.72	1.152	0.6875	1.154	0.5899
5	30.48	1.220	0.4851	1.164	0.3970
4	45.72	1.294	0.7721	1.194	0.6104
3	30.48	1.318	0.5242	1.186	0.4045
2	30.48	1.021	0.4061	0.951	0.3244
1	15.24	0.237	0.0472	0.247	0.0422

Cycle 3			
Node	**APF**	**Node height (cm)**	**Node power (MW)**
10	0.272	15.24	0.0465
9	0.842	64.11	0.6052
8	1.071	45.72	0.5489
7	1.133	45.72	0.5803
6	1.184	45.72	0.6067
5	1.211	30.48	0.4134
4	1.193	45.72	0.6113
3	1.103	30.48	0.3768
2	0.873	30.48	0.2982
1	0.253	15.24	0.0432

Table 37. Nodal Powers for 30,000 MWd/mtU Burnup

Node	Node height (cm)	Cycle 1		Cycle 2	
		APF	Node power (MW)	APF	Node power (MW)
10	15.2400	0.1859	0.0339	0.2504	0.0391
9	64.1100	0.7218	0.5531	0.8337	0.5471
8	45.7200	0.9992	0.5460	1.0580	0.4952
7	45.7200	1.0826	0.5915	1.1206	0.5244
6	45.7200	1.1525	0.6297	1.1535	0.5399
5	30.4800	1.2199	0.4444	1.1645	0.3633
4	45.7200	1.2943	0.7072	1.1936	0.5586
3	30.4800	1.3182	0.4802	1.1864	0.3702
2	30.4800	1.0213	0.3720	0.9514	0.2968
1	15.2400	0.2372	0.0432	0.2474	0.0386

Table 37. Nodal Powers for 30,000 MWd/mtU Burnup

		Cycle 3		Cycle 4	
Node	**Node height (cm)**	**APF**	**Node power (MW)**	**APF**	**Node power (MW)**
10	15.2400	0.2721	0.0425	0.3161	0.0357
9	64.1100	0.8424	0.5540	1.0230	0.4862
8	45.7200	1.0715	0.5025	1.2005	0.4069
7	45.7200	1.1328	0.5313	1.2171	0.4125
6	45.7200	1.1843	0.5554	1.1899	0.4033
5	30.4800	1.2105	0.3785	1.1141	0.2518
4	45.7200	1.1932	0.5596	0.9988	0.3385
3	30.4800	1.1033	0.3450	0.8854	0.2001
2	30.4800	0.8732	0.2730	0.7755	0.1752
1	15.2400	0.2528	0.0395	0.2376	0.0268

Table 38. Nodal Powers for 40,000 MWd/mtU Burnup

		Cycle 1		Cycle 2	
Node	**Node height (cm)**	**APF**	**Node power (MW)**	**APF**	**Node power (MW)**
10	15.24	0.186	0.0361	0.250	0.0417
9	64.11	0.722	0.5899	0.834	0.5838
8	45.72	0.999	0.5824	1.058	0.5284
7	45.72	1.083	0.6309	1.121	0.5596
6	45.72	1.152	0.6717	1.154	0.5761
5	30.48	1.220	0.4740	1.164	0.3877
4	45.72	1.294	0.7543	1.194	0.5961
3	30.48	1.318	0.5122	1.186	0.3950
2	30.48	1.021	0.3968	0.951	0.3168
1	15.24	0.237	0.0461	0.247	0.0412
		Cycle 3		**Cycle 4**	
Node	**Node height (cm)**	**APF**	**Node power (MW)**	**APF**	**Node power (MW)**
10	15.24	0.272	0.0454	0.316	0.0381
9	64.11	0.842	0.5910	1.023	0.5186
8	45.72	1.071	0.5360	1.201	0.4341
7	45.72	1.133	0.5667	1.217	0.4401
6	45.72	1.184	0.5925	1.190	0.4302
5	30.48	1.211	0.4037	1.114	0.2685
4	45.72	1.193	0.5969	0.999	0.3611
3	30.48	1.103	0.3679	0.885	0.2134
2	30.48	0.873	0.2912	0.776	0.1869
1	15.24	0.253	0.0422	0.238	0.0286

Table 39. Nodal Powers for 50,000 MWd/mtU Burnup

		Cycle 1		Cycle 2	
Node	**Node height (cm)**	**APF**	**Node power (MW)**	**APF**	**Node power (MW)**
10	15.24	0.1859	0.0376	0.2504	0.0434
9	64.11	0.72185	0.6145	0.83365	0.6081
8	45.72	0.99923	0.6066	1.058	0.5504
7	45.72	1.08257	0.6572	1.12057	0.5830
6	45.72	1.15247	0.6997	1.1535	0.6001
5	30.48	1.21985	0.4937	1.16445	0.4039
4	45.72	1.29433	0.7858	1.19357	0.6209
3	30.48	1.3182	0.5335	1.1864	0.4115
2	30.48	1.02125	0.4133	0.9514	0.3300
1	15.24	0.2372	0.0480	0.2474	0.0429

Table 39. Nodal Powers for 50,000 MWd/mtU Burnup

Node	Node height (cm)	Cycle 3		Cycle 4	
		APF	Node power (MW)	APF	Node power (MW)
10	15.24	0.2721	0.0473	0.3161	0.0397
9	64.11	0.84244	0.6156	1.02295	0.5403
8	45.72	1.07147	0.5583	1.2005	0.4522
7	45.72	1.1328	0.5903	1.2171	0.4584
6	45.72	1.1843	0.6171	1.1899	0.4482
5	30.48	1.2105	0.4205	1.1141	0.2797
4	45.72	1.19323	0.6218	0.99877	0.3762
3	30.48	1.10325	0.3833	0.8854	0.2223
2	30.48	0.87315	0.3033	0.7755	0.1947
1	15.24	0.2528	0.0439	0.2376	0.0298

5.3 MCNP INPUT DESCRIPTIONS

5.3.1 MCNP Geometry

The sketch referenced for the 44-BWR waste package dimensions is contained in Attachment I. The MCNP virtual model of the 44-BWR waste package follows the same description as that shown in the sketch of Attachment I for the intact configuration. The waste package was modeled in MCNP as containing 44 SNF assemblies with fully flooded conditions in order to maximize reactivity, and an effectively infinite water reflector surrounding the waste package.

For the degraded configuration, the waste package interior was represented with fuel assemblies positioned such that it represents a basket structure which has uniformly collapsed towards the bottom of the WP. The assemblies were not modeled as resting on the bottom of the WP because some oxide from corrosion of the side guides may be there to support them, and the approximate cylindrical geometry is more reactive than which would occur if the assemblies were resting on the bottom. The fuel assemblies were represented as being intact. It was assumed from previous degraded basket configurations (p. 48, Ref. 7.23) that a 58 volume percent (vol%) settled oxide configuration was the most limiting for a fully degraded waste package. In the degraded basket configuration MCNP representations, the 58 vol% settled iron oxide corrosion product and water mixture was modeled as filling the entire voidable area external to the assembly channels. The volume occupied by the iron oxide and water mixture was determined by conservation of mass and volume, and using a 58% dense packing. The 58% dense packing is similar to that of sand with tight packing (p. 17, Ref. 7.21). The channel interior and water rods for the assemblies submerged in the corrosion product mixture were represented as having regular water in them as there is no direct mechanism for corrosion product transport into them.

The physical dimensions for the fuel assembly design modeled in the MCNP representations were obtained from page 5 of Reference 7.3 and Sections A and C of Reference 7.16, and are presented in Table 40. A visual representation is presented in Figure 18.

Table 40. GE 8x8 Fuel Assembly Specifications

Assembly Component	Specification
Fuel Pellet Outer Diameter	1.0414 cm
Fuel Rod Cladding Inner Diameter	1.06426 cm
Fuel Rod Cladding Outer Diameter	1.2268 cm
Water Rod Inner Diameter	2.4561 cm
Water Rod Outer Diameter	2.6187 cm
Channel Inner Width	13.4061 cm
Channel Thickness	0.2032 cm
Active Fuel Length	368.91 cm
Gas Plenum Length	11.24 in (28.55 cm)
Clad Material	Zircaloy-2
Channel and Water Rod Material	Zircaloy-4
Upper End Cap Region	0.84 + 0.85 in = (4.293 cm)
Lower End Cap Region	0.62 + 0.625 in = (3.162 cm)

Source: p. 5, Ref. 7.3, pp. A-6 and C-10, Ref. 7.16

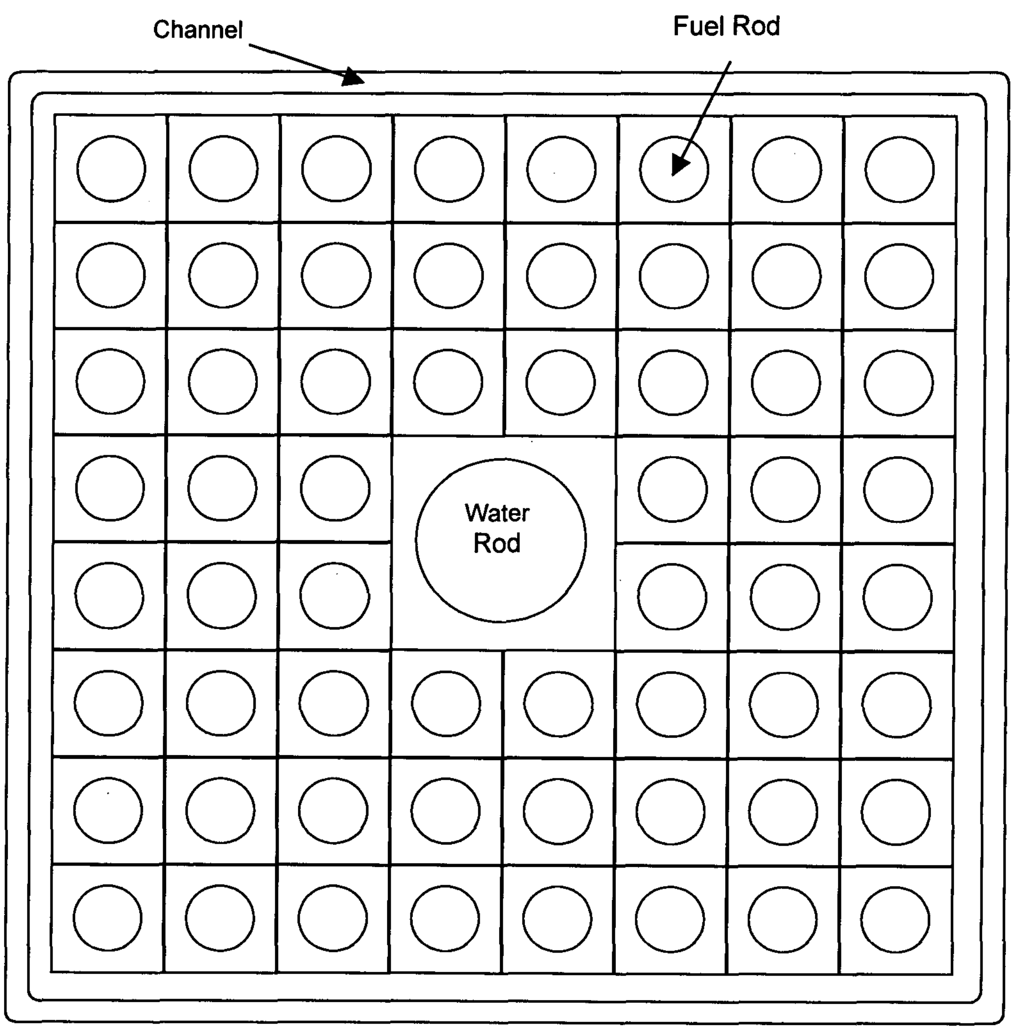


Figure 18. Fuel Rod, Water Rod, and Channel Locations in Fuel Assembly

5.3.2 MCNP Materials

The 44 BWR waste package configuration follows that shown in the sketch provided in Attachment I. The outer barrier was represented as SB-575 N06022 as described in Table 41. The inner barrier was represented as SA-240 S31600, which is nuclear grade 316 stainless steel (SS) with tightened control on carbon and nitrogen content (p. 931, Ref. 7.30, and Section II, SA-240, Table 1, Ref. 7.29) as described in Table 42. The fuel basket plates were represented as Neutronit A978 with 1.62 wt% boron as described in Table 43, and the thermal shunts were represented as aluminum 6061 as described in Table 44. The basket side and corner guides were represented as Grade 70 A 516 carbon steel as described in Table 45. The basket stiffeners were represented as water since they are not solid over the length of the basket, and representing them as water is conservative for criticality calculations.

The chromium, nickel, and iron elemental weight percents obtained from the references were expanded into their constituent natural isotopic weight percents for use in MCNP. This expansion was performed by: (1) calculating a natural weight fraction of each isotope in the elemental state, and (2) multiplying the elemental weight percent in the material of interest by the natural weight fraction of the isotope in the elemental state to obtain the weight percent of the isotope in the material of interest. This is described mathematically in Equations 35 and 36. The atomic mass values and atom percent of natural element values for these calculations are from Reference 7.24.

$$\begin{pmatrix} \text{Weight Fraction} \\ \text{of Isotope}_i \text{ in the} \\ \text{Natural Element} \end{pmatrix} = \frac{(\text{Atomic Mass of Isotope}_i)(\text{Atom Percent of Isotope}_i \text{ in Natural Element})}{\sum_{i=1}^{I} (\text{Atomic Mass of Isotope}_i)(\text{Atom Percent of Isotope}_i \text{ in Natural Element})}$$

(Eq. 35)

where

I = the total number of isotopes in the natural element

$$\begin{pmatrix} \text{Weight Percent} \\ \text{of Isotope}_i \text{ in} \\ \text{Material Composition} \end{pmatrix} = \begin{pmatrix} \text{Weight Fraction} \\ \text{of Isotope}_i \text{ in the} \\ \text{Natural Element} \end{pmatrix} \begin{pmatrix} \text{Reference Weight Percent of} \\ \text{Element in Material Composition} \end{pmatrix}$$

(Eq. 36)

Table 41. Alloy 22 (SB-575 N06022) Material Composition

Element/ Isotope	MCNP ZAID	Wt%[a]	Element/ Isotope	MCNP ZAID	Wt%[a]
C-nat	6000.50c	0.0150	Co-59	27059.50c	2.5000
Mn-55	25055.50c	0.5000	W-182	74182.55c	0.7877
Si-nat	14000.50c	0.0800	W-183	74183.55c	0.4278
Cr-50	24050.60c	0.8879	W-184	74184.55c	0.9209
Cr-52	24052.60c	17.7863	W-186	74186.55c	0.8636
Cr-53	24053.60c	2.0554	V	23000.50c	0.3500
Cr-54	24054.60c	0.5202	Fe-54	26054.60c	0.2260
Ni-58	28058.60c	36.8024	Fe-56	26056.60c	3.6759
Ni-60	28060.60c	14.6621	Fe-57	26057.60c	0.0865
Ni-61	28061.60c	0.6481	Fe-58	26058.60c	0.0116
Ni-62	28062.60c	2.0975	S-32	16032.50c	0.0200
Ni-64	28064.60c	0.5547	P-31	15031.50c	0.0200
Mo-nat	42000.50c	13.5000	Density = 8.69 g/cm^3		

NOTE: [a] Computed based on elemental compositions from Reference 7.13 and Equations 35 and 36

Table 42. Material Specifications for SS316NG

Element/Isotope	Zaid	Wt%[a]	Element/Isotope	Zaid	Wt%[a]
C-nat	6000.50c	0.0200	Fe-54	26054.60c	3.6911
N-14	7014.50c	0.0800	Fe-56	26056.60c	60.0322
Si-nat	14000.50c	1.0000	Fe-57	26057.60c	1.4119
P-31	15031.50c	0.0450	Fe-58	26058.60c	0.1897
S-nat	16032.50c	0.0300	Ni-58	28058.60c	8.0641
Cr-50	24050.60c	0.7103	Ni-60	28060.60c	3.2127
Cr-52	24052.60c	14.2291	Ni-61	28061.60c	0.1420
Cr-53	24053.60c	1.6443	Ni-62	28062.60c	0.4596
Cr-54	24054.60c	0.4162	Ni-64	28064.60c	0.1216
Mn-55	25055.50c	2.0000	Mo-nat	42000.50c	2.5000
Density = 7.98 g/cm^3					

NOTE: [a] Computed based on elemental compositions from page 931 of Reference 7.30 and Section II, SA-240, Table 1 of Reference 7.29, and Equations 35 and 36

Table 43. Material Specifications for Neutronit A978 with 1.62 wt% Boron

Element/Isotope	ZAID	Wt%[a]	Element/Isotope	ZAID	Wt%[a]
B-10	5010.50c	0.2986	Fe-57	26057.60c	1.3928
B-11	5011.56c	1.3214	Fe-58	26058.60c	0.1872
C-nat	6000.50c	0.0400	Co-59	27059.50c	0.2000
Cr-50	24050.60c	0.7730	Ni-58	28058.60c	8.7361
Cr-52	24052.60c	15.4846	Ni-60	28060.60c	3.4805
Cr-53	24053.60c	1.7894	Ni-61	28061.60c	0.1539
Cr-54	24054.60c	0.4529	Ni-62	28062.60c	0.4979
Fe-54	26054.60c	3.6411	Ni-64	28064.60c	0.1317
Fe-56	26056.60c	59.2189	Mo-nat	42000.50c	2.2000
Density = 7.76 g/cm^3					

NOTE: [a] Computed based on elemental compositions from Reference 7.34 and Equations 35 and 36

Table 44. Material Specifications for Al 6061

Element/Isotope	ZAID	Wt%[a]	Element/Isotope	ZAID	Wt%[a]
Si-nat	14000.50c	0.6000	Mg-nat	12000.50c	1.0000
Fe-54	26054.60c	0.0396	Cr-50	24050.60c	0.0081
Fe-56	26056.60c	0.6433	Cr-52	24052.60c	0.1632
Fe-57	26057.60c	0.0151	Cr-53	24053.60c	0.0189
Fe-58	26058.60c	0.0020	Cr-54	24054.60c	0.0048
Cu-63	29063.60c	0.1884	Ti-nat	22000.50c	0.1500
Cu-65	29065.60c	0.0866	Al-27	13027.50c	96.9300[b]
Mn-55	25055.50c	0.1500	Density = 2.7065 g/cm^3		

NOTES: [a] Computed based on elemental compositions from Reference 7.28 and Equations 35 and 36
[b] Zn cross-section data unavailable, therefore it was substituted as Al-27

Table 45. Grade 70 A516 Carbon Steel Composition

Element/Isotope	ZAID	Wt%[a]	Element/Isotope	ZAID	Wt%[a]
C-nat	6000.50c	0.2700	Fe-54	26054.60c	5.5558
Mn-55	25055.50c	1.0450	Fe-56	26056.60c	90.3584
P-31	15031.50c	0.0350	Fe-57	26057.60c	2.1252
S-nat	16032.50c	0.0350	Fe-58	26058.60c	0.2856
Si-nat	14000.50c	0.2900	Density = 7.850 g/cm^3		

NOTE: [a] Computed based on elemental compositions from Reference 7.27 and Equations 35 and 36

Table 46. Zircaloy-4 Composition for MCNP

Element/Isotope	ZAID	Wt%	Element/Isotope	ZAID	Wt%
O-16	6000.50c	0.1250	Fe-56	26056.60c	0.1930
Cr-50	24050.60c	0.0042	Fe-57	26057.60c	0.0045
Cr-52	24052.60c	0.0837	Fe-58	26058.60c	0.0006
Cr-53	24053.60c	0.0097	Sn	50000.35c	1.4500
Cr-54	24054.60c	0.0024	Zr	40000.60c	98.1150
Fe-54	26054.60c	0.0119	Density = 6.56 g/cm^3		

NOTE: Computed based on elemental compositions from Reference 7.28 and Equations 35 and 36

Table 47. Zircaloy-2 Composition for MCNP

Element/Isotope	ZAID	Wt%[a]	Element/Isotope	ZAID	Wt%[a]
O-16	6000.50c	0.1250	Fe-58	26058.60c	0.0004
Cr-50	24050.60c	0.0042	Ni-58	28058.60c	0.0370
Cr-52	24052.60c	0.0837	Ni-60	28060.60c	0.0147
Cr-53	24053.60c	0.0097	Ni-61	28061.60c	0.0007
Cr-54	24054.60c	0.0024	Ni-62	28062.60c	0.0021
Fe-54	26054.60c	0.0076	Ni-64	28064.60c	0.0006
Fe-56	26056.60c	0.1241	Sn	50000.35c	1.4500
Fe-57	26057.60c	0.0029	Zr	40000.60c	98.1350
Density = 6.55 g/cm^3					

NOTE: [a] Computed based on elemental compositions from Reference 7.28 and Equations 35 and 36

The waste package was represented in a fully flooded condition with an effectively infinite water reflector surrounding the waste package. The water composition is normal H_2O at 1.0 g/cm^3 density for the intact basket configuration, and 58 vol% settled iron oxide corrosion product and water mixture as specified in Table 49 for the fully degraded basket configuration. Number densities were calculated for the corrosion product and water mixtures by dividing the moles of each element per WP (as indicated in Table 48) by the void space they occupied (2.6274 m^3/0.58) and multiplying by Avogadro's Number (0.602214E24 atoms/mol [p. 59, Ref. 7.24]). These calculations resulted in the material specification for the corrosion product mixture as presented in Table 49.

Table 48. Corrosion Products Remaining Following Basket Degradation

Basket Corrosion Product[a]	Volume per WP (m^3)[a]	Moles/liter H_2O[a]	Moles/WP[b]
Diaspore (AlOOH)	1.8392E-01	3.60945	10424.0917
Hematite (Fe_2O_3)	2.3573E+00	26.78341	77350.4747
Pyrolusite (MnO_2)	2.7361E-02	0.55142	1592.4963
Ni_2SiO_4	3.5358E-02	0.28734	829.836
Nontronite-Ca ($Si_{3.7}Ca_{0.33}Al_{0.33}Fe_2H_2O_{12}$)	1.2874E-02	0.03403	98.28
Nontronite-K ($Si_{3.7}K_{0.17}Al_{0.33}Fe_2H_2O_{12}$)	5.6325E-04	0.00144	4.1637
Nontronite-Mg ($Si_{3.7}Mg_{0.2}Al_{0.33}Fe_2H_2O_{12}$)	8.9323E-03	0.02384	68.8415
Nontronite-Na ($Si_{3.7}Na_{0.33}Al_{0.33}Fe_2H_2O_{12}$)	9.0407E-04	0.00237	6.8432
Total	2.6272E+00		

NOTES: [a] Values were calculated based on Assumptions 3.5 and 3.6, and page 14 of Reference 7.22
[b] Calculated based on 2888 liters of water present, which is equivalent to the void space in a loaded WP with an undegraded basket (fuel assembly and channel volume in WP was calculated by taking the outer width of the channel squared multiplied by the total fuel rod length, which equals 0.0773 m^3)

Table 49. MCNP Corrosion Product Mixture Composition

Element	Composition ZAID[a]	Atom Density (atoms/b-cm)	Element	Composition ZAID	Atom Density (atoms/b-cm)
H	1001.50C	2.9512E-02	K	19000.50C	9.1337E-08
O	8016.50C	4.8811E-02	Ca	20000.50C	4.3118E-06
Na	11023.50C	3.0023E-07	Mn	25055.50C	2.1172E-04
Mg	12000.50C	1.5101E-06	Fe	26000.55C	2.0615E-02
Al	13027.50C	1.3937E-03	Ni	28000.50C	2.2065E-04
Si	14000.50C	1.9724E-04	Total		1.0097E-01

NOTE: [a] ZAID is the nuclide identification number in the MCNP input

The inter-assembly spacing for the degraded basket configuration was represented as 0.5 cm. This value is based on runs where the inter-assembly spacing was varied from 0.0 cm through 4.0 cm. The value of 0.5 cm may not be realistic in the sense that this amount of spacing is less than the original amount of basket material present initially. As the basket material oxidizes, the volume that the basket material would occupy increases. The value of 0.5 cm was chosen since it yielded the most reactive, and thus conservative, configuration. The results of the varied inter-assembly spacing runs are provided in Figure 19, with the MCNP inputs and outputs provided in Attachment III.

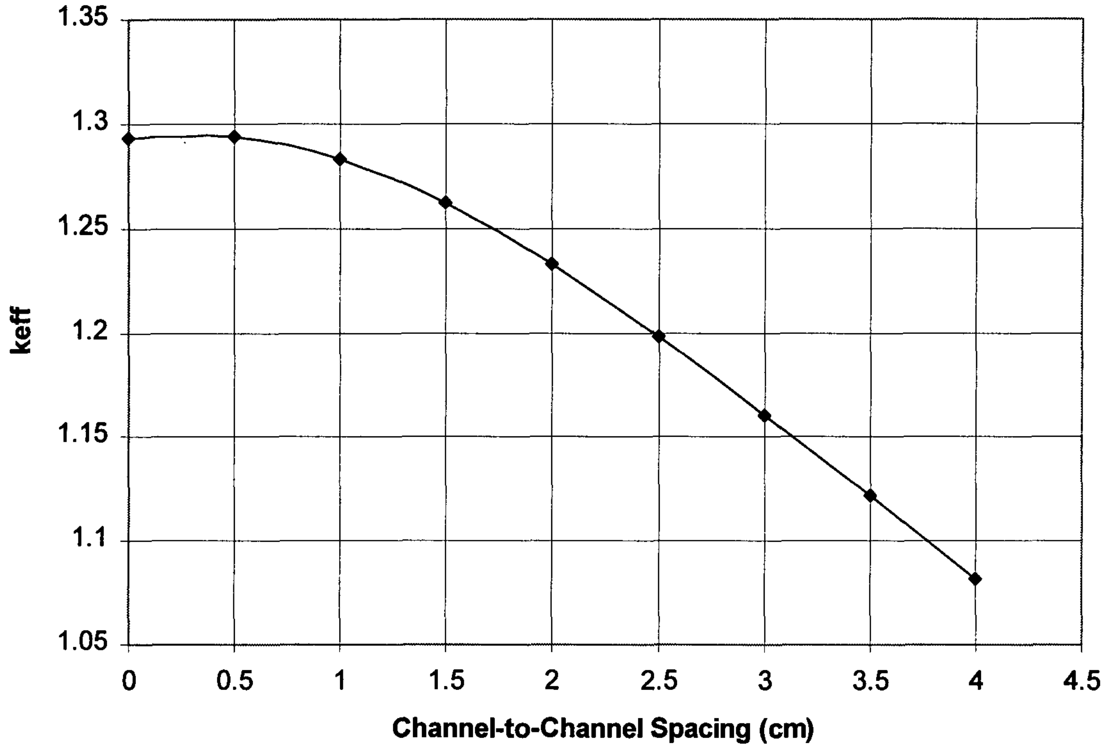


Figure 19. Inter-assembly Spacing Comparison

5.3.3 Fuel Material

The irradiated fuel for the loading curve analysis was delineated into 10 uniform-height axial regions each having a unique material composition. The height of each node was listed in Table 21. These nodal heights correspond directly to the nodal heights utilized in the fuel depletion calculations. The spent fuel isotopes used in the MCNP cases correspond to those of the Principal Isotope Set (p. 3-34, Ref. 7.10). Each nodal depleted fuel composition is contained on compact disc (CD) in Attachment III. The fuel rod components include the fuel rod cladding, the upper fuel rod plenum, end-caps, and the fuel. The fuel rod cladding was represented as Zircaloy-2 (p. 5, Ref. 7.3) in this analysis as presented in Table 47. The upper fuel rod plenum region was represented as containing He gas. The average composition of the fresh fuel for the WP fresh fuel calculation is presented in Table 50.

Several calculations are performed in order to make the proper conversions from the SAS2H/ORIGEN-S output files to values that are able to be put into MCNP input files. The SAS2H program creates files with decayed fuel isotopic concentrations at different decay times specified in the ORIGEN-S portion of the SAS2H input. These files are written in binary format and listed in Attachment II as *ft71f001.N** for each node. The Ft71v01 software reads these files and post-processes them into *ft71-case*.N** files which are in ASCII format for each decay case and node.

The values from the *ft71-case*.N** files are in units of moles, so in order to convert these into a mass value, the moles for each of the principal isotopes is multiplied of by it's corresponding atomic mass (Ref. 7.36) to convert to units of grams. These values are summed and added to the oxygen mass which is calculated using Equations 37 through 39. In Equations 37 and 38 the atomic mass values (*A*) come from Reference 7.36.

$$\frac{U\ Mass}{mol\ UO_2} = \begin{bmatrix} (A)(U^{234}\,wt\%) + (A)(U^{235}\,wt\%) + \\ (A)(U^{236}\,wt\%) + (A)(U^{238}\,wt\%) \end{bmatrix}(0.01)$$

(Eq. 37)

where the weight percentages of the uranium isotopes (U^{234}, U^{236}, and U^{238}) in uranium for a given initial enrichment were calculated using Equation 1.

$$\frac{O\ Mass}{mol\ UO_2} = (2)(A\ for\ O^{16})$$

(Eq. 38)

$$O\ Mass\ in\ UO_2 = \left(\frac{O\ Mass / mol\ UO_2}{U\ Mass / mol\ UO_2} \right)(U\ Mass\ in\ UO_2)$$

(Eq. 39)

where the *U Mass in* UO_2 is the sum of the uranium isotope masses (U^{234}, U^{235}, U^{236}, and U^{238}) from the spent fuel composition for that node.

The weight percent values for each isotope listed in the MCNP input files are calculated using Equation 40

$$wt\% = \frac{M_i W_i}{\sum_i^N M_i W_i + MassO_{node}}$$

(Eq. 40)

where

i is the individual isotope
M is the number of moles of the particular isotope

W is the atomic mass of the individual isotope
$Mass\ O_{node}$ is the mass of oxygen in the node from Equation 39
N is equal to 29 for the 29 principal isotopes

The density for the node is calculated by taking the total mass of the 29 principal isotopes plus the oxygen mass, and dividing it by the fuel volume. The fuel volume per node used in this calculation was 3201.251 cm^3 calculated as follows:

$$V = \frac{\pi}{4} D^2 N_p H \tag{Eq. 41}$$

where

D = Fuel pellet diameter in cm (0.9896)
N_p = The number of fuel pins present in the assembly (208)
H = the node height in cm (rounded to 20.01 cm)

The nodal fuel isotopic compositions are listed in the input files in terms of ZAID's, weight percents, and density (g/cm^3). Each nodal fuel composition is identified by node, initial enrichment, and burnup in the material specification section of the input files.

Table 50. MCNP Fresh Fuel Material Compositions

Enrichment (Wt% U-235)	Wt% U-234	Wt% U-235	Wt% U-236	Wt% U-238	Wt% O	Density (g/cm^3)
1.5	0.0106	1.3222	0.0061	86.8099	11.8512	10.3
2.0	0.0144	1.7630	0.0081	86.3626	11.8519	10.3
2.5	0.0184	2.2037	0.0101	85.9152	11.8526	10.3
3.0	0.0224	2.6444	0.0122	85.4678	11.8532	10.3
3.5	0.0265	3.0851	0.0142	85.0203	11.8539	10.3
4.0	0.0306	3.5258	0.0162	84.5728	11.8546	10.3
4.5	0.0348	3.9665	0.0182	84.1252	11.8553	10.3
5.0	0.0390	4.4072	0.0203	83.6776	11.8559	10.3

NOTE: The fresh fuel MCNP cases did not use natural uranium axial blankets. They were represented as uniformly loaded which is conservative with respect to criticality calculations

6. RESULTS

The loading curves for the 44 BWR waste package are presented in this section. The k_{eff} results represent the average combined collision, absorption, and track-length estimator from the MCNP calculations. The standard deviation (σ) represents the standard deviation of k_{eff} about the average combined collision, absorption, and track-length estimate due to the Monte Carlo calculation statistics. It should be noted that in the following sections, any reference to enrichment refers to assembly average initial enrichment.

It should be noted that the results presented throughout this section are highly conservative. Burned fuel assemblies were represented in the depletion calculations so as to maximize the end of life reactivity, no credit was taken for gadolinium poison material that may still be present in some burned assemblies, the degraded geometric configuration was set for optimum spacing, and other factors were also used in order to maximize k_{eff}.

6.1 MAXIMUM FRESH FUEL ENRICHMENT

This section presents the results of the maximum fresh fuel enrichments which can be loaded into the waste package with no burnup required. The determination on the maximum fresh fuel enrichment limit for the 44 BWR waste package is determined by calculating k_{eff} for a range of initial enrichments and plotting them against the initial enrichments. The k_{eff} values plotted in this analysis includes a two σ allowance for calculational uncertainty. The intersection of this curve and a line representing the critical limit (or USL) shows where the waste package has a potential for criticality. The results of the fresh fuel calculations are presented in 51 for the intact basket and degraded basket configurations, and are illustrated in Figure 20. These values were calculated using fuel material and the thermal $S(\alpha,\beta)$ treatment for water cross section data at room temperature (294K).

The corresponding MCNP input and output files for the cases used in this evaluation are contained on CD Attachments to this calculation (Attachment V). The MCNP input files are presented in Attachment III, and the MCNP output files are presented in Attachment IV.

Table 51. Fresh Fuel k_{eff} Results

Configuration	Intact		Degraded		Intact	Degraded
Enrichment (Wt % U-235)	k_{eff}	σ	k_{eff}	σ	$k_{eff} + 2\sigma$	$k_{eff} + 2\sigma$
1.5	0.67502	0.00039	1.02986	0.00041	0.6758	1.03068
2.0	0.75214	0.00046	1.12714	0.00039	0.75306	1.12792
2.5	0.81025	0.00044	1.19371	0.00043	0.81113	1.19457
3.0	0.85539	0.00051	1.24518	0.00039	0.85641	1.24596
3.5	0.89103	0.00052	1.28237	0.00044	0.89207	1.28325
4.0	0.92095	0.00051	-	-	0.92197	-
4.5	0.94549	0.00049	-	-	0.94647	-
5.0	0.96717	0.00051	-	-	0.96819	-

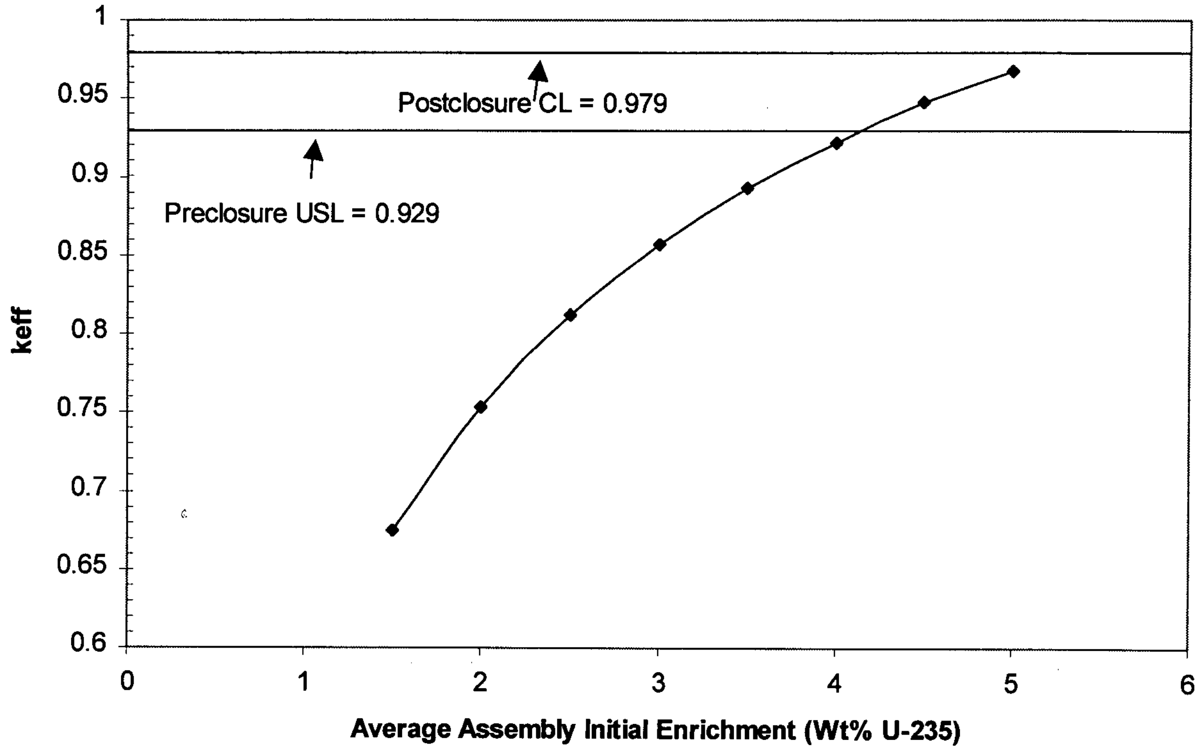


Figure 20. Fresh Fuel k_{eff} Results

6.2 BURNED FUEL

It should be noted that if the results from this section are used as input into documents directly relied upon for safety or waste isolation issues, the assumptions listed in Section 3 must be confirmed or else the results are required to be identified and tracked as TBV (to be verified) in accordance with appropriate procedures.

6.2.1 Preclosure Time Period

The results for spent fuel with five year decay time are presented in Table 52. During the preclosure time period, each waste package is to remain at or below the USL. The minimum burnup required for each initial enrichment is determined by plotting the calculated k_{eff} versus the burnup. The burnup value of the intersection of the plotted curve with the USL is the required minimum burnup. The k_{eff} values plotted in this analysis includes a two σ allowance for calculational uncertainty. Any burnup value greater than this will result in a k_{eff} less than the USL, and is acceptable to be loaded into the package. Taking the results from Table 52 and fitting them to the following expression:

$$C_0 + C_1{*}E + C_2{*}B = k_{eff} + 2\sigma$$

produces the coefficients listed in Table 53. Where B is burnup in GWd/mtU and E is initial enrichment in wt% U-235. The coefficients for the fitted equation presented in Table 53 were calculated from a standard linear regression. When performing a regression, a linear coefficient (noted as r^2) needs to be generated, which is a quantitative measure to evaluate the "goodness of fit". The closer r^2 approaches the value of 1, the better the fit of the data to the linear equation. The linear coefficients for the "goodness of fit" are presented in Table 53. The loading curve shown in Figure 21 was produced by setting the $k_{eff} + 2\sigma$ value to the USL of 0.929 and solving for E over a burnup range of 1 to 50 GWd/mtU.

Table 52. k_{eff} Values for 5 Year Decay Time

Initial Enrichment (Wt% U-235)	10 GWd/mtU k_{eff} / σ k_{eff} + 2σ	20 GWd/mtU k_{eff} / σ k_{eff} + 2σ	30 GWd/mtU k_{eff} / σ k_{eff} + 2σ	40 GWd/mtU k_{eff} / σ k_{eff} + 2σ	50 GWd/mtU k_{eff} / σ k_{eff} + 2σ
3.5	0.85479/ 0.00048	0.78767/ 0.00047	0.72901/ 0.00046	0.69597/ 0.00043	0.67116/ 0.00043
	0.85575	0.78861	0.72993	0.69683	0.67202
4.0	0.87795/ 0.00046	0.8139/ 0.00049	0.75864/ 0.00046	0.72172/ 0.00047	0.69214/ 0.00041
	0.87887	0.81488	0.75956	0.72266	0.69296
4.5	0.89779/ 0.00051	0.83839/ 0.0005	0.78334/ 0.00045	0.74605/ 0.00048	0.71273/ 0.00045
	0.89881	0.83939	0.78424	0.74701	0.71363
5.0	0.91614/ 0.00053	0.86013/ 0.00051	0.80842/ 0.00049	0.76784/ 0.00046	0.73500/ 0.00049
	0.9172	0.86115	0.8094	0.76876	0.73598

NOTE: [a] Initial enrichments lower than 3.5 wt% U-235 will yield lower k_{eff} values with burnup than the results reported, and therefore were not evaluated.

Table 53. Coefficients for Preclosure Loading Curve Correlation

Coefficient	Value
C_0	0.724872
C_1	0.046488
C_2	-0.0046
Linear coefficient (r^2)	0.979535

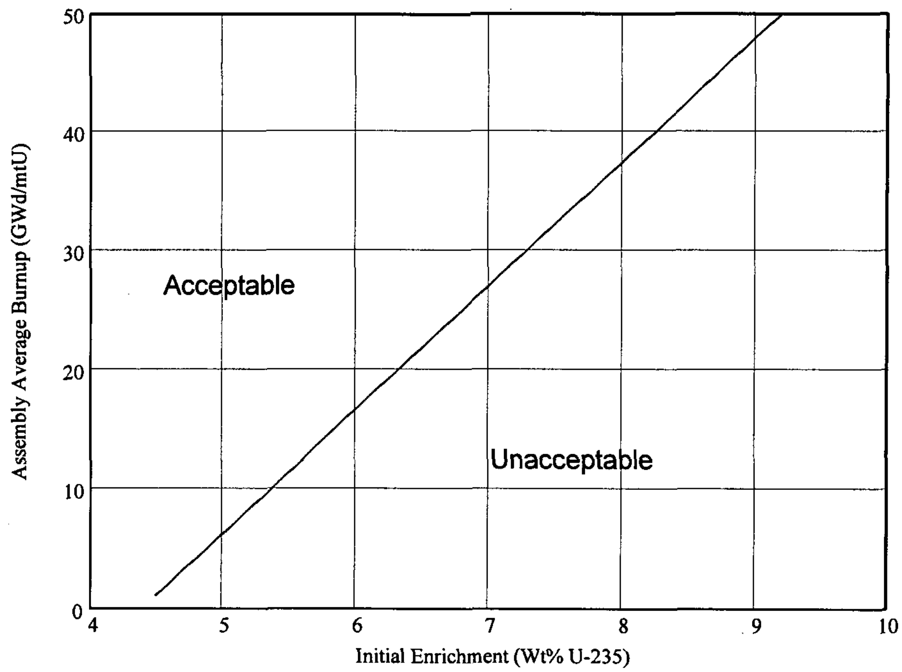


Figure 21. Preclosure Loading Curve for 0.928 Upper Subcritical Limit

6.2.2 Postclosure Time Period

The results of the MCNP calculations are tabulated in Tables 54 and 55 for the postclosure intact basket configuration and fully degraded basket configuration, respectively. Figure 3-5 of Reference 7.10 indicates that a regression expression is to be developed for a configuration class that has a potential for criticality. The form of the regression expression is as follows:

$$Peak\ k_{eff}+2\sigma = C_0+C_1E+C_2B$$

where B is burnup in GWd/mtU, E is initial enrichment in wt% U-235, and $Peak\ k_{eff}+2\sigma$ is the peak k_{eff} value plus 2 sigma for a given burnup/enrichment pair. This regression was used to develop the coefficicents as a function of initial enrichment and burnup. The loading curves shown in Figure 22 for the postclosure intact basket configuration and the postclosure degraded basket configuration was produced by setting the $peak\ k_{eff} + 2\sigma$ value to the CL of 0.979 and solving for E over a burnup range of 1 to 50 GWd/mtU. The coefficients of the regression expression are presented in Table 56 for each configuration. These loading curves can be used in a probabilistic assessment for determining the frequency of waste package criticality.

Table 54. Postclosure Intact Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	k_{eff} +2σ
5000	10	4	0.8759	0.00048	0.87686
10000	10	4	0.87559	0.0005	0.87659
11000	10	4	0.87475	0.00052	0.87579
12000	10	4	0.87583	0.00048	0.87679
13000	10	4	0.87635	0.00049	0.87733
14000	10	4	0.87728	0.00052	0.87832
15000	10	4	0.87612	0.00048	0.87708
16000	10	4	0.87599	0.00047	0.87693
18000	10	4	0.87557	0.00049	0.87655
20000	10	4	0.87448	0.00052	0.87552
22500	10	4	0.87458	0.0005	0.87558
25000	10	4	0.87344	0.0005	0.87444
27500	10	4	0.87292	0.00053	0.87398
30000	10	4	0.87126	0.00048	0.87222
35000	10	4	0.86977	0.00048	0.87073
5000	20	4	0.80455	0.00049	0.80553
10000	20	4	0.80539	0.00051	0.80641
11000	20	4	0.80485	0.00053	0.80591
12000	20	4	0.80539	0.00049	0.80637
13000	20	4	0.80422	0.00054	0.8053
14000	20	4	0.8033	0.00051	0.80432
15000	20	4	0.80425	0.00052	0.80529
16000	20	4	0.8043	0.00046	0.80522
18000	20	4	0.80328	0.0005	0.80428
20000	20	4	0.80218	0.00051	0.8032
22500	20	4	0.80133	0.00055	0.80243
25000	20	4	0.80063	0.00049	0.80161
27500	20	4	0.7988	0.00051	0.79982
30000	20	4	0.80032	0.00047	0.80126
35000	20	4	0.79577	0.0005	0.79677
5000	30	4	0.7378	0.00045	0.7387
10000	30	4	0.739	0.00046	0.73992
11000	30	4	0.73828	0.00049	0.73926
12000	30	4	0.73724	0.00046	0.73816
13000	30	4	0.73787	0.00046	0.73879
14000	30	4	0.73795	0.00051	0.73897
15000	30	4	0.73695	0.00045	0.73785
16000	30	4	0.73682	0.00045	0.73772
18000	30	4	0.73611	0.00044	0.73699
20000	30	4	0.7353	0.00045	0.7362
22500	30	4	0.73257	0.00041	0.73339
25000	30	4	0.73282	0.00044	0.7337
27500	30	4	0.73158	0.00044	0.73246
30000	30	4	0.72902	0.00046	0.72994
35000	30	4	0.72571	0.00041	0.72653
5000	40	4	0.69121	0.00048	0.69217
10000	40	4	0.69037	0.00044	0.69125
11000	40	4	0.6892	0.00046	0.69012
12000	40	4	0.68953	0.00043	0.69039
13000	40	4	0.68899	0.00045	0.68989
14000	40	4	0.6898	0.00046	0.69072
15000	40	4	0.68752	0.00042	0.68836

Table 54. Postclosure Intact Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	$k_{eff}+2\sigma$
16000	40	4	0.6878	0.00043	0.68866
18000	40	4	0.68698	0.00044	0.68786
20000	40	4	0.68603	0.00042	0.68687
22500	40	4	0.6836	0.00047	0.68454
25000	40	4	0.68226	0.0004	0.68306
27500	40	4	0.68004	0.00041	0.68086
30000	40	4	0.67683	0.00044	0.67771
35000	40	4	0.67356	0.00043	0.67442
5000	50	4	0.65111	0.00039	0.65189
10000	50	4	0.65011	0.0004	0.65091
11000	50	4	0.64957	0.00041	0.65039
12000	50	4	0.64842	0.00039	0.6492
13000	50	4	0.64784	0.00042	0.64868
14000	50	4	0.6477	0.00041	0.64852
15000	50	4	0.64679	0.00044	0.64767
16000	50	4	0.64651	0.0004	0.64731
18000	50	4	0.64496	0.0004	0.64576
20000	50	4	0.64302	0.0004	0.64382
22500	50	4	0.64062	0.00039	0.6414
25000	50	4	0.63825	0.00045	0.63915
27500	50	4	0.63547	0.00037	0.63621
30000	50	4	0.63343	0.00037	0.63417
35000	50	4	0.62714	0.00038	0.6279
5000	10	4.5	0.89618	0.00046	0.8971
10000	10	4.5	0.89615	0.00053	0.89721
11000	10	4.5	0.89767	0.00053	0.89873
12000	10	4.5	0.89746	0.0005	0.89846
13000	10	4.5	0.89621	0.00048	0.89717
14000	10	4.5	0.89619	0.00047	0.89713
15000	10	4.5	0.89753	0.00058	0.89869
16000	10	4.5	0.89705	0.00053	0.89811
18000	10	4.5	0.89673	0.00052	0.89777
20000	10	4.5	0.89527	0.00052	0.89631
22500	10	4.5	0.89539	0.00049	0.89637
25000	10	4.5	0.89496	0.00054	0.89604
27500	10	4.5	0.89534	0.0005	0.89634
30000	10	4.5	0.89348	0.00053	0.89454
35000	10	4.5	0.89167	0.00052	0.89271
5000	20	4.5	0.83001	0.00053	0.83107
10000	20	4.5	0.83235	0.00055	0.83345
11000	20	4.5	0.83288	0.00053	0.83394
12000	20	4.5	0.83066	0.00047	0.8316
13000	20	4.5	0.832	0.00051	0.83302
14000	20	4.5	0.83301	0.0005	0.83401
15000	20	4.5	0.83219	0.00049	0.83317
16000	20	4.5	0.83181	0.00053	0.83287
18000	20	4.5	0.83123	0.00054	0.83231
20000	20	4.5	0.82998	0.00049	0.83096
22500	20	4.5	0.82923	0.00051	0.83025
25000	20	4.5	0.82998	0.00051	0.831
27500	20	4.5	0.82811	0.00053	0.82917
30000	20	4.5	0.82722	0.00048	0.82818

Table 54. Postclosure Intact Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	k_{eff} +2σ
35000	20	4.5	0.82622	0.00048	0.82718
5000	30	4.5	0.76712	0.0005	0.76812
10000	30	4.5	0.76804	0.00045	0.76894
11000	30	4.5	0.76818	0.00047	0.76912
12000	30	4.5	0.76884	0.00046	0.76976
13000	30	4.5	0.76838	0.00048	0.76934
14000	30	4.5	0.76772	0.0005	0.76872
15000	30	4.5	0.76819	0.00052	0.76923
16000	30	4.5	0.76784	0.0005	0.76884
18000	30	4.5	0.76705	0.00051	0.76807
20000	30	4.5	0.76702	0.00052	0.76806
22500	30	4.5	0.76633	0.00051	0.76735
25000	30	4.5	0.76524	0.00048	0.7662
27500	30	4.5	0.76356	0.00049	0.76454
30000	30	4.5	0.76281	0.00048	0.76377
35000	30	4.5	0.75993	0.00047	0.76087
5000	40	4.5	0.71936	0.00042	0.7202
10000	40	4.5	0.72011	0.00044	0.72099
11000	40	4.5	0.71944	0.00042	0.72028
12000	40	4.5	0.72061	0.00046	0.72153
13000	40	4.5	0.7191	0.00048	0.72006
14000	40	4.5	0.71895	0.00046	0.71987
15000	40	4.5	0.71953	0.00048	0.72049
16000	40	4.5	0.71771	0.00046	0.71863
18000	40	4.5	0.71689	0.00046	0.71781
20000	40	4.5	0.71601	0.00043	0.71687
22500	40	4.5	0.71489	0.00046	0.71581
25000	40	4.5	0.71361	0.00043	0.71447
27500	40	4.5	0.71214	0.00036	0.71286
30000	40	4.5	0.71064	0.00047	0.71158
35000	40	4.5	0.7065	0.00042	0.70734
5000	50	4.5	0.6766	0.00043	0.67746
10000	50	4.5	0.67755	0.00043	0.67841
11000	50	4.5	0.67655	0.00045	0.67745
12000	50	4.5	0.67586	0.00045	0.67676
13000	50	4.5	0.67558	0.00046	0.6765
14000	50	4.5	0.67513	0.00045	0.67603
15000	50	4.5	0.67497	0.00042	0.67581
16000	50	4.5	0.67497	0.00045	0.67587
18000	50	4.5	0.67328	0.00045	0.67418
20000	50	4.5	0.6721	0.00042	0.67294
22500	50	4.5	0.66977	0.00045	0.67067
25000	50	4.5	0.66773	0.0004	0.66853
27500	50	4.5	0.66636	0.00039	0.66714
30000	50	4.5	0.66385	0.00044	0.66473
35000	50	4.5	0.65916	0.00043	0.66002
5000	10	5	0.91568	0.0005	0.91668
10000	10	5	0.91543	0.00054	0.91651
11000	10	5	0.91636	0.00049	0.91734
12000	10	5	0.91585	0.0005	0.91685
13000	10	5	0.91589	0.00052	0.91693
14000	10	5	0.91508	0.0005	0.91608

Table 54. Postclosure Intact Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	k_{eff} +2σ
15000	10	5	0.91555	0.00046	0.91647
16000	10	5	0.91589	0.00049	0.91687
18000	10	5	0.91541	0.0005	0.91641
20000	10	5	0.91656	0.00051	0.91758
22500	10	5	0.91591	0.00054	0.91699
25000	10	5	0.91512	0.00052	0.91616
27500	10	5	0.91398	0.00052	0.91502
30000	10	5	0.91467	0.00054	0.91575
35000	10	5	0.91267	0.00048	0.91363
5000	20	5	0.85372	0.00056	0.85484
10000	20	5	0.85468	0.00051	0.8557
11000	20	5	0.85522	0.00053	0.85628
12000	20	5	0.85644	0.00049	0.85742
13000	20	5	0.85619	0.00052	0.85723
14000	20	5	0.85665	0.00049	0.85763
15000	20	5	0.85481	0.00047	0.85575
16000	20	5	0.85596	0.00051	0.85698
18000	20	5	0.85578	0.00051	0.8568
20000	20	5	0.8546	0.00051	0.85562
22500	20	5	0.85478	0.00051	0.8558
25000	20	5	0.85451	0.00055	0.85561
27500	20	5	0.85396	0.00052	0.855
30000	20	5	0.85353	0.0005	0.85453
35000	20	5	0.85166	0.00052	0.8527
5000	30	5	0.79424	0.00048	0.7952
10000	30	5	0.79458	0.00053	0.79564
11000	30	5	0.79623	0.0005	0.79723
12000	30	5	0.79477	0.00052	0.79581
13000	30	5	0.79566	0.0005	0.79666
14000	30	5	0.79538	0.00048	0.79634
15000	30	5	0.79654	0.00052	0.79758
16000	30	5	0.79495	0.0005	0.79595
18000	30	5	0.79613	0.00056	0.79725
20000	30	5	0.79424	0.00048	0.7952
22500	30	5	0.79435	0.00052	0.79539
25000	30	5	0.79384	0.0005	0.79484
27500	30	5	0.79235	0.00052	0.79339
30000	30	5	0.79039	0.00054	0.79147
35000	30	5	0.78994	0.00054	0.79102
5000	40	5	0.74618	0.00045	0.74708
10000	40	5	0.74736	0.00043	0.74822
11000	40	5	0.74781	0.0005	0.74881
12000	40	5	0.74777	0.00046	0.74869
13000	40	5	0.74648	0.00046	0.7474
14000	40	5	0.7487	0.00048	0.74966
15000	40	5	0.74715	0.00043	0.74801
16000	40	5	0.74695	0.00048	0.74791
18000	40	5	0.74713	0.00047	0.74807
20000	40	5	0.74509	0.00042	0.74593
22500	40	5	0.74439	0.00044	0.74527
25000	40	5	0.74378	0.00047	0.74472
27500	40	5	0.74242	0.00046	0.74334

Table 54. Postclosure Intact Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	k_{eff} +2σ
30000	40	5	0.74005	0.0004	0.74085
35000	40	5	0.73713	0.00045	0.73803
5000	50	5	0.70254	0.00046	0.70346
10000	50	5	0.70329	0.00045	0.70419
11000	50	5	0.70374	0.00043	0.7046
12000	50	5	0.7028	0.00045	0.7037
13000	50	5	0.70327	0.00044	0.70415
14000	50	5	0.70344	0.00043	0.7043
15000	50	5	0.70242	0.00047	0.70336
16000	50	5	0.70159	0.00041	0.70241
18000	50	5	0.70026	0.00049	0.70124
20000	50	5	0.69899	0.00041	0.69981
22500	50	5	0.69813	0.00046	0.69905
25000	50	5	0.69673	0.00042	0.69757
27500	50	5	0.69464	0.00042	0.69548
30000	50	5	0.69216	0.00047	0.6931
35000	50	5	0.68952	0.00045	0.69042

Table 55. Postclosure Degraded Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	k_{eff} + 2σ
5000	10	2	1.07514	0.00047	1.07608
10000	10	2	1.07718	0.0005	1.07818
11000	10	2	1.0768	0.00053	1.07786
12000	10	2	1.07698	0.00055	1.07808
13000	10	2	1.07699	0.0005	1.07799
14000	10	2	1.07698	0.00053	1.07804
15000	10	2	1.07698	0.00052	1.07802
16000	10	2	1.07656	0.00049	1.07754
18000	10	2	1.07493	0.00052	1.07597
20000	10	2	1.0744	0.00048	1.07536
22500	10	2	1.07412	0.0005	1.07512
25000	10	2	1.0715	0.00044	1.07238
27500	10	2	1.07104	0.00049	1.07202
30000	10	2	1.06977	0.0005	1.07077
35000	10	2	1.06495	0.00052	1.06599
5000	20	2	0.94506	0.00052	0.9461
10000	20	2	0.94653	0.00044	0.94741
11000	20	2	0.94469	0.00048	0.94565
12000	20	2	0.94581	0.00056	0.94693
13000	20	2	0.94402	0.00049	0.945
14000	20	2	0.94497	0.00059	0.94615
15000	20	2	0.94359	0.00053	0.94465
16000	20	2	0.94194	0.00052	0.94298
18000	20	2	0.94127	0.00041	0.94209
20000	20	2	0.93886	0.00048	0.93982
22500	20	2	0.93761	0.00044	0.93849
25000	20	2	0.93451	0.00044	0.93539
27500	20	2	0.93279	0.00057	0.93393
30000	20	2	0.92987	0.00048	0.93083
35000	20	2	0.92351	0.00052	0.92455

Table 55. Postclosure Degraded Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	k_{eff} + 2σ
5000	30	2	0.84999	0.00044	0.85087
10000	30	2	0.8471	0.00045	0.848
11000	30	2	0.84656	0.00042	0.8474
12000	30	2	0.84555	0.00047	0.84649
13000	30	2	0.84597	0.0005	0.84697
14000	30	2	0.84498	0.00049	0.84596
15000	30	2	0.84338	0.00043	0.84424
16000	30	2	0.84295	0.00042	0.84379
18000	30	2	0.84097	0.0005	0.84197
20000	30	2	0.83792	0.00044	0.8388
22500	30	2	0.83494	0.00044	0.83582
25000	30	2	0.83113	0.00041	0.83195
27500	30	2	0.82793	0.00042	0.82877
30000	30	2	0.82412	0.00044	0.825
35000	30	2	0.81589	0.00044	0.81677
5000	40	2	0.80919	0.00049	0.81017
10000	40	2	0.80831	0.00042	0.80915
11000	40	2	0.80774	0.00044	0.80862
12000	40	2	0.80739	0.00043	0.80825
13000	40	2	0.8062	0.00045	0.8071
14000	40	2	0.80556	0.00045	0.80646
15000	40	2	0.80451	0.00041	0.80533
16000	40	2	0.80356	0.00041	0.80438
18000	40	2	0.80273	0.00049	0.80371
20000	40	2	0.79828	0.00046	0.7992
22500	40	2	0.79472	0.00043	0.79558
25000	40	2	0.79006	0.00041	0.79088
27500	40	2	0.78695	0.00037	0.78769
30000	40	2	0.78113	0.00044	0.78201
35000	40	2	0.77263	0.00043	0.77349
5000	50	2	0.78562	0.00043	0.78648
10000	50	2	0.78614	0.00043	0.787
11000	50	2	0.78585	0.00047	0.78679
12000	50	2	0.78564	0.00048	0.7866
13000	50	2	0.78421	0.00047	0.78515
14000	50	2	0.78407	0.00044	0.78495
15000	50	2	0.78356	0.00044	0.78444
16000	50	2	0.78106	0.00048	0.78202
18000	50	2	0.77998	0.00045	0.78088
20000	50	2	0.77753	0.00042	0.77837
22500	50	2	0.773	0.00045	0.7739
25000	50	2	0.76754	0.00046	0.76846
27500	50	2	0.76427	0.00041	0.76509
30000	50	2	0.76036	0.00041	0.76118
35000	50	2	0.75057	0.00045	0.75147
5000	10	2.5	1.13	0.00056	1.13112
10000	10	2.5	1.13216	0.00058	1.13332
11000	10	2.5	1.13216	0.00056	1.13328
12000	10	2.5	1.13209	0.00057	1.13323
13000	10	2.5	1.13259	0.00051	1.13361
14000	10	2.5	1.13203	0.00056	1.13315
15000	10	2.5	1.13126	0.00063	1.13252

Table 55. Postclosure Degraded Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	$k_{eff} + 2\sigma$
16000	10	2.5	1.13028	0.0006	1.13148
18000	10	2.5	1.13121	0.00051	1.13223
20000	10	2.5	1.13098	0.00055	1.13208
22500	10	2.5	1.13065	0.00047	1.13159
25000	10	2.5	1.12919	0.00055	1.13029
27500	10	2.5	1.12794	0.00063	1.1292
30000	10	2.5	1.12675	0.00049	1.12773
35000	10	2.5	1.12376	0.00054	1.12484
5000	20	2.5	1.00917	0.00056	1.01029
10000	20	2.5	1.00963	0.00051	1.01065
11000	20	2.5	1.00964	0.0006	1.01084
12000	20	2.5	1.01007	0.0005	1.01107
13000	20	2.5	1.00866	0.00051	1.00968
14000	20	2.5	1.00926	0.00047	1.0102
15000	20	2.5	1.00957	0.00055	1.01067
16000	20	2.5	1.00913	0.00059	1.01031
18000	20	2.5	1.00816	0.00053	1.00922
20000	20	2.5	1.0071	0.0005	1.0081
22500	20	2.5	1.00477	0.00055	1.00587
25000	20	2.5	1.00369	0.00062	1.00493
27500	20	2.5	1.00209	0.00057	1.00323
30000	20	2.5	0.99885	0.00051	0.99987
35000	20	2.5	0.99535	0.00055	0.99645
5000	30	2.5	0.90734	0.00047	0.90828
10000	30	2.5	0.91016	0.00048	0.91112
11000	30	2.5	0.90872	0.0005	0.90972
12000	30	2.5	0.90834	0.00053	0.9094
13000	30	2.5	0.90754	0.00047	0.90848
14000	30	2.5	0.9071	0.00049	0.90808
15000	30	2.5	0.90668	0.00053	0.90774
16000	30	2.5	0.90656	0.0005	0.90756
18000	30	2.5	0.90378	0.0005	0.90478
20000	30	2.5	0.90332	0.00045	0.90422
22500	30	2.5	0.89974	0.00045	0.90064
25000	30	2.5	0.89757	0.00049	0.89855
27500	30	2.5	0.89445	0.00046	0.89537
30000	30	2.5	0.89159	0.0005	0.89259
35000	30	2.5	0.88503	0.00049	0.88601
5000	40	2.5	0.85531	0.0005	0.85631
10000	40	2.5	0.85639	0.0005	0.85739
11000	40	2.5	0.85532	0.00047	0.85626
12000	40	2.5	0.85534	0.00054	0.85642
13000	40	2.5	0.85428	0.00045	0.85518
14000	40	2.5	0.85454	0.00048	0.8555
15000	40	2.5	0.85258	0.00048	0.85354
16000	40	2.5	0.85168	0.0005	0.85268
18000	40	2.5	0.84935	0.00045	0.85025
20000	40	2.5	0.84756	0.00049	0.84854
22500	40	2.5	0.84377	0.00046	0.84469
25000	40	2.5	0.84201	0.00043	0.84287
27500	40	2.5	0.8374	0.00054	0.83848
30000	40	2.5	0.83281	0.0004	0.83361

Table 55. Postclosure Degraded Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	k_{eff} + 2σ
35000	40	2.5	0.8253	0.00046	0.82622
5000	50	2.5	0.82117	0.00048	0.82213
10000	50	2.5	0.82082	0.00043	0.82168
11000	50	2.5	0.82039	0.0005	0.82139
12000	50	2.5	0.82094	0.00047	0.82188
13000	50	2.5	0.82054	0.00055	0.82164
14000	50	2.5	0.8194	0.00047	0.82034
15000	50	2.5	0.81913	0.00045	0.82003
16000	50	2.5	0.81773	0.00045	0.81863
18000	50	2.5	0.8151	0.00042	0.81594
20000	50	2.5	0.81282	0.00043	0.81368
22500	50	2.5	0.80956	0.00051	0.81058
25000	50	2.5	0.80508	0.00045	0.80598
27500	50	2.5	0.80096	0.00045	0.80186
30000	50	2.5	0.79556	0.00048	0.79652
35000	50	2.5	0.78895	0.00046	0.78987
5000	10	3	1.16844	0.00051	1.16946
10000	10	3	1.17138	0.00052	1.17242
11000	10	3	1.17183	0.00054	1.17291
12000	10	3	1.17321	0.0005	1.17421
13000	10	3	1.1709	0.00051	1.17192
14000	10	3	1.17278	0.0005	1.17378
15000	10	3	1.17293	0.00052	1.17397
16000	10	3	1.17287	0.00051	1.17389
18000	10	3	1.17225	0.00052	1.17329
20000	10	3	1.17168	0.00056	1.1728
22500	10	3	1.17017	0.00049	1.17115
25000	10	3	1.17255	0.00046	1.17347
27500	10	3	1.17012	0.00052	1.17116
30000	10	3	1.16965	0.00055	1.17075
35000	10	3	1.16844	0.00058	1.1696
5000	20	3	1.05931	0.00062	1.06055
10000	20	3	1.06141	0.0006	1.06261
11000	20	3	1.06105	0.00066	1.06237
12000	20	3	1.06028	0.00057	1.06142
13000	20	3	1.06026	0.00062	1.0615
14000	20	3	1.06294	0.00056	1.06406
15000	20	3	1.06241	0.00055	1.06351
16000	20	3	1.06046	0.00059	1.06164
18000	20	3	1.06198	0.00057	1.06312
20000	20	3	1.05952	0.00064	1.0608
22500	20	3	1.05877	0.00051	1.05979
25000	20	3	1.05865	0.00055	1.05975
27500	20	3	1.0568	0.0006	1.058
30000	20	3	1.05539	0.00062	1.05663
35000	20	3	1.05199	0.00056	1.05311
5000	30	3	0.96132	0.00055	0.96242
10000	30	3	0.96276	0.00054	0.96384
11000	30	3	0.96312	0.00056	0.96424
12000	30	3	0.9621	0.0005	0.9631
13000	30	3	0.96267	0.0005	0.96367
14000	30	3	0.96275	0.00051	0.96377

Table 55. Postclosure Degraded Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	$k_{eff} + 2\sigma$
15000	30	3	0.96213	0.00045	0.96303
16000	30	3	0.96196	0.00056	0.96308
18000	30	3	0.96176	0.00049	0.96274
20000	30	3	0.9587	0.00054	0.95978
22500	30	3	0.95811	0.00056	0.95923
25000	30	3	0.95648	0.00054	0.95756
27500	30	3	0.95407	0.00052	0.95511
30000	30	3	0.95134	0.00052	0.95238
35000	30	3	0.94599	0.0005	0.94699
5000	40	3	0.89977	0.00053	0.90083
10000	40	3	0.90083	0.00053	0.90189
11000	40	3	0.90085	0.00049	0.90183
12000	40	3	0.9007	0.0005	0.9017
13000	40	3	0.90155	0.00053	0.90261
14000	40	3	0.89978	0.00045	0.90068
15000	40	3	0.89921	0.00051	0.90023
16000	40	3	0.8983	0.00051	0.89932
18000	40	3	0.89648	0.00048	0.89744
20000	40	3	0.89545	0.00044	0.89633
22500	40	3	0.8933	0.00049	0.89428
25000	40	3	0.89068	0.00053	0.89174
27500	40	3	0.88694	0.00051	0.88796
30000	40	3	0.88378	0.00043	0.88464
35000	40	3	0.87805	0.00046	0.87897
5000	50	3	0.85493	0.00046	0.85585
10000	50	3	0.8554	0.00048	0.85636
11000	50	3	0.85687	0.00049	0.85785
12000	50	3	0.85575	0.00047	0.85669
13000	50	3	0.85494	0.00043	0.8558
14000	50	3	0.85449	0.00051	0.85551
15000	50	3	0.8527	0.00052	0.85374
16000	50	3	0.85205	0.00048	0.85301
18000	50	3	0.85094	0.00044	0.85182
20000	50	3	0.84913	0.00047	0.85007
22500	50	3	0.84683	0.00047	0.84777
25000	50	3	0.84188	0.00042	0.84272
27500	50	3	0.83773	0.00054	0.83881
30000	50	3	0.83484	0.00045	0.83574
35000	50	3	0.82652	0.00042	0.82736
5000	10	3.5	1.19999	0.00056	1.20111
10000	10	3.5	1.20285	0.00054	1.20393
11000	10	3.5	1.20319	0.00049	1.20417
12000	10	3.5	1.20324	0.00051	1.20426
13000	10	3.5	1.20451	0.00056	1.20563
14000	10	3.5	1.2047	0.00056	1.20582
15000	10	3.5	1.20664	0.00054	1.20772
16000	10	3.5	1.20517	0.00049	1.20615
18000	10	3.5	1.20571	0.00053	1.20677
20000	10	3.5	1.20584	0.00053	1.2069
22500	10	3.5	1.20511	0.00049	1.20609
25000	10	3.5	1.20344	0.00051	1.20446
27500	10	3.5	1.20386	0.00052	1.2049

Table 55. Postclosure Degraded Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	$k_{eff} + 2\sigma$
30000	10	3.5	1.20351	0.00055	1.20461
35000	10	3.5	1.20187	0.00051	1.20289
5000	20	3.5	1.10005	0.00064	1.10133
10000	20	3.5	1.10278	0.00059	1.10396
11000	20	3.5	1.10496	0.00058	1.10612
12000	20	3.5	1.10422	0.00065	1.10552
13000	20	3.5	1.10474	0.00055	1.10584
14000	20	3.5	1.10472	0.00059	1.1059
15000	20	3.5	1.10538	0.00063	1.10664
16000	20	3.5	1.10528	0.00061	1.1065
18000	20	3.5	1.10348	0.0006	1.10468
20000	20	3.5	1.10387	0.00063	1.10513
22500	20	3.5	1.10512	0.0005	1.10612
25000	20	3.5	1.10295	0.0006	1.10415
27500	20	3.5	1.10105	0.00058	1.10221
30000	20	3.5	1.10159	0.00063	1.10285
35000	20	3.5	1.09685	0.00057	1.09799
5000	30	3.5	1.00604	0.00056	1.00716
10000	30	3.5	1.01083	0.00053	1.01189
11000	30	3.5	1.00994	0.00054	1.01102
12000	30	3.5	1.01014	0.00059	1.01132
13000	30	3.5	1.00924	0.00057	1.01038
14000	30	3.5	1.01146	0.00048	1.01242
15000	30	3.5	1.01015	0.00055	1.01125
16000	30	3.5	1.0106	0.00057	1.01174
18000	30	3.5	1.00936	0.00064	1.01064
20000	30	3.5	1.00956	0.00053	1.01062
22500	30	3.5	1.00813	0.00051	1.00915
25000	30	3.5	1.00649	0.00054	1.00757
27500	30	3.5	1.00647	0.00052	1.00751
30000	30	3.5	1.00241	0.0005	1.00341
35000	30	3.5	0.99883	0.00058	0.99999
5000	40	3.5	0.942	0.00052	0.94304
10000	40	3.5	0.94396	0.00055	0.94506
11000	40	3.5	0.94398	0.00051	0.945
12000	40	3.5	0.94393	0.00053	0.94499
13000	40	3.5	0.94425	0.00051	0.94527
14000	40	3.5	0.94456	0.00055	0.94566
15000	40	3.5	0.94451	0.00047	0.94545
16000	40	3.5	0.94434	0.00053	0.9454
18000	40	3.5	0.94143	0.0005	0.94243
20000	40	3.5	0.9409	0.00049	0.94188
22500	40	3.5	0.93956	0.00047	0.9405
25000	40	3.5	0.93772	0.00048	0.93868
27500	40	3.5	0.93479	0.00054	0.93587
30000	40	3.5	0.93213	0.00045	0.93303
35000	40	3.5	0.92725	0.00053	0.92831
5000	50	3.5	0.88956	0.00049	0.89054
10000	50	3.5	0.8915	0.00055	0.8926
11000	50	3.5	0.8915	0.00053	0.89256
12000	50	3.5	0.89185	0.00052	0.89289
13000	50	3.5	0.89096	0.00046	0.89188

Table 55. Postclosure Degraded Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	k_{eff} + 2σ
14000	50	3.5	0.8896	0.00046	0.89052
15000	50	3.5	0.88946	0.00046	0.89038
16000	50	3.5	0.88943	0.00049	0.89041
18000	50	3.5	0.8867	0.00049	0.88768
20000	50	3.5	0.88585	0.00053	0.88691
22500	50	3.5	0.88432	0.00049	0.8853
25000	50	3.5	0.88143	0.00046	0.88235
27500	50	3.5	0.87772	0.00044	0.8786
30000	50	3.5	0.87399	0.00047	0.87493
35000	50	3.5	0.86775	0.00042	0.86859
5000	10	4	1.22629	0.00053	1.22735
10000	10	4	1.23097	0.00053	1.23203
11000	10	4	1.2304	0.00053	1.23146
12000	10	4	1.2314	0.00059	1.23258
13000	10	4	1.23047	0.00047	1.23141
14000	10	4	1.23251	0.00049	1.23349
15000	10	4	1.23118	0.00048	1.23214
16000	10	4	1.23059	0.00051	1.23161
18000	10	4	1.2305	0.00058	1.23166
20000	10	4	1.2336	0.00056	1.23472
22500	10	4	1.23182	0.00049	1.2328
25000	10	4	1.23036	0.00057	1.2315
27500	10	4	1.23167	0.00053	1.23273
30000	10	4	1.23145	0.00052	1.23249
35000	10	4	1.22942	0.00047	1.23036
5000	20	4	1.13485	0.00065	1.13615
10000	20	4	1.13757	0.00054	1.13865
11000	20	4	1.14098	0.00063	1.14224
12000	20	4	1.14028	0.00061	1.1415
13000	20	4	1.13974	0.0007	1.14114
14000	20	4	1.14018	0.00057	1.14132
15000	20	4	1.14008	0.00057	1.14122
16000	20	4	1.14127	0.0006	1.14247
18000	20	4	1.14194	0.00052	1.14298
20000	20	4	1.14238	0.00062	1.14362
22500	20	4	1.14168	0.00065	1.14298
25000	20	4	1.14029	0.00056	1.14141
27500	20	4	1.14095	0.00058	1.14211
30000	20	4	1.13956	0.00051	1.14058
35000	20	4	1.1365	0.00059	1.13768
5000	30	4	1.04605	0.00055	1.04715
10000	30	4	1.05012	0.00064	1.0514
11000	30	4	1.05083	0.00057	1.05197
12000	30	4	1.05107	0.00067	1.05241
13000	30	4	1.05236	0.00058	1.05352
14000	30	4	1.05223	0.00058	1.05339
15000	30	4	1.05205	0.00064	1.05333
16000	30	4	1.05459	0.00054	1.05567
18000	30	4	1.05203	0.00056	1.05315
20000	30	4	1.05183	0.00062	1.05307
22500	30	4	1.05112	0.0006	1.05232
25000	30	4	1.05017	0.00061	1.05139

Table 55. Postclosure Degraded Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	$k_{eff} + 2\sigma$
27500	30	4	1.04924	0.00062	1.05048
30000	30	4	1.04861	0.00052	1.04965
35000	30	4	1.04473	0.00059	1.04591
5000	40	4	0.98253	0.00057	0.98367
10000	40	4	0.9838	0.00055	0.9849
11000	40	4	0.98478	0.00057	0.98592
12000	40	4	0.98464	0.00052	0.98568
13000	40	4	0.98463	0.00062	0.98587
14000	40	4	0.98489	0.0005	0.98589
15000	40	4	0.98555	0.00059	0.98673
16000	40	4	0.98388	0.0005	0.98488
18000	40	4	0.98464	0.00058	0.9858
20000	40	4	0.98351	0.00051	0.98453
22500	40	4	0.9827	0.00049	0.98368
25000	40	4	0.98162	0.00054	0.9827
27500	40	4	0.97891	0.00055	0.98001
30000	40	4	0.97722	0.00053	0.97828
35000	40	4	0.97289	0.00052	0.97393
5000	50	4	0.92387	0.00058	0.92503
10000	50	4	0.92777	0.00058	0.92893
11000	50	4	0.92538	0.00053	0.92644
12000	50	4	0.92694	0.00049	0.92792
13000	50	4	0.92682	0.00051	0.92784
14000	50	4	0.92644	0.00052	0.92748
15000	50	4	0.92677	0.00049	0.92775
16000	50	4	0.92655	0.00046	0.92747
18000	50	4	0.92536	0.0005	0.92636
20000	50	4	0.92392	0.00052	0.92496
22500	50	4	0.92184	0.0005	0.92284
25000	50	4	0.9191	0.00053	0.92016
27500	50	4	0.91679	0.00046	0.91771
30000	50	4	0.91474	0.00049	0.91572
35000	50	4	0.90891	0.00046	0.90983
5000	10	4.5	1.24841	0.00057	1.24955
10000	10	4.5	1.25212	0.00052	1.25316
11000	10	4.5	1.25262	0.00054	1.2537
12000	10	4.5	1.25391	0.00052	1.25495
13000	10	4.5	1.25361	0.00058	1.25477
14000	10	4.5	1.25469	0.00053	1.25575
15000	10	4.5	1.25371	0.00055	1.25481
16000	10	4.5	1.25357	0.00056	1.25469
18000	10	4.5	1.25401	0.00057	1.25515
20000	10	4.5	1.25445	0.00057	1.25559
22500	10	4.5	1.25521	0.0005	1.25621
25000	10	4.5	1.25587	0.00062	1.25711
27500	10	4.5	1.25535	0.00049	1.25633
30000	10	4.5	1.25545	0.00054	1.25653
35000	10	4.5	1.25494	0.00064	1.25622
5000	20	4.5	1.16554	0.0006	1.16674
10000	20	4.5	1.17033	0.00064	1.17161
11000	20	4.5	1.1699	0.00055	1.171
12000	20	4.5	1.16907	0.00056	1.17019

Table 55. Postclosure Degraded Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	k_{eff} + 2σ
13000	20	4.5	1.17085	0.00064	1.17213
14000	20	4.5	1.17042	0.00062	1.17166
15000	20	4.5	1.17174	0.00063	1.173
16000	20	4.5	1.17034	0.00064	1.17162
18000	20	4.5	1.17179	0.00056	1.17291
20000	20	4.5	1.17193	0.0006	1.17313
22500	20	4.5	1.1714	0.00059	1.17258
25000	20	4.5	1.17024	0.00058	1.1714
27500	20	4.5	1.17308	0.00057	1.17422
30000	20	4.5	1.17091	0.00063	1.17217
35000	20	4.5	1.17088	0.00062	1.17212
5000	30	4.5	1.08226	0.00057	1.0834
10000	30	4.5	1.0869	0.00066	1.08822
11000	30	4.5	1.08677	0.0006	1.08797
12000	30	4.5	1.0875	0.00058	1.08866
13000	30	4.5	1.08863	0.00057	1.08977
14000	30	4.5	1.08994	0.00065	1.09124
15000	30	4.5	1.08824	0.00069	1.08962
16000	30	4.5	1.09039	0.00063	1.09165
18000	30	4.5	1.08925	0.00064	1.09053
20000	30	4.5	1.09	0.00059	1.09118
22500	30	4.5	1.08827	0.00061	1.08949
25000	30	4.5	1.08803	0.0006	1.08923
27500	30	4.5	1.08947	0.00057	1.09061
30000	30	4.5	1.08776	0.00064	1.08904
35000	30	4.5	1.08475	0.00057	1.08589
5000	40	4.5	1.01692	0.00065	1.01822
10000	40	4.5	1.02059	0.0005	1.02159
11000	40	4.5	1.02038	0.00056	1.0215
12000	40	4.5	1.02162	0.00053	1.02268
13000	40	4.5	1.0219	0.0006	1.0231
14000	40	4.5	1.02272	0.00052	1.02376
15000	40	4.5	1.02054	0.00055	1.02164
16000	40	4.5	1.02258	0.00063	1.02384
18000	40	4.5	1.02418	0.00052	1.02522
20000	40	4.5	1.02221	0.00054	1.02329
22500	40	4.5	1.02052	0.00056	1.02164
25000	40	4.5	1.02037	0.00052	1.02141
27500	40	4.5	1.01915	0.00052	1.02019
30000	40	4.5	1.01691	0.00056	1.01803
35000	40	4.5	1.01401	0.00052	1.01505
5000	50	4.5	0.9568	0.00051	0.95782
10000	50	4.5	0.96104	0.00052	0.96208
11000	50	4.5	0.96096	0.00051	0.96198
12000	50	4.5	0.96053	0.00054	0.96161
13000	50	4.5	0.96182	0.00046	0.96274
14000	50	4.5	0.96091	0.00051	0.96193
15000	50	4.5	0.9609	0.00048	0.96186
16000	50	4.5	0.96096	0.00052	0.962
18000	50	4.5	0.95981	0.00053	0.96087
20000	50	4.5	0.95943	0.0005	0.96043
22500	50	4.5	0.95879	0.00045	0.95969

Table 55. Postclosure Degraded Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	k_{eff} + 2σ
25000	50	4.5	0.95751	0.00049	0.95849
27500	50	4.5	0.9542	0.00047	0.95514
30000	50	4.5	0.95278	0.00049	0.95376
35000	50	4.5	0.94806	0.00051	0.94908
5000	10	5	1.26642	0.00055	1.26752
10000	10	5	1.27158	0.00053	1.27264
11000	10	5	1.27315	0.00058	1.27431
12000	10	5	1.27172	0.00052	1.27276
13000	10	5	1.27259	0.00058	1.27375
14000	10	5	1.27362	0.00055	1.27472
15000	10	5	1.2727	0.0005	1.2737
16000	10	5	1.27444	0.00056	1.27556
18000	10	5	1.27494	0.00054	1.27602
20000	10	5	1.2752	0.00057	1.27634
22500	10	5	1.27488	0.00053	1.27594
25000	10	5	1.2752	0.00052	1.27624
27500	10	5	1.27532	0.0005	1.27632
30000	10	5	1.27543	0.00054	1.27651
35000	10	5	1.27423	0.0006	1.27543
5000	20	5	1.19119	0.00057	1.19233
10000	20	5	1.19665	0.00053	1.19771
11000	20	5	1.19439	0.00062	1.19563
12000	20	5	1.19753	0.00063	1.19879
13000	20	5	1.19737	0.00062	1.19861
14000	20	5	1.19812	0.00058	1.19928
15000	20	5	1.19882	0.0006	1.20002
16000	20	5	1.19874	0.00054	1.19982
18000	20	5	1.19832	0.00053	1.19938
20000	20	5	1.19957	0.00066	1.20089
22500	20	5	1.1991	0.00059	1.20028
25000	20	5	1.19896	0.00061	1.20018
27500	20	5	1.19989	0.00065	1.20119
30000	20	5	1.20073	0.00064	1.20201
35000	20	5	1.19879	0.00065	1.20009
5000	30	5	1.11233	0.0007	1.11373
10000	30	5	1.11883	0.00065	1.12013
11000	30	5	1.11852	0.00067	1.11986
12000	30	5	1.11895	0.00062	1.12019
13000	30	5	1.12094	0.00064	1.12222
14000	30	5	1.12154	0.00066	1.12286
15000	30	5	1.12216	0.0006	1.12336
16000	30	5	1.12042	0.00066	1.12174
18000	30	5	1.12139	0.00072	1.12283
20000	30	5	1.12256	0.00065	1.12386
22500	30	5	1.12203	0.00066	1.12335
25000	30	5	1.12215	0.00066	1.12347
27500	30	5	1.121	0.0007	1.1224
30000	30	5	1.12013	0.00071	1.12155
35000	30	5	1.11708	0.00064	1.11836
5000	40	5	1.04839	0.00057	1.04953
10000	40	5	1.05216	0.00055	1.05326
11000	40	5	1.05303	0.00055	1.05413

Table 55. Postclosure Degraded Basket k_{eff} Results

Decay Time (yrs)	Burnup (GWd/mtU)	Enrichment (Wt% U-235)	k_{eff}	σ	$k_{eff} + 2\sigma$
12000	40	5	1.05464	0.00056	1.05576
13000	40	5	1.05423	0.00058	1.05539
14000	40	5	1.05594	0.00059	1.05712
15000	40	5	1.05533	0.0006	1.05653
16000	40	5	1.05631	0.00062	1.05755
18000	40	5	1.05574	0.00063	1.057
20000	40	5	1.0574	0.00059	1.05858
22500	40	5	1.05452	0.00057	1.05566
25000	40	5	1.05478	0.0006	1.05598
27500	40	5	1.05438	0.00051	1.0554
30000	40	5	1.05385	0.00063	1.05511
35000	40	5	1.05171	0.00055	1.05281
5000	50	5	0.98881	0.00056	0.98993
10000	50	5	0.99288	0.00055	0.99398
11000	50	5	0.99325	0.00057	0.99439
12000	50	5	0.99363	0.00051	0.99465
13000	50	5	0.99436	0.00055	0.99546
14000	50	5	0.99349	0.00054	0.99457
15000	50	5	0.99475	0.00057	0.99589
16000	50	5	0.99594	0.0005	0.99694
18000	50	5	0.99495	0.0006	0.99615
20000	50	5	0.99355	0.00049	0.99453
22500	50	5	0.99327	0.00057	0.99441
25000	50	5	0.99171	0.00052	0.99275
27500	50	5	0.99025	0.00051	0.99127
30000	50	5	0.98763	0.00056	0.98875
35000	50	5	0.98508	0.00047	0.98602

Table 56. Coefficients for Postclosure Loading Curve Correlation

Coefficient	Intact Basket Configuration	Degraded Basket Configuration
C_0	0.712789	0.97662
C_1	0.051668	0.078439
C_2	-0.00551	-0.00756
Linear coefficient (r^2)	0.990456	0.974872

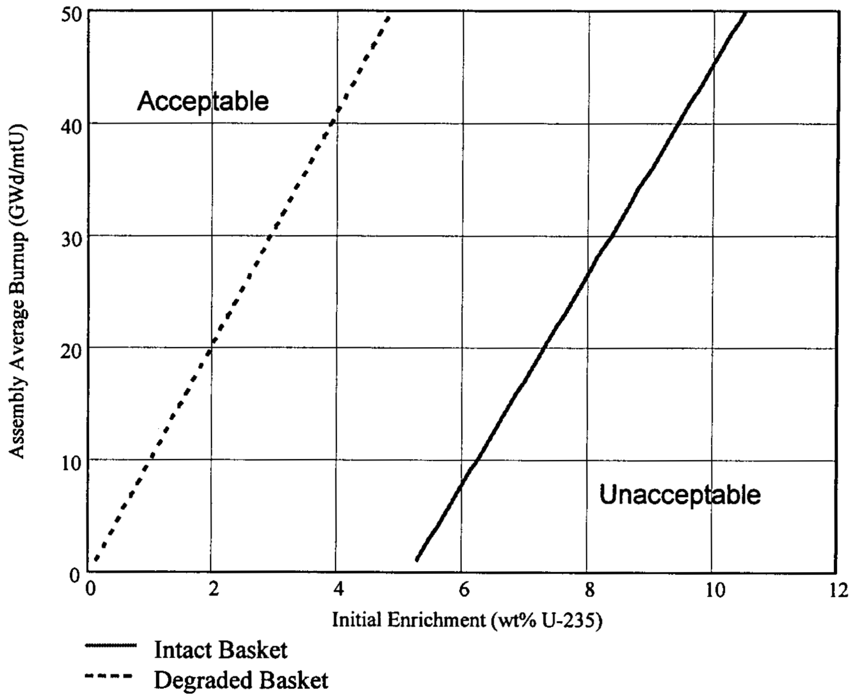


Figure 22. Postclosure Degraded Loading Curves

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7.28 MO9906RIB00048.000. Waste Package Material Properties: Waste Form Materials. Submittal date: 6/9/1999.

7.29 ASME (American Society of Mechanical Engineers) 1998. *1998 ASME Boiler and Pressure Vessel Code.* 1998 Edition with 1999 and 2000 Addenda. New York, New York: American Society of Mechanical Engineers. TIC: 247429.

7.30 ASM International 1987. *Corrosion.* Volume 13 of *Metals Handbook.* 9th Edition. Metals Park, Ohio: ASM International. TIC: 209807.

7.31 CRWMS M&O 1998. *Calculation of Upper Subcritical Limits for Nuclear Criticality in a Repository.* B00000000-01717-0210-00027 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980729.0420.

7.32 [Reserved]

7.33 MO9906RIB00054.000. Waste Package Material Properties: Structural Materials. Submittal date: 06/17/1999.

7.34 MO0109RIB00049.001. Waste Package Material Properties: Neutron Absorbing Materials. Submittal date: 09/17/2001.

7.35 AP-3.12Q, Rev. 0, ICN 4. *Calculations.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20010404.0008.

7.36 Audi, G. and Wapstra, A.H. 1995. *Atomic Mass Adjustment, Mass List for Analysis.* [Upton, New York: Brookhaven National Laboratory, National Nuclear Data Center]. TIC: 242718.

7.37 BSC 2001. *Software Code: Ft71v01.* 01. HP. 10493-01-00.

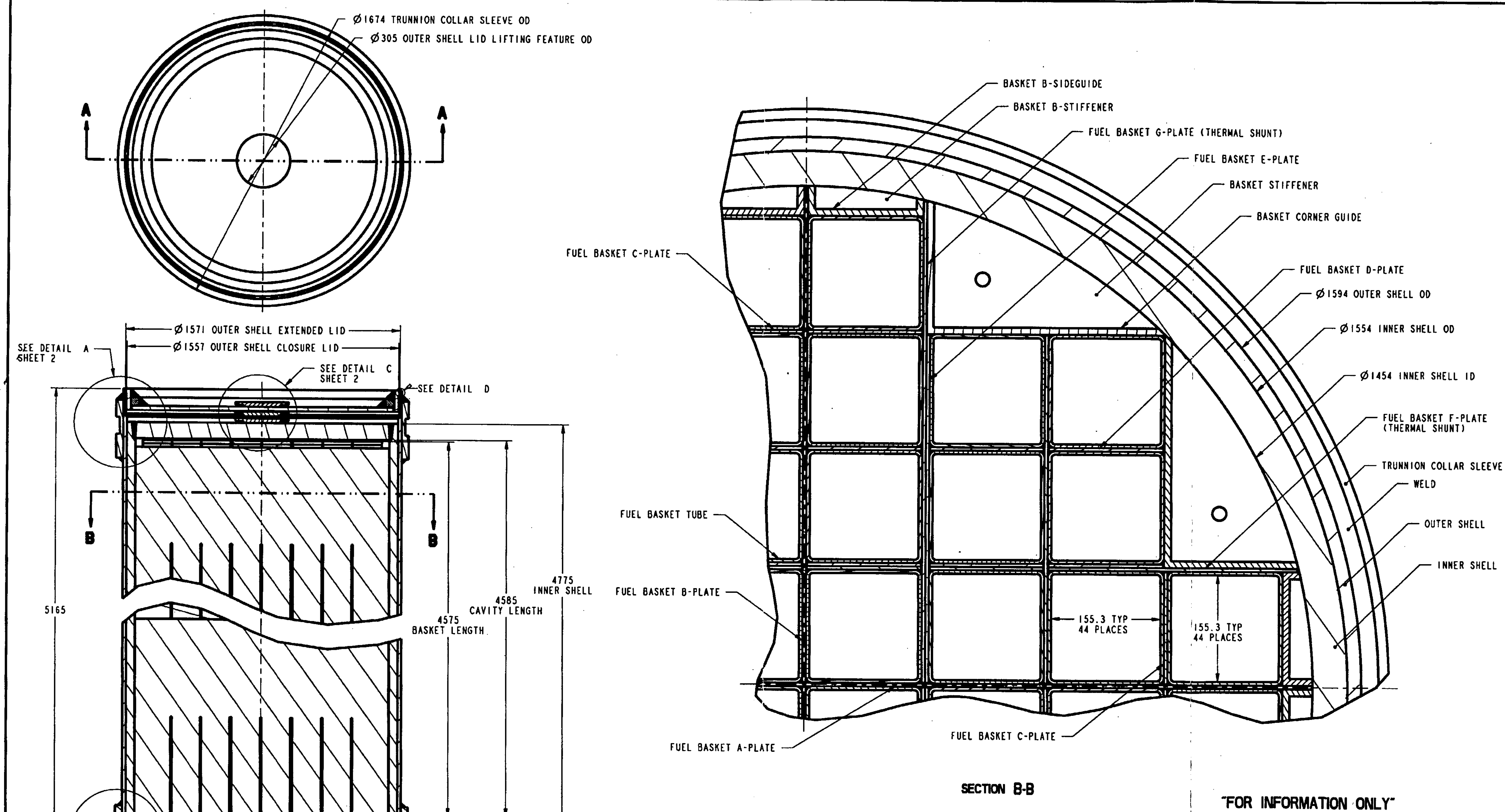
7.38 CRWMS M&O 1997. *Waste Container Cavity Size Determination.* BBAA00000-01717-0200-00026 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980106.0061.

8. ATTACHMENTS

Table 57 presents the attachment specifications for this calculation file.

Table 57. Attachment Listing

Attachment #	# of Pages	Date Created	Description
I	2	01/24/00	44 BWR Waste Package Configuration for Site Reccomendation Sketch
II	2	N/A	Listing of file attributes on CD attachment
III	N/A	10/17/2001	CD Attachment

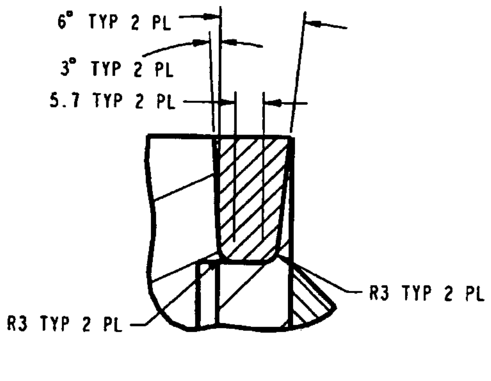


"FOR INFORMATION ONLY"

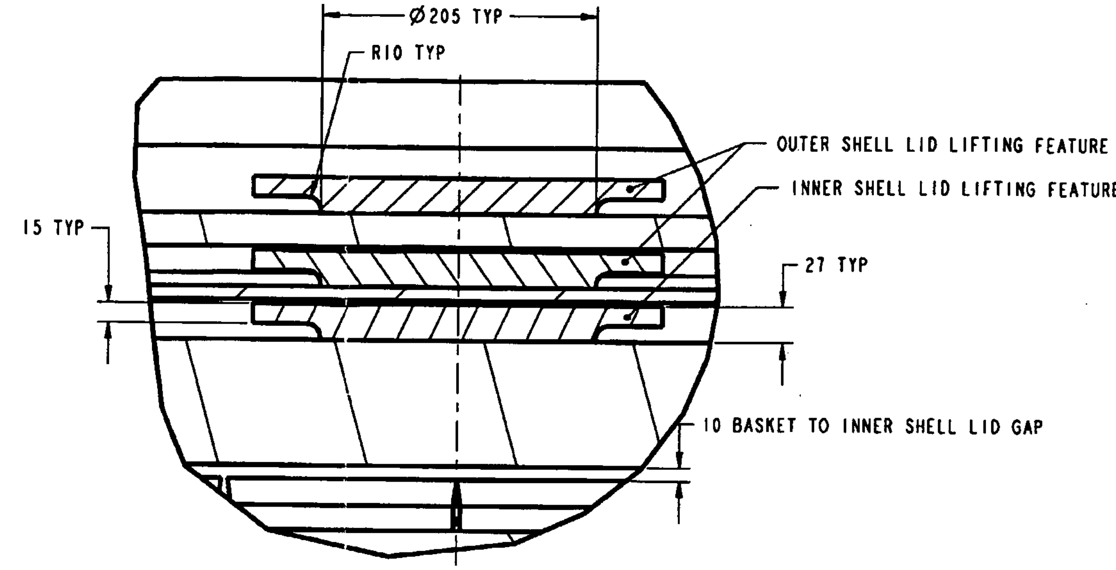
UNITS: mm

DO NOT SCALE FROM SKETCH

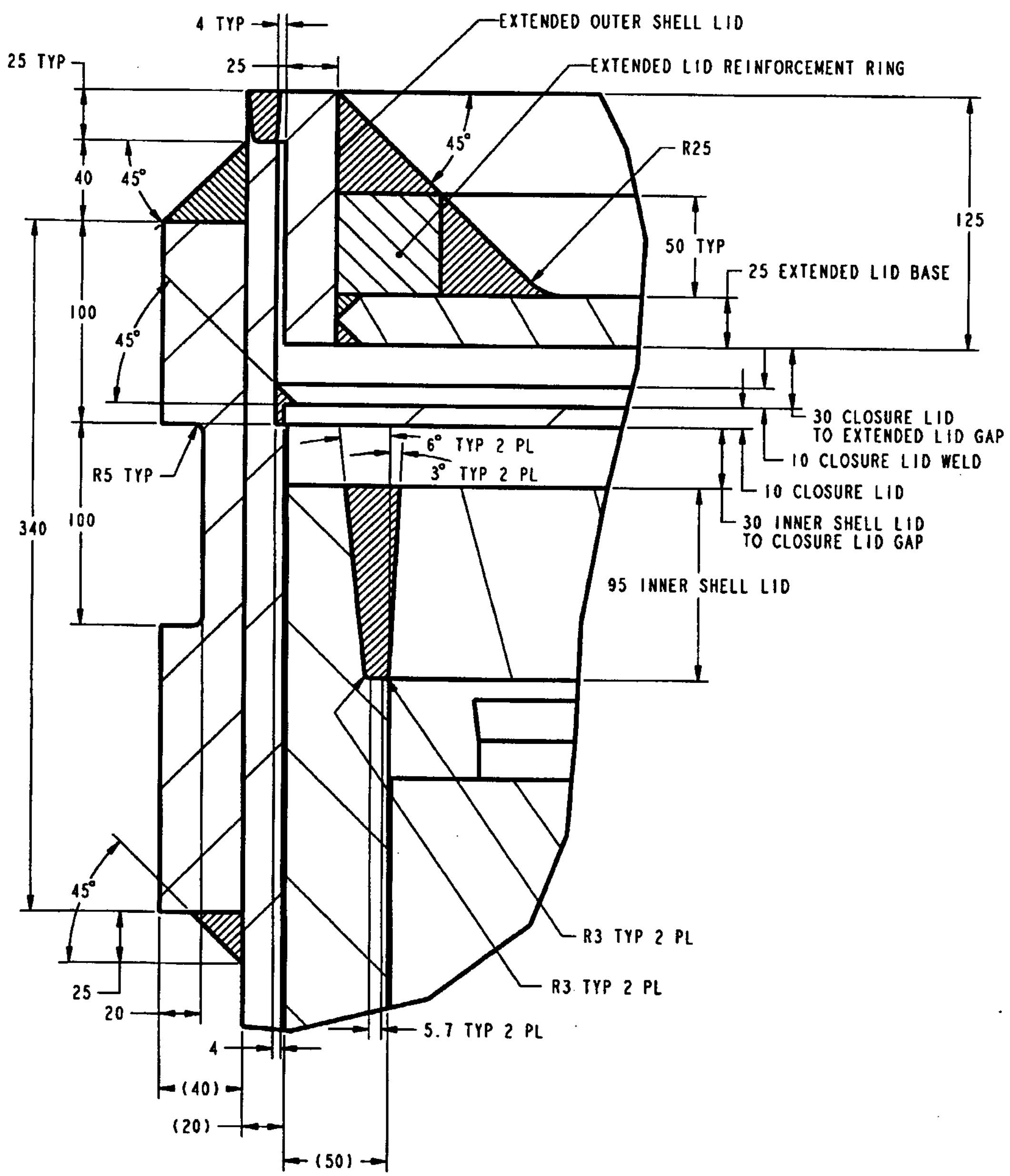
44-BWR WASTE PACKAGE CONFIGURATION FOR SITE RECOMMENDATION	
SKETCH NUMBER: SK-0192 REV 00	SHEET 1 OF 2
SKETCHED BY: BRYAN HARKINS	BH
DATE: 01/21/00	21Jan00 Joe 1/24/00 SMB 01/24/00
FILE: home/pro_library/checkout/sketches/44bwr/sk-0192.dwg	



DETAIL D



DETAIL C

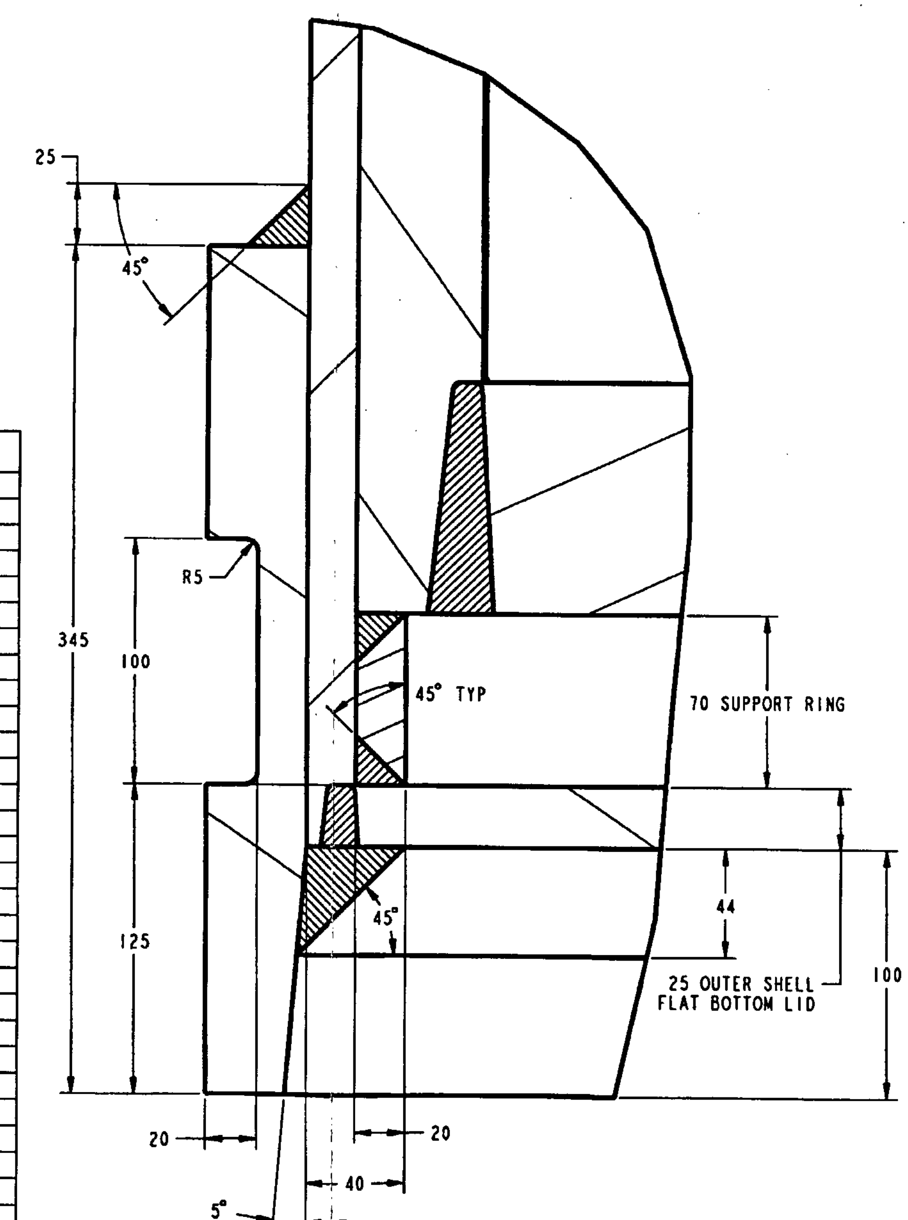


DETAIL A

COMPONENT NAME	MATERIAL	THICKNESS	MASS (KG)	QTY RQD
BASKET B-SIDEGUIDE	SA-516 K02700	10	19	32
BASKET B-STIFFENER	SA-516 K02700	10	0.31	64
BASKET CORNERGUIDE	SA-516 K02700	10	46	32
BASKET STIFFENER	SA-516 K02700	10	2.7	64
FUEL BASKET A-PLATE	NEUTRONIT A 978	5	63	4
FUEL BASKET B-PLATE	NEUTRONIT A 978	5	63	4
FUEL BASKET C-PLATE	NEUTRONIT A 978	5	15	16
FUEL BASKET D-PLATE	NEUTRONIT A 978	5	44	16
FUEL BASKET E-PLATE	NEUTRONIT A 978	5	44	16
FUEL BASKET F-PLATE	SB-209 A96061 T4	5	21	8
FUEL BASKET G-PLATE	SB-209 A96061 T4	5	21	8
FUEL BASKET TUBE	SA-516 K02700	5	113	44
INNER SHELL	SA-240 S31600	50	8886	1
INNER SHELL LID	SA-240 S31600	95	1251	2
INNER SHELL LID LIFTING FEATURE	SA-240 S31600	27	12	1
OUTER SHELL	SB-575 N06022	20	4275	1
EXTENDED OUTER SHELL LID	SB-575 N06022	25	135	1
EXTENDED OUTER SHELL LID BASE	SB-575 N06022	25	381	1
OUTER SHELL LID LIFTING FEATURE	SB-575 N06022	27	13	2
EXTENDED LID REINFORCEMENT RING	SB-575 N06022	50	99	1
OUTER SHELL FLAT CLOSURE LID	SB-575 N06022	10	165	1
OUTER SHELL FLAT BOTTOM LID	SB-575 N06022	25	412	1
UPPER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	517	1
LOWER TRUNNION COLLAR SLEEVE	SB-575 N06022	40	507	1
INNER SHELL SUPPORT RING	SB-575 N06022	20	42	1
TOTAL ALLOY 22 WELDS	SFA-5.14 N06022	-	253	**
TOTAL 316 WELDS	SFA-5.9 S31680	-	131	**
WASTE PACKAGE ASSEMBLY	-	-	28068	1
BWR FUEL ASSEMBLY	-	-	328.4*	44
WASTE PACKAGE ASSEMBLY WITH SNF	-	-	42517	1

* CRWMS M&O 1997. WASTE CONTAINER CAVITY SIZE DETERMINATION. BBAA00000-01717-0200-00026 REV 00
LAS VEGAS, NV: CRWMS M&O. ACC: MOL.19980106.0061

** REFER TO SK-0193 REV 00 "SINGLE CRM 44-BWR WASTE PACKAGE ASSEMBLY WELD CONFIGURATION"



DETAIL B

SK-0192 REV 00 | SHEET 2 OF 2

ATTACHMENT II

This attachment contains a listing and description of the zip file contained on the attachment CD of this calculation. The CD was written using the Hewlett Packard (HP) CD-Writer Plus model 7200e external CD-rewritable drive for personal computers, and the zip archive was created using WINZIP 7.0. The zip file attributes on the CD are as follows:

Archive Filename	File Size (bytes)	File Date	File Time
Att.zip	120,687,593	10-17-01	4:48p

There are 11384 files contained in a unique directory structure. Upon file extraction the top level directories will correspond as follows:

/AttII/ - contains the SAS2H input files, the binary extracted output files, and the FT71V01 software application processed files.
/AttIII/ - contains the MCNP input files
/AttIV/ - contains the MCNP output files

In AttII the files are contained in a directory structure as follows:

/X.X/YYBu/...

where X.X is the initial enrichment of the fuel and YY is the burnup in GWd/mtU (i.e. 1.5/10Bu/..., represents 1.5 wt% enriched fuel at 10 GWd/mtU burnup).

For the filenames that are contained in each directory, the N01, N02, ..., N10 labels indicate the fuel assembly axial node. Certain filenames contain a case# in them that corresponds to a specific decay time. The case# and decay time relationship is specified in Table II-1.

Table II-1. Case # and Decay Time Relationships

Case #	01	02	03	04	05	06	07	08	09
Decay Time (yrs)	0	5	10	33	100	333	1,000	3,333	5,000
Case #	10	11	12	13	14	15	16	17	18
Decay Time (yrs)	10,000	11,000	12,000	13,000	14,000	15,000	16,000	18,000	20,000
Case #	19	20	21	22	23	24	25		
Decay Time (yrs)	22,500	25,000	27,500	30,000	35,000	50,000	75,000		

The following provides a description of the different filenames:

- *N*.inp* files are the SAS2H input files
- *N*.msgs* files contain the standard run-time messages associated with the SAS2H calculations (these are generated by SAS2H).
- *ft71f001.N** files are the binary files generated by ORIGEN-S for each time step.
- *ft71-case*.N** files are the ASCII files generated by the Ft71v01 software for each case and node

The files contained under the directories */AttIII/* and */AttIV/* are for the MCNP input and output files, respectively, for the loading curve evaluations that were performed in this analysis. The output files are denoted the same as the input files but have an "*O*" at the end of the name. Upon file extraction from the attachment CD there are multiple files with the same file names. The files are arranged in a directory structure that separates files with the same filenames. The directory structure is as follows:

/preclosure/:	Spent fuel with 5-year decay time and intact basket configuration
/preclosure/fresh/:	Fresh fuel with intact basket configuration
/preclosure/fresh_degraded/:	Fresh fuel with fully degraded basket configuration
/degraded/:	Spent fuel with fully degraded basket configuration
/post_intact/:	Spent fuel with intact basket configuration
/spacing/:	Inter-assembly spacing sensitivity cases

For the fresh fuel cases, the filenames are listed as X.XatY where the X.X is the initial fresh fuel enrichment and Y is the burnup. For the spent fuel cases, the file names are listed as X.XYYZZ where the X.X is the initial fresh fuel enrichment, the YY is the burnup in GWd/mtU, and the ZZ corresponds to the case# which is related to a decay time as specified in Table II-1. For the spacing sensitivity cases, the file names are listed as spXX, where the XX corresponds to the channel-to-channel spacing in cm.

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

1. QA: QA

Page: 1 of: 1

Complete Only Applicable Items

This is a placeholder page for records that cannot be scanned.

2. Record Date 11/05/2001	3. Accession Number ATT-TO MOL.20011114.0132
4. Author Name(s) JOHN M. SCAGLIONE	5. Author Organization N/A
6. Title/Description 44 BWR WASTE PACKAGE LOADING CURVE EVALUATION	
7. Document Number(s) CAL-UDC-NU-000005	8. Version Designator REV. 00
9. Document Type DATA	10. Medium CD-ROM
11. Access Control Code PUB	
12. Traceability Designator DC# 25017	(AB) 11-14-01

13. Comments

THIS IS A SPECIAL PROCESS CD-ROM AS PART OF ATTACHMENT III AND ~~CAN BE LOCATED THROUGH THE RPC~~.

THIS DATA SUBMITTAL TO THE RECORDS PROCESSING CENTER IS FOR ARCHIVE PURPOSES ONLY, AND IS NOT AVAILABLE FOR VIEWING OR REPRODUCTION

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ELECTRONIC FILE CERTIFICATION

QA: N/A

1. DOCUMENT TITLE: 44 BWR Waste Package Loading Curve Evaluation	
2. IDENTIFIER (e.g., DI OR PI): CAL-UDC-NU-000005	3. REVISION DESIGNATOR: Rev. 00

ATTACHED SOFTWARE FILE INFORMATION

4. PDF FILE SUBMITTED: ☐ YES ☑ NO

5. FILE NAMES(S) WITH FILE EXTENSION(S) PROVIDED BY THE SOFTWARE: See Attached		
6. DATE LAST MODIFIED: See Attached	7. NATIVE APPLICATION: (i.e., EXCEL, WORD, CORELDRAW) WIN ZIP 7.0	8. FILE SIZE IN KILOBYTES: See Attached
9. FILE LINKAGE INSTRUCTIONS/INFORMATION: Standard		
10. PRINTER SPECIFICATION (I.E., HP4SI) INCLUDING POSTSCRIPT INFORMATION (i.e., PRINTER DRIVER) AND PRINTING PAGE SETUP: (i.e., LANDSCAPE, 11 X 17 PAPER) 8 1/2 x 11(portrait)= HP5SI 11 x 17 (landscape)=HP5SI		
11. COMPUTING PLATFORM USED: (i.e., PC, SUN, WIN 95, NT, HP) PC# 112113	12. OPERATING SYSTEM AND VERSION: (i.e., WINDOWS UNIX, SOLARIS) Windows 95	
13. ADDITIONAL HARDWARE/SOFTWARE REQUIREMENT USED TO CREATE FILE(S): None	14. ACCESS RESTRICTIONS: (COPYRIGHT OR LICENSE ISSUES) None	

COMMENTS/SPECIAL INSTRUCTIONS

15. IS SOFTWARE AVAILABLE FROM SOFTWARE CONFIGURATION MANAGEMENT? ☑ YES ☐ NO
SOFTWARE MEDIA TRACKING NUMBER N/A.

Note: The software product(s) to develop this document are Commercial-Off-The-Shelf (COTS) software products which require no Software Media Number (SMN). The COTS software products are under Software Configuration Management (SCM) control.

Originator: John Scaglione

CERTIFICATION

16. DOCUMENT OWNER (Print and Sign): Abdelhalim Alsaed *[signature]*			17. DATE: 11/06/2001
18. ORGANIZATION: BSC	19. DEPARTMENT: Criticality	20. LOCATION/MAIL STOP: MS423/1000E	21. PHONE: 295-3437
22. SUBMITTED BY (Print and Sign): Daynett D. Vosicky *Daynett D. Vosicky*			23. DATE:

DC USE ONLY

24. DATE RECEIVED: 11/08/01	25. DATE FILES TRANSFERRED: N/A	26. DC NO.: 25017
27. NAME (Print and Sign): N/A		28. DATE: N/A

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