FRAMATOME ANP

CALCULATION SUMMARY SHEET (CSS)

DOC.20040108.0003

Document Identifier 32 - 5033756 - 00

Title PWR Axial Profile Evaluation

PREPARED BY:		REVIEWED BY:	
		METHOD: ☒ DETAILED CHECK ☐ INDEPENDENT CALCULATION	
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TITLE PRIN. ENG.	DATE 9/30/03	TITLE PRIN. ENG.	DATE 9/30/03
COST CENTER 62015	REF. PAGE(S) 13	TM STATEMENT: REVIEWER INDEPENDENCE	MKP for WJD

PURPOSE AND SUMMARY OF RESULTS:

This calculation compares results from criticality evaluations for a 21-assembly pressurized water reactor (PWR) waste package based on 12 axial burnup profile representations for commercial spent nuclear fuel (SNF) assemblies. The burnup profiles encompass the axial variations caused by different fuel assembly irradiation histories in a commercial PWR, including end effects, and the concomitant effect on reactivity in the waste package.

The bounding axial burnup profiles in Table 5 of reference 6.3 are used for this analysis. Criticality evaluations are performed using the MCNP computer program (References 6.4 and 6.5). Axial burnup data for the analysis is obtained from reference 6.6. The calculations evaluate five methods for modeling isotopic concentrations representing the bounding axial burnup profiles in a 21-assembly PWR waste package:

1. Axial profiles with best-estimate isotopic concentrations
2. Axial profiles with principal isotope isotopic concentrations
3. Axially homogenized best-estimate isotopic concentrations
4. Axially homogenized principal isotopic concentrations
5. Isotopic concentrations from generic PWR database (reference 6.8)

The waste package model is discussed in Section 5.1 and the MCNP analysis are results are discussed in Section 5.2. The results of the MCNP calculations for k_{eff}, sigma, AENCF, and $\%\Delta k/k$ are summarized in Table 2.

This engineering calculation was performed under Framatome ANP Administrative Procedure 0402-01, Preparing and Processing FANP Calculations (reference 6.1) and Framatome Quality Management Manual (reference 6.2). The best estimate, axial profile k_{eff} values are larger than the best-estimate and principal isotope k_{eff} values for the axially homogenized cases for burnup groups 1 through 9. For the groups with the lower burnup values (groups 10 through 12) this is not always true. For groups 10 through 12 the axially homogenized cases are conservative with respect to the best-estimate, axial profile cases with the exception of the axially homogenized principal isotope case for group 10. Although the isotopic database k_{eff} values are always larger than the corresponding best-estimate, axial profile k_{eff} values (i.e. conservative), they are not always larger than the corresponding principal isotope, axial profile k_{eff} values. This is the case for burnup groups 7 and 9. For group 9, the bounding axial burnup profile is from cycle 1B of Crystal River 3. The k_{eff} value for this assembly is the least conservative of the 12-burnup groups. The $\%\Delta k/k$ value for the isotopic database for this assembly is 0.34. The $\%\Delta k/k$ value for the principal isotope, axial profile case for group 9 is 0.70, which is more conservative than the isotopic database. Thus, the isotopic database is not overly conservative when viewing all 12 burnup groups but is sufficiently conservative.

The conclusion that the isotopic database is sufficiently conservative is based in part on results from reference 6.8. Part of the confirmation of the conservatism in the isotopic database is based on comparisons made with CRC data. From Table 22 of reference 6.8, it is seen that when the isotopic database isotopic concentrations are substituted for the best-estimate values for this fuel assembly k_{eff} increased by 0.13%. Based on measured criticality data the isotopic database is conservative for this and all other assemblies tested in reference 6.8.

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:		THE DOCUMENT CONTAINS ASSUMPTIONS THAT MUST BE VERIFIED PRIOR TO USE ON SAFETY-RELATED WORK
CODE/VERSION/REV	CODE/VERSION/REV	
MCNP 4.B2		
		☐ YES ☒ NO

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

RECORD OF REVISIONS

Revision Number	Date
00 (Initial)	September 2003

1. PURPOSE

This calculation provides a comparison of results from criticality evaluations for a 21-assembly pressurized water reactor (PWR) waste package based on 12-axial burnup profile representations for commercial spent nuclear fuel (SNF) assemblies. The burnup profiles encompass the axial variations caused by different fuel assembly irradiation histories in a commercial PWR, including end effects, and the concomitant effect on reactivity in the waste package.

This engineering calculation was performed under Framatome ANP Administrative Procedure 0402-01, Preparing and Processing FANP Calculations (Reference 6.1) and Framatome Quality Management Manual (Reference 6.2).

2. METHOD

The bounding axial burnup profiles presented in Table 5 of reference 6.3 are used for this analysis. Criticality evaluations are performed using the MCNP computer program (references 6.4 and 6.5). Axial burnup data for the analysis is obtained from reference 6.6. Commercial SNF isotopic concentrations corresponding to the burnup data is taken from reference 6.7.

The bounding axial burnup profiles from reference 6.3 represent various PWR fuel assembly designs, which include variation in enrichment, burnup, and absorber rods, along with varying PWR operating histories. The PWR SNF data from reference 6.6 includes axial burnup, moderator density, and fuel temperature profiles. The data in references 6.6 and 6.7 is used to provide SNF isotopic concentrations for the criticality evaluations for a 21-assembly waste package representing the 12-bounding axial burnup profiles from reference 6.3. The data selected from references 6.6 and 6.7 is from commercial reactor criticality (CRC) statepoints, which represents commercial SNF assemblies in known critical configurations. The selection process for choosing the burnup values corresponding to the 12- burnup groups of reference 6.3 is presented in Appendix A of this document.

The method used for the calculations presented in this document includes the following steps:

1. Select burnup data from the CRC summary report for Crystal River 3 (reference 6.6) that encompass the bounding burnup profiles from Table 5 of reference 6.3. This will necessitate using composite data from several fuel assemblies from the same fuel batch to match the bounding profiles for the various burnup groups. This process is presented in Appendix A of this document.

2. Select isotopic concentrations from the CRC reactivity calculation report for Crystal River 3 (reference 6.7) that correspond to the burnup data selected in step 1. This includes both best-estimate and principal isotope concentrations.

3. Perform analyses for a 21-fuel assembly PWR waste package (reference 6.8, Section 5.2.1) using fuel isotopic concentrations (for 18-axial fuel nodes) corresponding to the bounding profiles for each burnup group. These analyses are performed for both best-estimate and principal isotope sets.

4. Repeat analyses for a 21-fuel assembly PWR waste package using best-estimate and principal isotope fuel isotopic concentrations that have been collapsed (volume weighted) from 18 axial nodes to one axial node.

5. Repeat analyses for a 21-fuel assembly PWR waste package using fuel isotopic concentrations from the isotopic database for the PWR application model (reference 6.8). These analyses are based on assembly-averaged burnup values for each burnup group and correspond to the same initial fuel enrichment as used in the best-estimate/principal isotope calculations (items 3 and 4 above). The same isotopic concentration set is used for all 18-axial nodes for a given burnup/enrichment pair corresponding to a given burnup group.

These analyses quantify the magnitude of the "end-effect" associated with the bounding axial burnup profiles (for each burnup group) presented in 6.3. The base calculation of each burnup group is the 18-axial node, best-estimate waste package calculation (item 3 above). The reactivity worth of the principal isotopes (with bounding profile) based on CRC depletion calculations, the reactivity worth of the collapsed axial node best-estimate and principal isotope sets, and the reactivity worth of the isotopic database for the PWR application model are established from these analyses.

3. ASSUMPTIONS

The following assumptions were used for all PWR CRC axial profile evaluations.

3.1 Data from Crystal River 3 is appropriate for representing the bounding axial burnup profiles from reference 6.3. The basis for this assumption is taken from page 42 of reference 6.3. Observation 1 from Section 4.2.3 of reference 6.3 states:

"1. Some of the B&W plants, such as Davis Besse and Crystal River, have used control rods for routine reactor control, which suppresses the burnup near the top...and leads to more reactive axial profiles. Also, B&W plants are the only ones that use axial power shaping rods, which can suppress the burnup near the center...Of the 12 bounding profiles...eleven are from B&W 15 x 15 plants."

3.2 The use of composite data from several fuel assemblies from the same fuel batch to construct bounding profiles for the various burnup groups is appropriate. The basis for this assumption is that preserving the axial location in the fuel assembly (see criterion 2 in Appendix A of this document) from which the data is taken appropriately accounts for axial operating history effects in the fuel assembly. This would include moderator temperature/density and fuel temperature.

4. USE OF COMPUTER SOFTWARE AND MODELS

The calculations in this file are performed using the computer program MCNP (Reference 6.4) version 4B2L. The computer code has been certified according to Framatome ANP procedure 0902-06 (Reference 6.5)

5. CALCULATION

This section describes the calculations performed to evaluate five methods for modeling the isotopic concentrations representing the bounding axial burnup profiles in a 21-assembly PWR waste package. The five methods include:

1. Axial profiles with best-estimate isotopic concentrations.
2. Axial profiles with principal isotope isotopic concentrations.
3. Axially homogenized best-estimate isotopic concentrations.
4. Axially homogenized principal isotopic concentrations.
5. Isotopic concentrations from generic PWR database (reference 6.8).

The waste package model is discussed is Section 5.1 and the MCNP analysis and results are discussed in Section 5.2.

5.1 Waste Package Model

The MCNP computer program was used for the waste package model. For methods 1 and 2, the base 21-fuel assembly PWR waste package model comes from reference 6.8, Section 5.2.1. The fuel inside the container is a Mark-B 15x15 assembly. SNF isotopic concentrations (both best-estimate and principal isotope) for the waste package are taken from reference 6.7. The isotopic concentrations are for the fuel assemblies and statepoints identified (at each axial node) in Appendix A for each of the 12 burnup groups. Each fuel assembly in the waste package is modeled with 18 axial nodes. A single composite assembly from the CRC reactivity calculation is substituted for each of the 21 assemblies in the waste package MCNP model. The description of the composite assembly is given in Appendix A of this document.

Each axial node in the MCNP model is kept at the correct level to preserve the axial burnup shape from the CRC calculation. This entails substituting the correct fuel material on the "M6xxx" cards as well as the correct fuel density on the fuel cell cards. For methods 3 and 4, the calculations are repeated except that the fuel from the CRC was axially homogenized using the axial node height to volume weight the nodes. For method 5, the calculations are repeated using fuel from the generic PWR database, which is a function of initial enrichment and burnup, rather than using the isotopes from the CRC calculation.

5.2 MCNP Analysis and Results

Five MCNP calculations are performed for each of the 12-burnup groups. Thus, the total number of MCNP waste package calculations performed is 60. The five MCNP calculations representing the five methods for modeling the isotopic concentrations for the bounding axial burnup profiles are as follows:

1. The first calculation for each burnup group uses a best-estimate axial burnup profile derived from the Crystal River 3 best-estimate isotope data (reference 6.7).

2. The second calculation for each burnup group uses a principle isotope axial burnup profile derived from the Crystal River 3 principle isotopes data (reference 6.7).

3. The third calculation for each burnup group uses a best estimate homogenized burnup derived from the Crystal River 3 best estimate isotope data. The homogenized burnup is volume weighted based on the relative axial node heights, e.g.

$$N = \frac{\sum_{i=1}^{18} (N_i \times Axial\ Height_i)}{\sum_{i=1}^{18} (Axial\ Height_i)}$$

4. The fourth calculation for each burnup group uses a principle isotopes homogenized burnup derived from the Crystal River 3 principle isotope data. The homogenized burnup is volume weighted based on the relative axial node heights.

5. The fifth calculation for each burnup group uses the generic PWR isotopic database (reference 6.8) that models the isotopic atom fractions as a function of burnup and initial (fresh batch) enrichment. Reference 6.6 (Section 3) is used in determining the fresh batch enrichment for the fuel assemblies comprising each group. The fresh batch enrichment and average burnup are used in determining the atom fractions from the generic PWR isotopic database. In the fifth calculation, the values of the average burnup, initial enrichment, and isotopic atom fractions are the same for every axial node in the MCNP model (i.e. uniform axially). Table 1 summarizes the average burnup and initial enrichment values for each burnup group.

Table 1. Average Burnup and Enrichment for Each Burnup Group

Burnup Group	Crystal River 3 Fuel Cycle for Statepoint	Initial Cycle & Fuel Batch	Average Burnup (GWd/MtU)	Enrichment (wt% ^{235}U)
1	10	7 (Batch 9)	48.16	3.84
2	10	9 (Batch 11)	43.37	3.90
3	8	6 (Batch 8)	38.88	3.49
4	8-9	7 (Batch 9)	34.64	3.84
5	8	7 (Batch 9)	33.68	3.84
6	8-9	8 (Batch 10)	27.62	3.94
7	8-9	8 (Batch 10)	25.92	3.94
8	3-4	2 (Batch 4)	22.16	2.64
9	1B	1B (Batch 1)	13.40	2.00
10	1B	1A (Batch 1)	12.26	1.93
11	2-4	2 (Batch 4)	9.69	2.64
12	2-4	2 (Batch 4)	3.18	2.64

The results of the MCNP calculations are summarized in Table 2. This includes the k_{eff}, sigma, AENCF, and %Δk/k values from the MCNP calculations.

The average energy of a neutron causing fission (weighted) and the average weight of the neutron causing fission are located in the summary page balance sheet of the MCNP output. The equation for the average energy (MeV) of a neutron causing fission (AENCF) is

$$AENCF = E / w$$

where,

w = the weight of the average neutron causing fission, and
E = the weighted average of a neutron causing fission (g/cm^3)

The %Δk/k is the relative percent deviation of the k_{eff} value from the second, third, fourth, and fifth calculation for each group from the k_{eff} value for the first calculation (using best-estimate isotopic concentrations) e.g.,

$$\frac{\Delta k}{k} = \frac{(k_i - k_{BE})}{k_{BE}}$$

where,

i	is the 2nd, 3rd, 4th, or 5th calculation
k_i	is the k_{eff} value for calculation i
k_{BE}	is the k_{eff} value for 1st calculation using best-estimate isotopic concentrations.

For the column with the header "Source of Isotopic Concentrations" in Table 2,

BE	stands for best-estimate isotopic concentrations (from reference 6.7)
PI	stands for principal isotope isotopic concentrations (from reference 6.7)
IDB	stands for isotopic database isotopic concentrations (from reference 6.8).

A review of the data in Table 2 reveals that the best-estimate, axial profile k_{eff} value is always smaller than principal isotope, axial profile k_{eff} value and the isotopic database k_{eff} value. The best estimate, axial profile k_{eff} values are larger than the best-estimate and principal isotope k_{eff} values for the axially homogenized cases for burnup groups 1 through 9. For the groups with the lower burnup values (groups 10 through 12) this is not always true. For groups 10 through 12 the axially homogenized cases are conservative with respect to the best-estimate, axial profile cases with the exception of the axially homogenized principal isotope case for group 10.

Although the isotopic database k_{eff} values are always larger than the corresponding best-estimate, axial profile k_{eff} values (i.e. conservative), they are not always larger than the corresponding principal isotope, axial profile k_{eff} values. This is the case for burnup groups 7 and 9.

For group 9, the bounding axial burnup profile is from cycle 1B of Crystal River 3. The k_{eff} value for this assembly is the least conservative of the 12-burnup groups. The %Δk/k value for the isotopic database for this assembly is 0.34. The %Δk/k value for the principal isotope, axial profile case for group 9 is 0.70, which is more conservative than the isotopic database. Thus, the isotopic database is not overly conservative when viewing all 12 burnup groups but is sufficiently conservative.

The conclusion that the isotopic database is sufficiently conservative is based in part on results from reference 6.8. Part of the confirmation of the conservatism in the isotopic database is based on comparisons made with CRC data. From Table 22 of reference 6.8, it is seen that when the isotopic database isotopic concentrations are substituted for the best-estimate values for this fuel assembly k_{eff} increased by 0.13%.

Based on measured criticality data the isotopic database is conservative for this and all other assemblies tested in reference 6.8.

Table 2. Comparison of Results from Five Methods of Representing Axial Burnup Profiles

Burnup group	Source of Isotopic Concentrations	Type of Calculation*	k_{eff}	sigma	AENCF	% Δk / k
1	BE	Axial profile	0.80050	0.00039	0.228968	
1	PI	Axial profile	0.81629	0.00041	0.225478	1.97
1	BE	Homogenized axially	0.75254	0.00030	0.254174	-5.99
1	PI	Homogenized axially	0.77645	0.00030	0.247236	-3.00
1	IDB	Uniform axially	0.82611	0.00035	0.253851	3.20
2	BE	Axial profile	0.82651	0.00042	0.220094	
2	PI	Axial profile	0.84330	0.00039	0.217188	2.03
2	BE	Homogenized axially	0.78943	0.00034	0.239898	-4.49
2	PI	Homogenized axially	0.81341	0.00037	0.232693	-1.58
2	IDB	Uniform axially	0.84791	0.00041	0.244459	2.59
3	BE	Axial profile	0.81124	0.00037	0.225758	
3	PI	Axial profile	0.82670	0.00038	0.223164	1.91
3	BE	Homogenized axially	0.77956	0.00035	0.243099	-3.91
3	PI	Homogenized axially	0.80138	0.00037	0.237344	-1.22
3	IDB	Uniform axially	0.85157	0.00039	0.244474	4.97
4	BE	Axial profile	0.87299	0.00023	0.207871	
4	PI	Axial profile	0.88706	0.00028	0.205156	1.61
4	BE	Homogenized axially	0.83735	0.00026	0.224521	-4.08
4	PI	Homogenized axially	0.85773	0.00025	0.219292	-1.75
4	IDB	Uniform axially	0.89117	0.00030	0.229454	2.08
5	BE	Axial profile	0.87459	0.00028	0.207694	
5	PI	Axial profile	0.88977	0.00033	0.205189	1.74
5	BE	Homogenized axially	0.84589	0.00027	0.222128	-3.28
5	PI	Homogenized axially	0.86655	0.00037	0.216810	-0.92
5	IDB	Uniform axially	0.89523	0.00029	0.228375	2.36
6	BE	Axial profile	0.91802	0.00026	0.198543	
6	PI	Axial profile	0.93288	0.00027	0.196270	1.62
6	BE	Homogenized axially	0.89348	0.00026	0.208457	-2.67
6	PI	Homogenized axially	0.91434	0.00026	0.204120	-0.40
6	IDB	Uniform axially	0.93505	0.00038	0.215753	1.86
7	BE	Axial profile	0.93196	0.00023	0.194794	
7	PI	Axial profile	0.94375	0.00028	0.192926	1.27
7	BE	Homogenized axially	0.90432	0.00025	0.205973	-2.97
7	PI	Homogenized axially	0.92496	0.00024	0.201019	-0.75
7	IDB	Uniform axially	0.94371	0.00039	0.212555	1.26
8	BE	Axial profile	0.84507	0.00041	0.216723	
8	PI	Axial profile	0.85602	0.00041	0.214810	1.30
8	BE	Homogenized axially	0.82634	0.00026	0.229522	-2.22
8	PI	Homogenized axially	0.84120	0.00024	0.225355	-0.46
8	IDB	Uniform axially	0.87629	0.00038	0.230407	3.69
9	BE	Axial profile	0.86927	0.00036	0.208457	
9	PI	Axial profile	0.87535	0.00036	0.207787	0.70
9	BE	Homogenized axially	0.82651	0.00036	0.225557	-4.92
9	PI	Homogenized axially	0.83579	0.00038	0.223034	-3.85
9	IDB	Uniform axially	0.87226	0.00036	0.228493	0.34
10	BE	Axial profile	0.83105	0.00026	0.220810	
10	PI	Axial profile	0.85759	0.00027	0.213541	3.19
10	BE	Homogenized axially	0.81468	0.00027	0.226041	-1.97
10	PI	Homogenized axially	0.83189	0.00024	0.221132	0.10
10	IDB	Uniform axially	0.87251	0.00036	0.227550	4.99
11	BE	Axial profile	0.91142	0.00023	0.200053	
11	PI	Axial profile	0.91909	0.00026	0.198688	0.84
11	BE	Homogenized axially	0.91564	0.00021	0.199359	0.46
11	PI	Homogenized axially	0.92383	0.00027	0.197653	1.36
11	IDB	Uniform axially	0.95298	0.00039	0.202632	4.56
12	BE	Axial profile	0.97116	0.00040	0.181347	
12	PI	Axial profile	0.97396	0.00027	0.180643	0.29
12	BE	Homogenized axially	0.97277	0.00028	0.180547	0.17
12	PI	Homogenized axially	0.97559	0.00028	0.180571	0.46
12	IDB	Uniform axially	0.99422	0.00039	0.184859	2.37

*Table 3 on p. 14 provides a list of the MCNP output file names for each calculation listed in Table 2.

6. REFERENCES

6.1. Framatome ANP, Administrative Procedure, Number: 0402-01, Preparing and Processing FANP Calculations, February 2003, Framatome ANP, Lynchburg, Virginia.

6.2. Framatome ANP Inc., Quality Assurance, Quality Management Manual, 56-5015885, May 2002, Framatome ANP, Lynchburg, VA, 24506

6.3. Wagner, J.C, Dehart, M.D., and Parks, C.V. 2003, *Recommendations for Addressing Axial Burnup in PWR Burnup Credit.* NUREG/CR-6801. Oak Ridge, Tennessee, Oak Ridge National Laboratory.

6.4. Breismeister, J.F., Ed., *MCNP^{TM} – A General Monte Carlo N-Particle Transport Code, Version 4B.* LA-12625-M. Los Alamos National Laboratory (LANL), March 1997.

6.5. Framatome ANP, Administrative Procedure, Number: 0902-06, Software Certification, November 2002, Framatome ANP, Lynchburg, Virginia.

6.6. Framatome ANP Doc. 38-5034259-00, *Summary Report of Commercial Reactor Criticality Data for Crystal River Unit 3.* TDR-UDC-NU-000001 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010702.0087.

6.7. Framatome ANP Doc. 38-5034260-00, *CRC Reactivity Calculations for Crystal River Unit 3.* DI#: B00000000-01717-0210-00002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980728.0004.

6.8. Framatome ANP Doc. 38-5034166-00, *Isotopic Generation and Confirmation of the PWR Application Model*, CAL-DSU-NU-000004 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company.

6.9. Nakamura, S. 1977. *Computational Methods in Engineering and Science.* Page 3. New York, New York: John Wiley & Sons.

7. COLD LISTING

Table 3. Files on COLD

File Name	File Size	Date	Time	Description		
				Burnup Group	Source of Isotopic Concentrations	Type of Calculation
b83407	403400	Sep 30 2003	11:02:12	2	PI	Axial profile
b83445	451573	Sep 30 2003	11:02:13	3	BE	Axial profile
b83447	449145	Sep 30 2003	11:02:13	2	BE	Axial profile
b83455	405414	Sep 30 2003	11:02:13	3	PI	Axial profile
b83762	427576	Sep 30 2003	11:02:13	2	PI	Homogenized axially
b83765	429290	Sep 30 2003	11:02:13	3	PI	Homogenized axially
b84633	514859	Sep 30 2003	11:02:13	2	BE	Homogenized axially
b84634	518732	Sep 30 2003	11:02:13	3	BE	Homogenized axially
b85979	450282	Sep 30 2003	11:02:13	1	BE	Axial profile
b86205	403371	Sep 30 2003	11:02:13	1	PI	Axial profile
b86225	403125	Sep 30 2003	11:02:14	9	PI	Axial profile
b86235	446062	Sep 30 2003	11:02:14	9	BE	Axial profile
b86524	428598	Sep 30 2003	11:02:14	5	PI	Homogenized axially
b86528	508609	Sep 30 2003	11:02:14	9	BE	Homogenized axially
b86529	428090	Sep 30 2003	11:02:14	9	PI	Homogenized axially
b86833	615624	Sep 30 2003	11:02:14	1	BE	Homogenized axially
b86834	528120	Sep 30 2003	11:02:14	1	PI	Homogenized axially
b86944	506544	Sep 30 2003	11:02:14	5	PI	Axial profile
b87080	549188	Sep 30 2003	11:02:14	11	PI	Axial profile
b87116	436909	Sep 30 2003	11:02:15	12	BE	Axial profile
b87157	575417	Sep 30 2003	11:02:15	11	PI	Homogenized axially
b87158	640055	Sep 30 2003	11:02:15	12	BE	Homogenized axially
b87159	574070	Sep 30 2003	11:02:15	12	PI	Homogenized axially
b87160	690710	Sep 30 2003	11:02:15	11	BE	Axial profile
b87164	551059	Sep 30 2003	11:02:15	12	PI	Axial profile
b87234	848551	Sep 30 2003	11:02:15	11	BE	Homogenized axially
b87238	428762	Sep 30 2003	11:02:15	3	IDB	Uniform axially
b87239	428182	Sep 30 2003	11:02:16	2	IDB	Uniform axially
b87241	428576	Sep 30 2003	11:02:16	1	IDB	Uniform axially
b87244	428575	Sep 30 2003	11:02:16	6	IDB	Uniform axially
b87245	427376	Sep 30 2003	11:02:16	7	IDB	Uniform axially
b87246	428181	Sep 30 2003	11:02:16	8	IDB	Uniform axially

b87247	426981	Sep 30 2003	11:02:16	9	IDB	Uniform axially
b87248	428181	Sep 30 2003	11:02:16	10	IDB	Uniform axially
b87249	426981	Sep 30 2003	11:02:16	11	IDB	Uniform axially
b87250	428182	Sep 30 2003	11:02:17	12	IDB	Uniform axially
b87408	571815	Sep 30 2003	11:02:17	4	IDB	Uniform axially
b87409	573219	Sep 30 2003	11:02:17	5	IDB	Uniform axially
b88181	599610	Sep 30 2003	11:02:17	4	PI	Axial profile
b88182	646713	Sep 30 2003	11:02:17	6	BE	Axial profile
b88183	599613	Sep 30 2003	11:02:17	6	PI	Axial profile
b88185	601035	Sep 30 2003	11:02:17	7	PI	Axial profile
b88188	714435	Sep 30 2003	11:02:17	4	BE	Homogenized axially
b88189	623395	Sep 30 2003	11:02:17	4	PI	Homogenized axially
b88190	709993	Sep 30 2003	11:02:18	6	BE	Homogenized axially
b88191	623396	Sep 30 2003	11:02:18	6	PI	Homogenized axially
b88192	711332	Sep 30 2003	11:02:18	7	BE	Homogenized axially
b88193	623395	Sep 30 2003	11:02:18	7	PI	Homogenized axially
b88335	741316	Sep 30 2003	11:02:18	4	BE	Axial profile
b88336	744189	Sep 30 2003	11:02:18	7	BE	Axial profile
b89260	595895	Sep 30 2003	11:02:18	5	BE	Axial profile
b89269	666204	Sep 30 2003	11:02:18	5	BE	Homogenized axially
b89481	594375	Sep 30 2003	11:02:19	10	BE	Axial profile
b89482	550025	Sep 30 2003	11:02:19	10	PI	Axial profile
b89493	660261	Sep 30 2003	11:02:19	10	BE	Homogenized axially
b89494	577403	Sep 30 2003	11:02:19	10	PI	Homogenized axially
b89527	450236	Sep 30 2003	11:02:19	8	BE	Axial profile
b89528	404094	Sep 30 2003	11:02:19	8	PI	Axial profile
b89533	709536	Sep 30 2003	11:02:19	8	BE	Homogenized axially
b89534	623394	Sep 30 2003	11:02:19	8	PI	Homogenized axially

APPENDIX A: DEVELOPMENT OF AXIAL BURNUP PROFILES

A set of bounding axial burnup profiles for addressing burnup credit for PWR SNF is provided in reference 6.3 (Table 5, p. 20). Normalized axial burnup profiles for 12-burnup groups are presented in this reference. The burnup groups range from > 46 GWd/mtU for group 1 down to < 6 GWd/mtU for group 12. The fuel assemblies for the SNF are assumed to be 144-inches long and are divided into 18-axial fuel assembly segments (each 8-inch long).

Crystal River Unit 3 was chosen to provide axial burnup data corresponding to the bounding axial profiles. This data is presented in reference 6.6 and is the source of the reactor operating data used in the CRC reactivity calculations for Crystal River Unit 3 (reference 6.7). The isotopic concentrations used for the PWR axial profile evaluations were taken from reference 6.7. The selection of the burnup data for the 12-burnup groups is summarized in Table A-1 through Table A-12 and Figure A-1 through Figure A-12. These tables present the burnup values for each axial node for the 12-burnup groups. Also included is the fuel assembly identification and statepoint (reference 6.6, Tables 4-2 through 4-162) from which the burnup values were chosen. The criteria used in selecting the burnup data is as follows:

1. For a given burnup group, axial burnup data must be selected from a single fuel batch (i.e. same assembly type and enrichment).
2. Burnup values for a given burnup group may come from several different fuel assemblies but must be from the same fuel batch and from the correct axial node (e.g. data from axial node 3 may not be used for axial node 4).
3. Burnup values are selected for each burnup group that provide the best representation of the normalized bounding burnup profiles.
4. To assure conservatism, the CRC normalized average burnup values for the top two and bottom two nodes must be less than the corresponding values from the bounding profile data. This data is given in last column of Tables A-1 through A-12 as the "Weighted % Difference". The only exception is for burnup group 9 where the actual bounding profile is from cycle 1B of Crystal River Unit 3 and the actual values were used.

The axial node spacing for the bounding axial burnup profiles in reference 6.3 do not correspond to the node spacing for the Crystal River data (reference 6.6, p.4-1). Lagrange interpolation (reference 6.9) was used to transform the bounding profiles to correspond to the axial node spacing for the Crystal River data. A second order polynomial was used, where the interpolation is applied over three adjacent nodes. If the end point for the interpolated data is beyond that of the base data, extrapolation is used. The final interpolation is tested by plotting the original bounding axial burnup profiles and the interpolated profiles and observing the agreement.

The results of the transformation are presented in Table A-13 through Table A-15 and Figure A-13 through Figure A-24. Table A-13 presents the original (reference 6.3) bounding axial burnup profiles by group. The data is presented as a function of axial height percent instead of axial node spacing. The top node is at 97.222 % from the bottom of the assembly. [Each node represents an 8-inch axial segment. There are 18 axial nodes, with the center at the midpoint, or 4 inches. The top node is at ((17 x 8 in) – 4) x 100%) / 144 in = 97.222 %.]

Data for burnup groups 1 and 2 were taken from cycle 10 of Crystal River Unit 3. Data for burnup groups 3 through 12 were taken from cycles 1 through 9. The axial node spacing for the calculations for cycles 1 through 9 and cycle 10 were different (reference 6.6, p. 4-1). Table A-14 presents the transformed bounding axial burnup profiles for groups 1 and 2 along with the axial height percent corresponding to cycle 10 for the Crystal River data. Table A-15 presents the transformed bounding axial burnup profiles for groups 3 through 12 along with the axial height percent corresponding to cycles 1 through 9 for the Crystal River data. The transformed bounding axial burnup profile values were used in selecting the axial burnup values presented in Table A-1 through Table A-12.

The Lagrange interpolation formula for a second order polynomial is given below.

$$F(x)=\frac{(x-x_2)\cdot(x-x_3)}{(x_1-x_2)\cdot(x_1-x_3)}\cdot F(x_1)+\frac{(x-x_1)\cdot(x-x_3)}{(x_2-x_1)\cdot(x_2-x_3)}\cdot F(x_2)+\frac{(x-x_1)\cdot(x-x_2)}{(x_3-x_1)\cdot(x_3-x_2)}\cdot F(x_3)$$

where,

x is the percent axial height corresponding to the CRC data
$x_1/x_2/x_3$ are percent axial height values corresponding to three bounding profile data points
$F(x)$ is the interpolated burnup value for the bounding profile at CRC percent axial height x
$F(x_1)$ is the bounding profile value at x_1
$F(x_2)$ is the bounding profile value at x_2
$F(x_3)$ is the bounding profile value at x_3

This formula was used in calculating the transformed bounding axial burnup profile values presented in Table A-1 through Table A-12.

Table A-1. Selection of CRC Burnup Data for Analysis of Burnup Group 1

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	G8 (SP33)	17.4777	23.520	0.488	0.491	-5.437
2	G8 (SP33)	20.0025	34.983	0.726	0.805	
3	G27a (SP33)	20.0025	49.713	1.032	0.980	0.805
4	G27a (SP33)	20.0025	52.052	1.081	1.046	
5	G27a (SP33)	20.0025	52.758	1.095	1.071	
6	G27a (SP33)	20.0025	52.918	1.099	1.079	
7	G27a (SP33)	20.0025	52.918	1.099	1.084	
8	G27a (SP33)	20.0025	52.882	1.098	1.088	
9	G27a (SP33)	20.0025	52.852	1.097	1.091	
10	G27a (SP33)	20.0025	52.842	1.097	1.095	
11	G27a (SP33)	20.0025	52.864	1.098	1.100	
12	G27a (SP33)	20.0025	52.924	1.099	1.104	
13	G27a (SP33)	20.0025	52.991	1.100	1.110	
14	G27a (SP33)	20.0025	52.949	1.099	1.113	
15	G27a (SP33)	20.0025	52.527	1.091	1.105	
16	G27a (SP33)	20.0025	50.952	1.058	1.065	
17	G27a (SP33)	20.0025	45.798	0.951	0.918	-3.599
18	G8 (SP33)	19.5936	24.845	0.516	0.579	

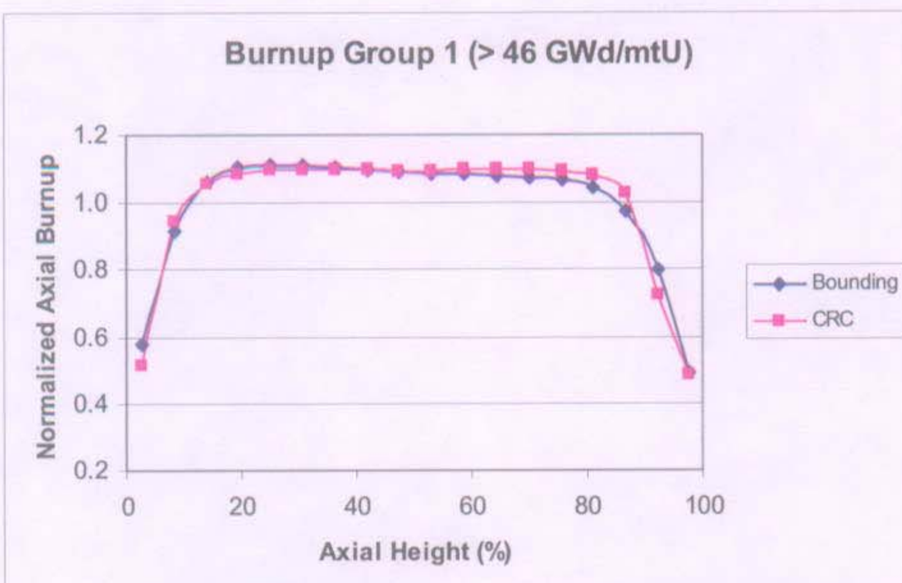

Figure A-1. CRC and Bounding Axial Profiles for Burnup Group 1

Table A-2. Selection of CRC Burnup Data for Analysis of Burnup Group 2

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	I27a (SP33)	17.4777	21.453	0.495	0.491	
2	I6 (SP33)	20.0025	32.671	0.753	0.782	-1.586
3	I10a (SP33)	20.0025	43.713	1.008	0.995	
4	I12a (SP33)	20.0025	46.173	1.065	1.065	
5	I12a (SP33)	20.0025	46.914	1.082	1.082	
6	I12a (SP33)	20.0025	47.152	1.087	1.086	
7	I12a (SP33)	20.0025	47.243	1.089	1.086	
8	I12a (SP33)	20.0025	47.295	1.091	1.085	
9	I10a (SP33)	20.0025	46.975	1.083	1.084	0.357
10	I10a (SP33)	20.0025	47.040	1.085	1.084	
11	I10a (SP33)	20.0025	47.148	1.087	1.085	
12	I10a (SP33)	20.0025	47.312	1.091	1.085	
13	I10a (SP33)	20.0025	47.483	1.095	1.090	
14	I10a (SP33)	20.0025	47.507	1.096	1.089	
15	I10a (SP33)	20.0025	47.145	1.087	1.081	
16	I10a (SP33)	20.0025	45.684	1.053	1.048	
17	I12 (SP33)	20.0025	40.147	0.926	0.942	-1.464
18	I12 (SP33)	19.5936	28.448	0.656	0.664	

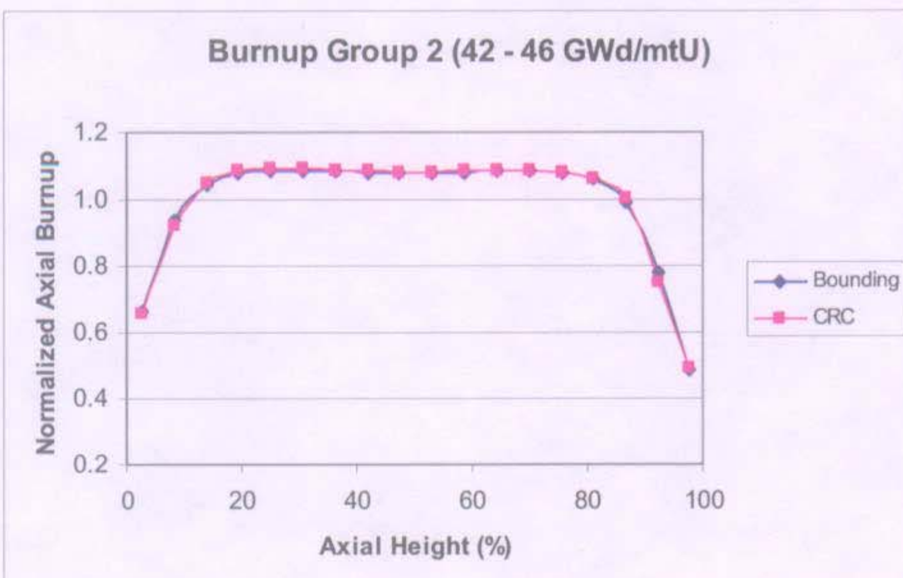

Figure A-1. CRC and Bounding Axial Profiles for Burnup Group 2

Table A-3. Selection of CRC Burnup Data for Analysis of Burnup Group 3

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	F19a (SP25)	17.7800	19.864	0.511	0.505	
2	F19a (SP26)	20.0025	30.404	0.782	0.796	-0.335
3	F19a (SP27)	20.0025	38.856	1.000	0.982	
4	F19a (SP27)	20.0025	40.905	1.052	1.052	
5	F19a (SP27)	20.0025	41.627	1.071	1.075	
6	F19a (SP27)	20.0025	41.901	1.078	1.083	
7	F19a (SP27)	20.0025	42.053	1.082	1.086	
8	F19a (SP27)	20.0025	42.188	1.085	1.088	
9	F19a (SP27)	20.0025	42.317	1.089	1.088	0.216
10	F19a (SP27)	20.0025	42.427	1.091	1.089	
11	F19a (SP27)	20.0025	42.536	1.094	1.090	
12	F19a (SP27)	20.0025	42.662	1.097	1.092	
13	F19a (SP27)	20.0025	42.741	1.099	1.093	
14	F19a (SP27)	20.0025	42.668	1.098	1.092	
15	F19a (SP27)	20.0025	42.266	1.087	1.083	
16	F19a (SP27)	20.0025	40.950	1.053	1.053	
17	F19a (SP27)	20.0025	37.072	0.954	0.957	-1.622
18	F19a (SP27)	22.3520	25.744	0.662	0.681	

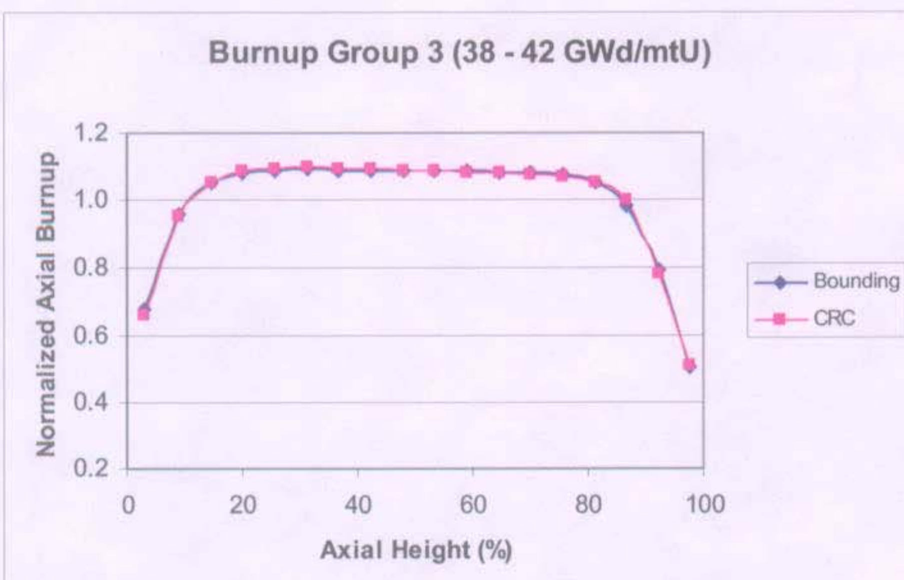

Figure A-3. CRC and Bounding Axial Profiles for Burnup Group 3

Table A-4. Selection of CRC Burnup Data for Analysis of Burnup Group 4

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	G25 (SP26)	17.7800	14.890	0.430	0.429	-1.248
2	G14 (SP26)	20.0025	24.055	0.695	0.713	
3	G14 (SP29)	20.0025	33.389	0.964	0.956	0.273
4	G23 (SP30)	20.0025	36.959	1.067	1.050	
5	G23 (SP30)	20.0025	37.722	1.089	1.079	
6	G23 (SP30)	20.0025	37.996	1.097	1.090	
7	G23 (SP30)	20.0025	38.107	1.100	1.095	
8	G23 (SP30)	20.0025	38.159	1.102	1.097	
9	G23 (SP30)	20.0025	38.192	1.103	1.099	
10	G23 (SP30)	20.0025	38.228	1.104	1.102	
11	G23 (SP30)	20.0025	38.285	1.105	1.105	
12	G23 (SP30)	20.0025	38.395	1.109	1.107	
13	G23 (SP30)	20.0025	38.536	1.113	1.112	
14	G23 (SP30)	20.0025	38.516	1.112	1.112	
15	G23 (SP30)	20.0025	38.101	1.100	1.106	
16	G23 (SP30)	20.0025	36.778	1.062	1.078	
17	G23 (SP30)	20.0025	33.162	0.957	0.978	-1.289
18	G23 (SP30)	22.3520	23.126	0.668	0.671	

Figure A-4. CRC and Bounding Axial Profiles for Burnup Group 4

Table A-5. Selection of CRC Burnup Data for Analysis of Burnup Group 5

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	G25 (SP26)	17.7800	14.890	0.442	0.445	
2	G14 (SP25)	20.0025	23.919	0.710	0.709	-0.266
3	G14 (SP28)	20.0025	31.878	0.947	0.952	
4	G12 (SP25)	20.0025	35.489	1.054	1.052	
5	G12 (SP26)	20.0025	36.339	1.079	1.084	
6	G12 (SP26)	20.0025	36.571	1.086	1.094	
7	G12 (SP26)	20.0025	36.691	1.090	1.096	
8	G12 (SP26)	20.0025	36.789	1.092	1.095	
9	G12 (SP26)	20.0025	36.886	1.095	1.094	0.001
10	G12 (SP26)	20.0025	36.984	1.098	1.094	
11	G12 (SP26)	20.0025	37.096	1.102	1.097	
12	G12 (SP26)	20.0025	37.249	1.106	1.101	
13	G12 (SP26)	20.0025	37.417	1.111	1.106	
14	G12 (SP26)	20.0025	37.418	1.111	1.108	
15	G12 (SP26)	20.0025	37.047	1.100	1.105	
16	G17 (SP25)	20.0025	36.664	1.089	1.081	
17	G17 (SP26)	20.0025	33.441	0.993	0.990	-0.231
18	G12 (SP26)	22.3520	22.614	0.672	0.676	

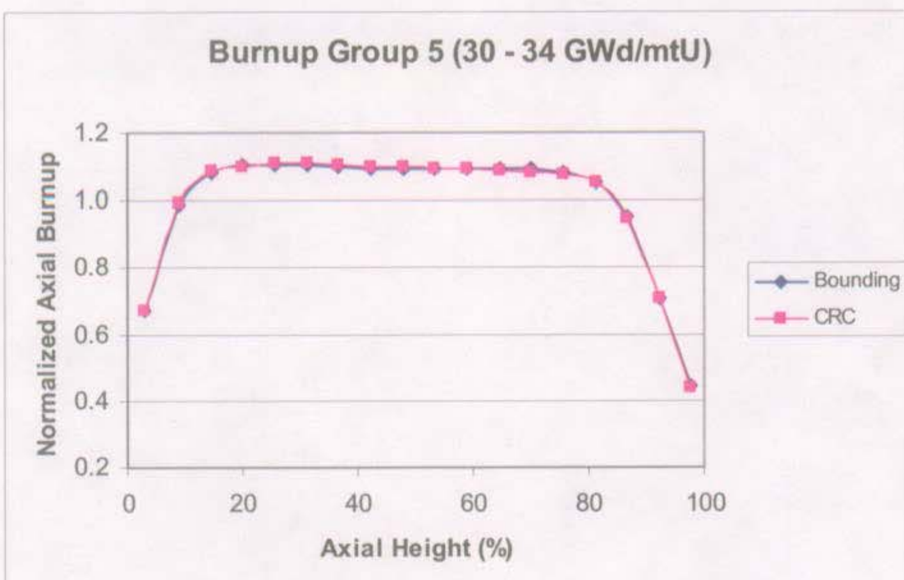

Figure A-5. CRC and Bounding Axial Profiles for Burnup Group 5

Table A-6. Selection of CRC Burnup Data for Analysis of Burnup Group 6

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	H12 (SP27)	17.7800	12.102	0.438	0.440	-0.034
2	H10 (SP28)	20.0025	18.762	0.679	0.677	
3	H19 (SP29)	20.0025	23.915	0.866	0.863	0.064
4	H12 (SP29)	20.0025	28.593	1.035	1.033	
5	H6 (SP30)	20.0025	30.930	1.120	1.110	
6	H19 (SP31)	20.0025	31.420	1.138	1.134	
7	H19 (SP31)	20.0025	31.535	1.142	1.143	
8	H19 (SP31)	20.0025	31.602	1.144	1.143	
9	H6 (SP30)	20.0025	31.605	1.144	1.137	
10	H4 (SP30)	20.0025	30.858	1.117	1.126	
11	H10 (SP31)	20.0025	30.539	1.106	1.113	
12	H10 (SP31)	20.0025	30.585	1.108	1.105	
13	H12 (SP29)	20.0025	30.528	1.105	1.101	
14	H12 (SP29)	20.0025	30.528	1.105	1.103	
15	H12 (SP29)	20.0025	30.141	1.091	1.099	
16	H4 (SP30)	20.0025	29.328	1.062	1.065	
17	H12 (SP29)	20.0025	26.253	0.951	0.948	-1.030
18	H19 (SP30)	22.3520	17.334	0.628	0.642	

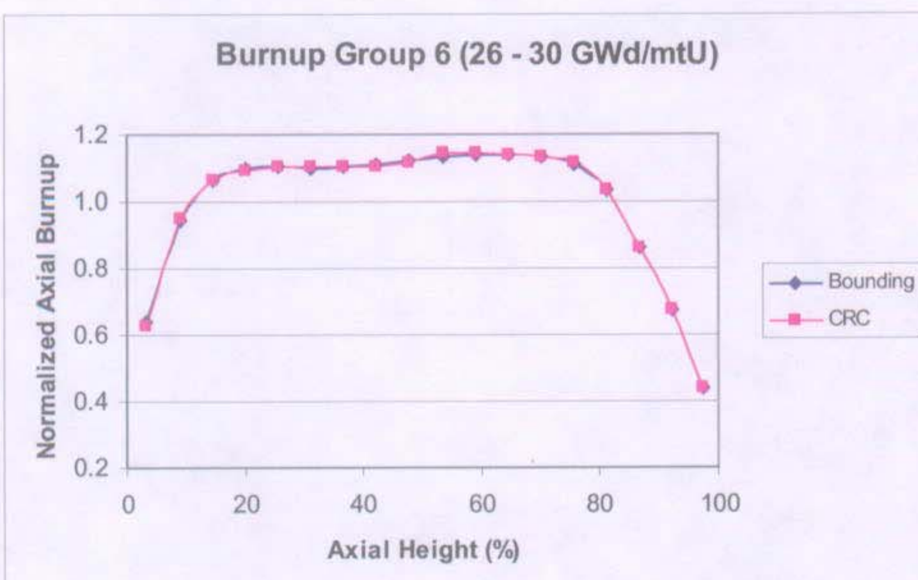

Figure A-6. CRC and Bounding Axial Profiles for Burnup Group 6

Table A-7. Selection of CRC Burnup Data for Analysis of Burnup Group 7

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	H6 (SP27)	17.7800	11.339	0.437	0.433	-1.467
2	H6 (SP27)	20.0025	16.599	0.640	0.665	
3	H17 (SP28)	20.0025	21.871	0.844	0.851	0.130
4	H10 (SP30)	20.0025	26.845	1.036	1.027	
5	H17 (SP30)	20.0025	28.722	1.108	1.104	
6	H12 (SP29)	20.0025	29.283	1.130	1.127	
7	H12 (SP29)	20.0025	29.442	1.136	1.135	
8	H12 (SP29)	20.0025	29.549	1.140	1.135	
9	H23a (SP31)	20.0025	29.348	1.132	1.132	
10	H6 (SP29)	20.0025	29.201	1.126	1.127	
11	H4 (SP29)	20.0025	29.110	1.123	1.120	
12	H25 (SP31)	20.0025	28.809	1.111	1.113	
13	H25 (SP31)	20.0025	28.882	1.114	1.109	
14	H25 (SP31)	20.0025	28.841	1.113	1.108	
15	H14 (SP30)	20.0025	28.652	1.105	1.105	
16	H6 (SP29)	20.0025	27.848	1.074	1.075	
17	H6 (SP29)	20.0025	25.115	0.969	0.960	-0.489
18	H10 (SP29)	22.3520	16.630	0.642	0.653	

Figure A-7. CRC and Bounding Axial Profiles for Burnup Group 7

Table A-8. Selection of CRC Burnup Data for Analysis of Burnup Group 8

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	B29 (SP8)	17.7800	7.805	0.352	0.356	-0.876
2	B25 (SP8)	20.0025	14.011	0.632	0.638	
3	B29 (SP9)	20.0025	20.228	0.913	0.911	0.265
4	B21a (SP9)	20.0025	24.033	1.085	1.039	
5	B21a (SP9)	20.0025	24.883	1.123	1.101	
6	B21a (SP9)	20.0025	25.241	1.139	1.128	
7	B21a (SP9)	20.0025	25.323	1.143	1.137	
8	B15 (SP9)	20.0025	25.253	1.140	1.140	
9	B25 (SP10)	20.0025	25.138	1.134	1.136	
10	B27 (SP9)	20.0025	24.903	1.124	1.123	
11	B27 (SP10)	20.0025	24.364	1.099	1.098	
12	B27 (SP9)	20.0025	23.793	1.074	1.071	
13	B29 (SP10)	20.0025	22.955	1.036	1.049	
14	B29 (SP9)	20.0025	23.027	1.039	1.051	
15	B29 (SP9)	20.0025	23.574	1.064	1.088	
16	B29 (SP10)	20.0025	25.539	1.153	1.152	
17	B29 (SP9)	20.0025	22.924	1.035	1.060	-2.266
18	B29 (SP9)	22.3520	15.105	0.682	0.696	

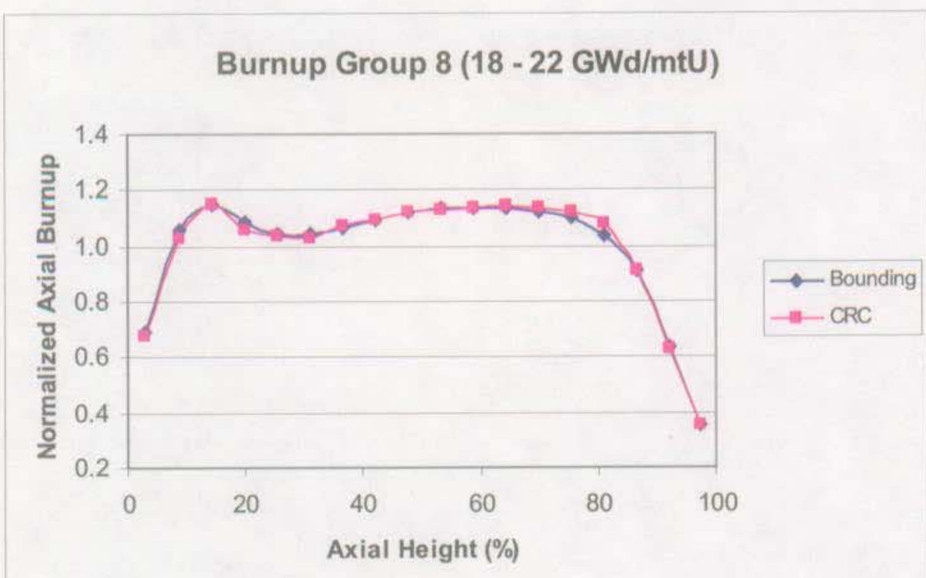

Figure A-8. CRC and Bounding Axial Profiles for Burnup Group 8

Table A-9. Selection of CRC Burnup Data for Analysis of Burnup Group 9

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	O1 (SP3)	17.7800	3.557	0.265	0.271	
2	O1 (SP3)	20.0025	6.090	0.454	0.462	-1.888
3	O1 (SP3)	20.0025	7.986	0.596	0.599	
4	O1 (SP3)	20.0025	9.617	0.718	0.734	
5	O1 (SP3)	20.0025	13.312	0.993	0.999	
6	O1 (SP3)	20.0025	15.391	1.148	1.146	
7	O1 (SP3)	20.0025	15.966	1.191	1.188	
8	O1 (SP3)	20.0025	16.080	1.200	1.195	
9	O1 (SP3)	20.0025	16.048	1.197	1.192	-0.071
10	O1 (SP3)	20.0025	15.996	1.193	1.188	
11	O1 (SP3)	20.0025	15.991	1.193	1.189	
12	O1 (SP3)	20.0025	16.060	1.198	1.194	
13	O1 (SP3)	20.0025	16.174	1.207	1.207	
14	O1 (SP3)	20.0025	16.247	1.212	1.214	
15	O1 (SP3)	20.0025	16.258	1.213	1.215	
16	O1 (SP3)	20.0025	16.316	1.217	1.217	
17	O1 (SP3)	20.0025	14.517	1.083	1.075	0.163
18	O1 (SP3)	22.3520	9.061	0.676	0.678	

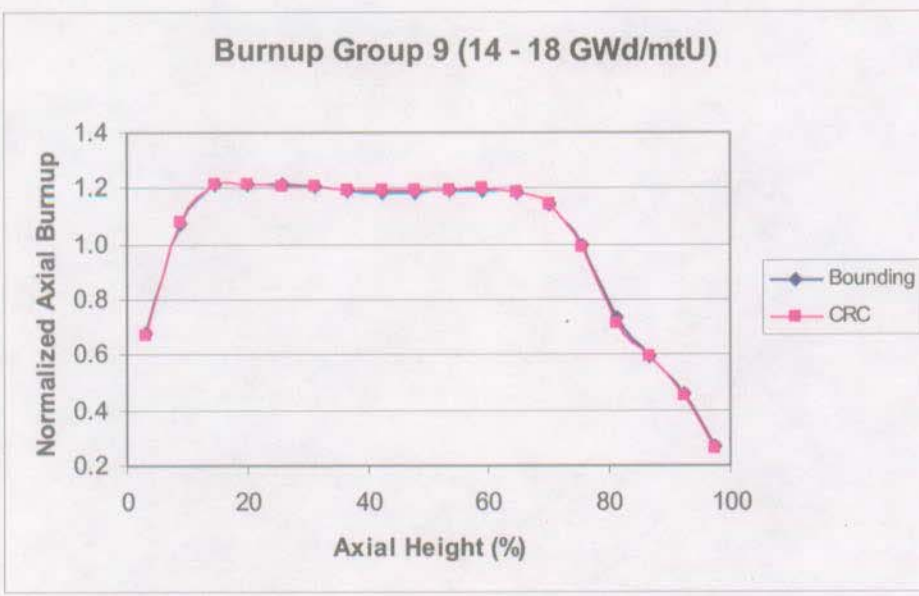

Figure A-9. CRC and Bounding Axial Profiles for Burnup Group 9

Table A-10. Selection of CRC Burnup Data for Analysis of Burnup Group 10

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	A18b (SP3)	17.7800	5.861	0.478	0.492	
2	A18b (SP3)	20.0025	9.956	0.812	0.831	-2.455
3	A18b (SP3)	20.0025	12.792	1.044	1.056	
4	A18b (SP3)	20.0025	14.424	1.177	1.183	
5	A18b (SP3)	20.0025	15.255	1.245	1.246	
6	A18b (SP3)	20.0025	15.627	1.275	1.274	
7	A18b (SP3)	20.0025	15.760	1.286	1.283	
8	A18b (SP3)	20.0025	15.750	1.285	1.280	
9	A18b (SP3)	20.0025	15.564	1.270	1.258	0.139
10	A18b (SP3)	20.0025	14.951	1.220	1.198	
11	A24 (SP3)	20.0025	12.701	1.036	1.034	
12	A22 (SP2)	20.0025	10.054	0.820	0.822	
13	A18b (SP3)	20.0025	9.090	0.742	0.756	
14	A13 (SP2)	20.0025	9.394	0.767	0.770	
15	A5 (SP2)	20.0025	10.418	0.850	0.843	
16	A26 (SP3)	20.0025	12.576	1.026	1.010	
17	A18b (SP3)	20.0025	12.257	1.000	1.009	-1.508
18	A18b (SP3)	22.3520	7.957	0.649	0.663	

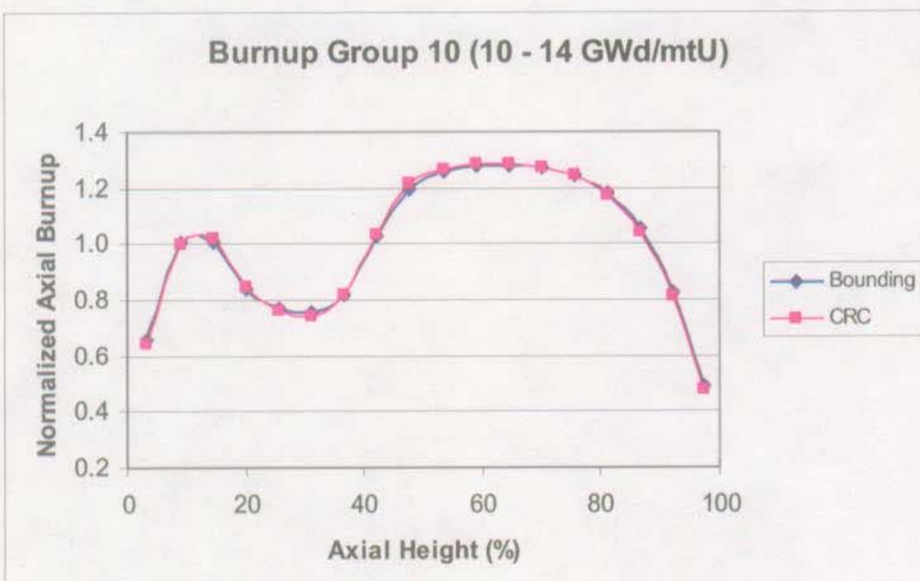

Figure A-10. CRC and Bounding Axial Profiles for Burnup Group 10

Table A-11. Selection of CRC Burnup Data for Analysis of Burnup Group 11

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	B28a (SP9)	17.7800	5.231	0.540	0.546	-0.183
2	B20 (SP6)	20.0025	8.441	0.871	0.866	
3	B15 (SP6)	20.0025	9.707	1.002	1.033	0.462
4	B28 (SP6)	20.0025	10.617	1.096	1.097	
5	B15 (SP6)	20.0025	10.777	1.113	1.119	
6	B15 (SP6)	20.0025	10.844	1.119	1.124	
7	B15 (SP6)	20.0025	10.791	1.114	1.122	
8	B15 (SP6)	20.0025	10.641	1.099	1.112	
9	B28 (SP6)	20.0025	10.448	1.079	1.086	
10	B28 (SP6)	20.0025	10.111	1.044	1.036	
11	B21 (SP6)	20.0025	9.640	0.995	0.992	
12	B21 (SP6)	20.0025	9.772	1.009	0.978	
13	B21 (SP6)	20.0025	10.034	1.036	0.987	
14	B21 (SP6)	20.0025	10.323	1.066	1.017	
15	B21 (SP6)	20.0025	10.398	1.073	1.066	
16	B8 (SP6)	20.0025	10.426	1.076	1.094	
17	B15 (SP6)	20.0025	9.513	0.982	1.031	-3.190
18	B25 (SP6)	22.3520	6.520	0.673	0.686	

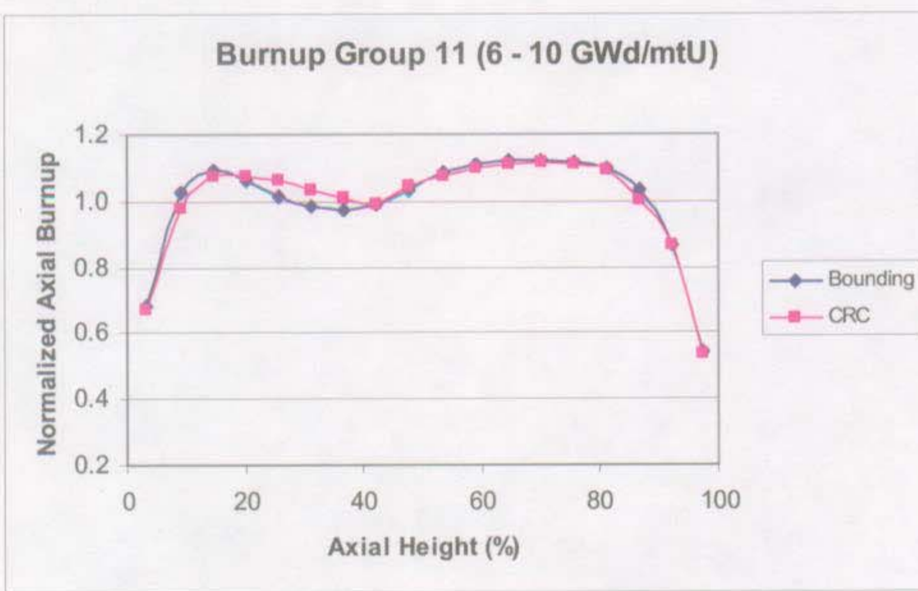

Figure A-11. CRC and Bounding Axial Profiles for Burnup Group 11

Table A-12. Selection of CRC Burnup Data for Analysis of Burnup Group 12

Axial Node	Assembly And Statepoint	Node Spacing (cm)	Node Burnup (GWd/mtU)	CRC Burnup Profile	Group 2 Bounding Profile	Weighted % Diff
1	B15 (SP5)	17.7800	1.572	0.494	0.502	-3.814
2	B8 (SP5)	20.0025	2.453	0.771	0.818	
3	B8 (SP5)	20.0025	3.071	0.965	0.984	1.099
4	B8 (SP5)	20.0025	3.349	1.052	1.047	
5	B8 (SP5)	20.0025	3.457	1.086	1.071	
6	B8 (SP5)	20.0025	3.491	1.097	1.079	
7	B8 (SP5)	20.0025	3.494	1.098	1.077	
8	B8 (SP5)	20.0025	3.484	1.095	1.071	
9	B8 (SP5)	20.0025	3.467	1.089	1.061	
10	B8 (SP5)	20.0025	3.449	1.084	1.051	
11	B8 (SP5)	20.0025	3.436	1.080	1.047	
12	B8 (SP5)	20.0025	3.432	1.078	1.050	
13	B8 (SP5)	20.0025	3.435	1.079	1.066	
14	B8 (SP5)	20.0025	3.453	1.085	1.094	
15	B8 (SP5)	20.0025	3.490	1.097	1.131	
16	B15 (SP5)	20.0025	3.660	1.150	1.141	
17	B15 (SP5)	20.0025	3.168	0.995	1.035	-6.803
18	B15 (SP5)	22.3520	1.901	0.597	0.660	

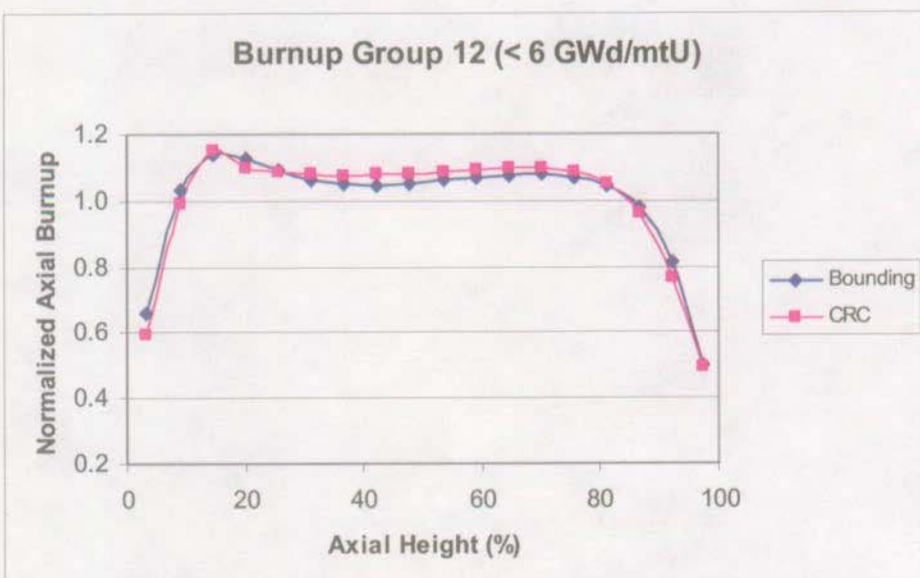

Figure A-12. CRC and Bounding Axial Profiles for Burnup Group 12

Table A-13. Bounding Axial Burnup Profiles by Group

Axial Height (%)	Burnup Group											
	12	11	10	9	8	7	6	5	4	3	2	1
	Burnup Ranges (GWd/mtU)											
	<6	6-10	10-14	14-18	18-22	22-26	26-30	30-34	34-38	38-42	42-46	>46
97.222	0.525	0.569	0.515	0.284	0.373	0.448	0.456	0.462	0.447	0.525	0.512	0.515
91.667	0.845	0.894	0.863	0.481	0.669	0.689	0.701	0.738	0.743	0.823	0.811	0.833
86.111	0.996	1.045	1.075	0.614	0.933	0.871	0.882	0.971	0.974	0.996	1.010	0.992
80.556	1.052	1.101	1.193	0.756	1.049	1.041	1.047	1.059	1.056	1.057	1.069	1.050
75.000	1.073	1.120	1.251	1.022	1.106	1.109	1.115	1.086	1.081	1.077	1.083	1.072
69.444	1.079	1.124	1.276	1.156	1.130	1.129	1.136	1.095	1.091	1.084	1.086	1.080
63.889	1.077	1.121	1.283	1.190	1.138	1.135	1.143	1.096	1.095	1.086	1.086	1.084
58.333	1.070	1.110	1.278	1.195	1.140	1.135	1.143	1.095	1.097	1.088	1.085	1.088
52.778	1.060	1.082	1.253	1.192	1.135	1.132	1.136	1.094	1.099	1.088	1.084	1.091
47.222	1.050	1.031	1.185	1.188	1.121	1.126	1.125	1.094	1.102	1.089	1.084	1.095
41.667	1.047	0.989	1.013	1.189	1.095	1.119	1.112	1.097	1.105	1.090	1.085	1.100
35.111	1.053	0.978	0.785	1.197	1.064	1.112	1.103	1.102	1.108	1.092	1.086	1.105
30.556	1.069	0.989	0.754	1.208	1.048	1.109	1.101	1.106	1.112	1.093	1.090	1.110
25.000	1.098	1.022	0.776	1.214	1.053	1.108	1.103	1.108	1.112	1.091	1.089	1.113
19.444	1.133	1.070	0.857	1.215	1.094	1.103	1.097	1.103	1.104	1.080	1.081	1.105
13.889	1.135	1.091	1.019	1.208	1.150	1.066	1.056	1.074	1.070	1.045	1.048	1.065
8.333	1.007	1.007	0.989	1.044	1.034	0.936	0.924	0.967	0.955	0.936	0.944	0.920
2.778	0.631	0.658	0.633	0.649	0.668	0.630	0.619	0.652	0.648	0.660	0.666	0.582

Reference 6.3, p. 20

Table A-14. Bounding Axial Burnup Profiles for Comparison with CRC Data – Groups 1 & 2

Axial Height (Percent)	Burnup Group 2	Burnup Group 1
	Burnup Ranges (GWd/mtU)	
	42-46	>46
97.553	0.491	0.491
92.305	0.782	0.805
86.704	0.995	0.980
81.103	1.065	1.046
75.502	1.082	1.071
69.900	1.086	1.079
64.299	1.086	1.084
58.698	1.085	1.088
53.097	1.084	1.091
47.496	1.084	1.095
41.894	1.085	1.100
36.293	1.085	1.104
30.692	1.090	1.110
25.091	1.089	1.113
19.490	1.081	1.105
13.888	1.048	1.065
8.287	0.942	0.918
2.743	0.664	0.579

Table A-15. Bounding Axial Burnup Profiles for Comparison with CRC Data – Groups 1 - 12

Axial	Burnup Group									
	12	11	10	9	8	7	6	5	4	3
Height	Burnup Ranges (GWd/mtU)									
(Percent)	<6	6-10	10-14	14-18	18-22	22-26	26-30	30-34	34-38	38-42
97.532	0.502	0.546	0.492	0.271	0.356	0.433	0.440	0.445	0.429	0.505
92.287	0.818	0.866	0.831	0.462	0.638	0.665	0.677	0.709	0.713	0.796
86.733	0.984	1.033	1.056	0.599	0.911	0.851	0.863	0.952	0.956	0.982
81.179	1.047	1.097	1.183	0.734	1.039	1.027	1.033	1.052	1.050	1.052
75.626	1.071	1.119	1.246	0.999	1.101	1.104	1.110	1.084	1.079	1.075
70.072	1.079	1.124	1.274	1.146	1.128	1.127	1.134	1.094	1.090	1.083
64.519	1.077	1.122	1.283	1.188	1.137	1.135	1.143	1.096	1.095	1.086
58.965	1.071	1.112	1.280	1.195	1.140	1.135	1.143	1.095	1.097	1.088
53.411	1.061	1.086	1.258	1.192	1.136	1.132	1.137	1.094	1.099	1.088
47.858	1.051	1.036	1.198	1.188	1.123	1.127	1.126	1.094	1.102	1.089
42.304	1.047	0.992	1.034	1.189	1.098	1.120	1.113	1.097	1.105	1.090
36.751	1.050	0.978	0.822	1.194	1.071	1.113	1.105	1.101	1.107	1.092
31.197	1.066	0.987	0.756	1.207	1.049	1.109	1.101	1.106	1.112	1.093
25.644	1.094	1.017	0.770	1.214	1.051	1.108	1.103	1.108	1.112	1.092
20.090	1.131	1.066	0.843	1.215	1.088	1.105	1.099	1.105	1.106	1.083
14.536	1.141	1.094	1.010	1.217	1.152	1.075	1.065	1.081	1.078	1.053
8.983	1.035	1.031	1.009	1.075	1.060	0.960	0.948	0.990	0.978	0.957
3.103	0.660	0.686	0.663	0.678	0.696	0.653	0.642	0.676	0.671	0.681

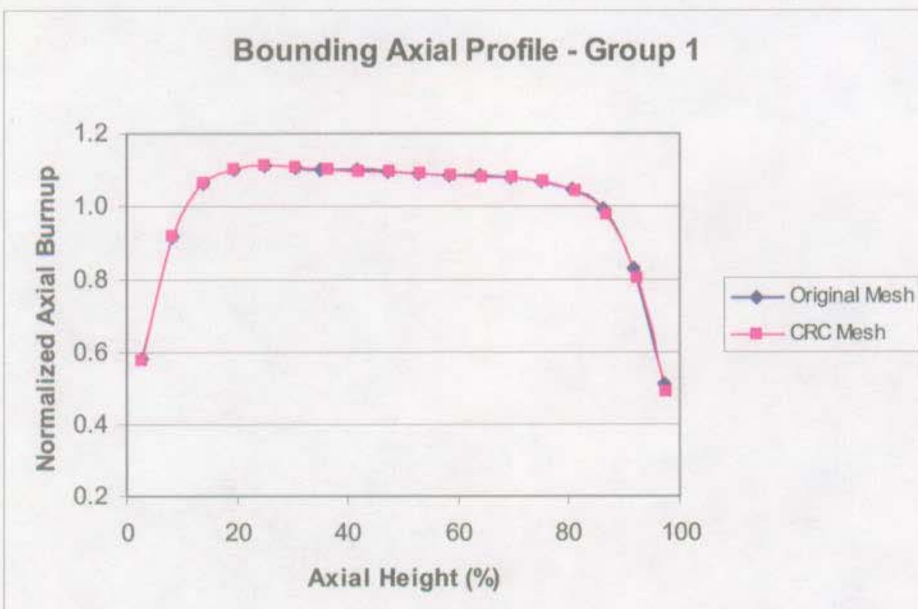

Figure A-13. Bounding Axial Profile Comparison for Burnup Group 1 – Original Mesh/CRC Mesh

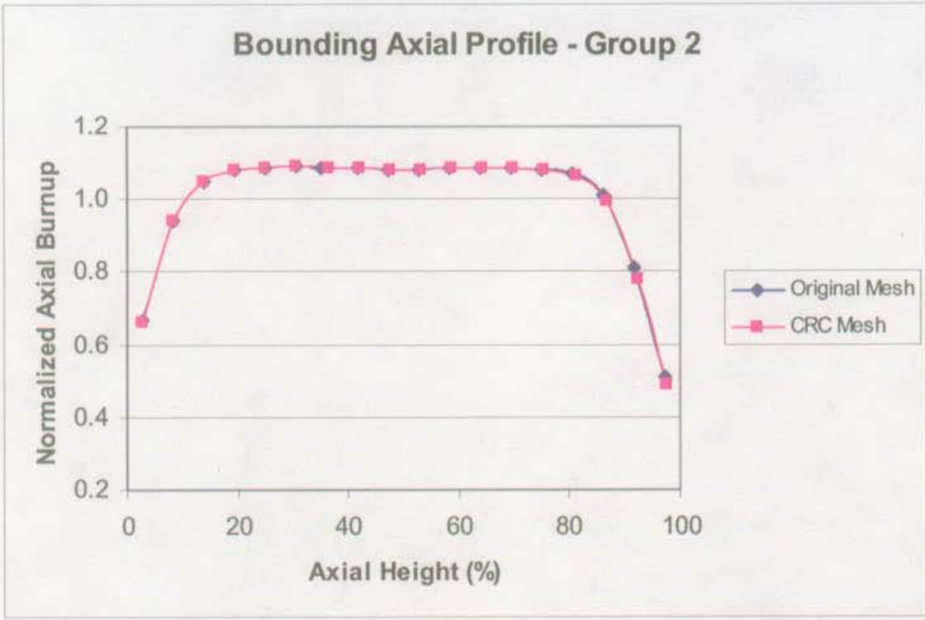

Figure A-14. Bounding Axial Profile Comparison for Burnup Group 2 – Original Mesh/CRC Mesh

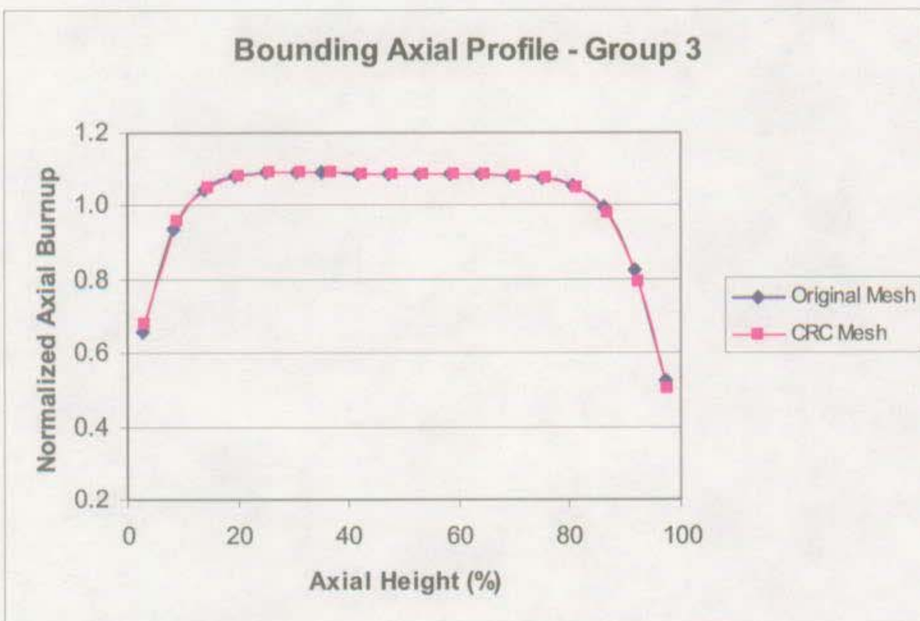

Figure A-15. Bounding Axial Profile Comparison for Burnup Group 3 – Original Mesh/CRC Mesh

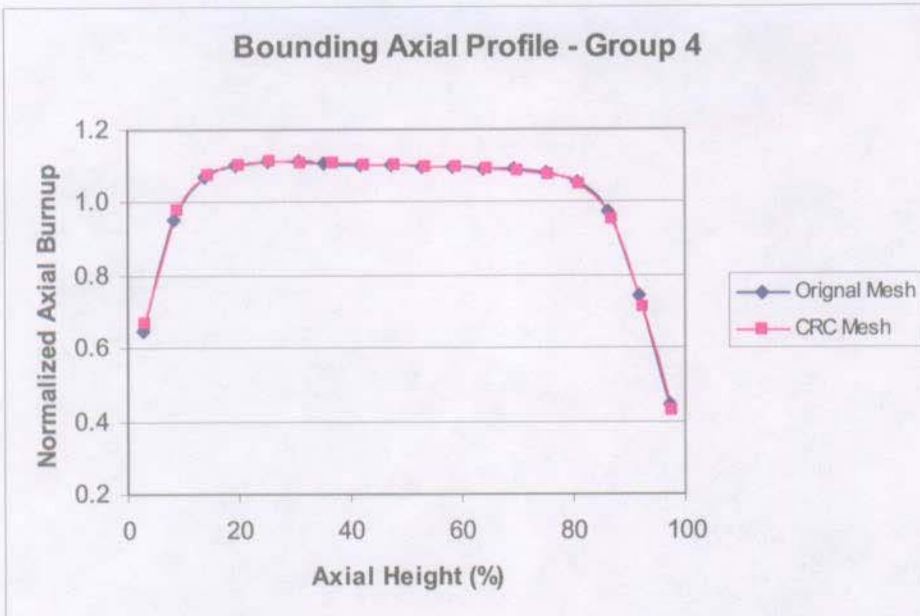

Figure A-16. Bounding Axial Profile Comparison for Burnup Group 4 – Original Mesh/CRC Mesh

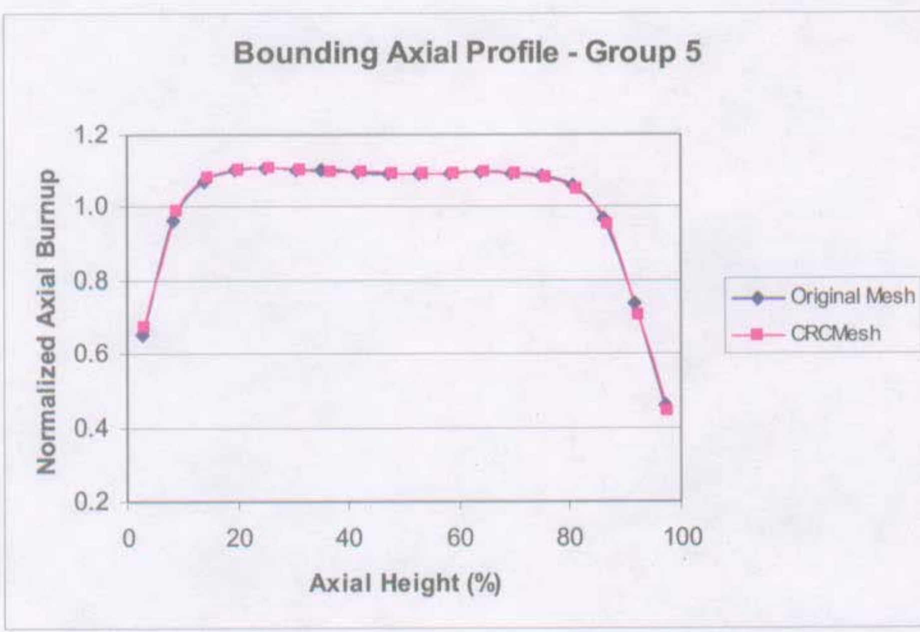

Figure A-17. Bounding Axial Profile Comparison for Burnup Group 5 – Original Mesh/CRC Mesh

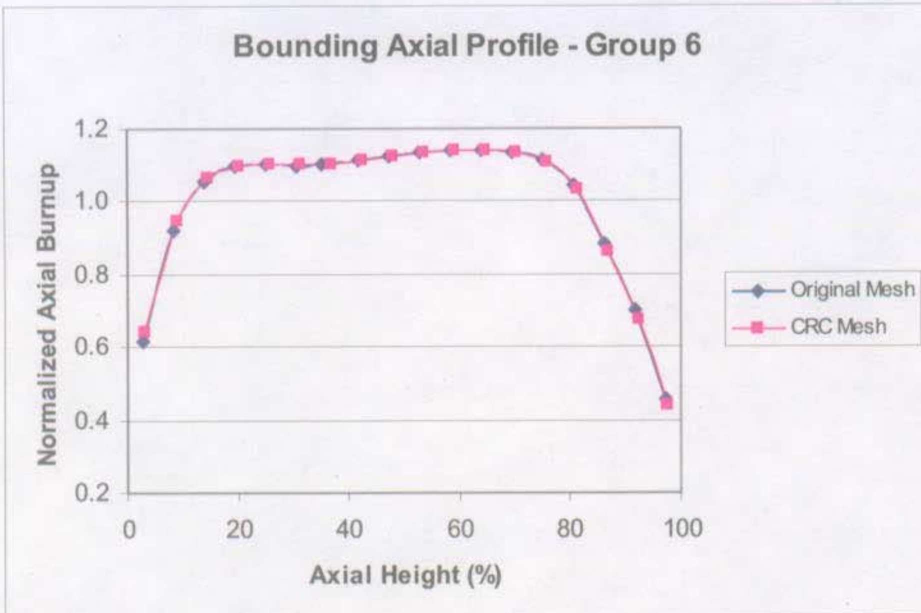

Figure A-18. Bounding Axial Profile Comparison for Burnup Group 6 – Original Mesh/CRC Mesh

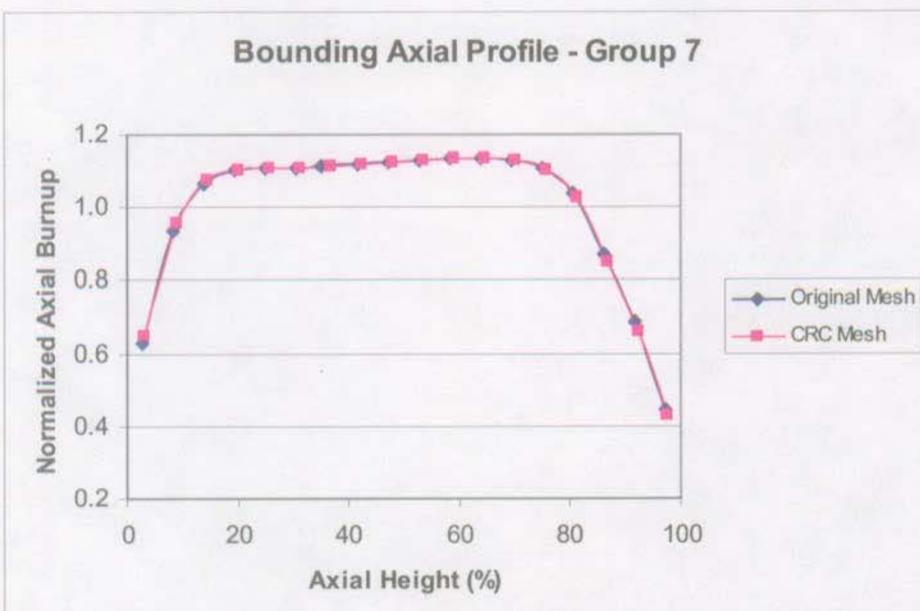

Figure A-19. Bounding Axial Profile Comparison for Burnup Group 7 – Original Mesh/CRC Mesh

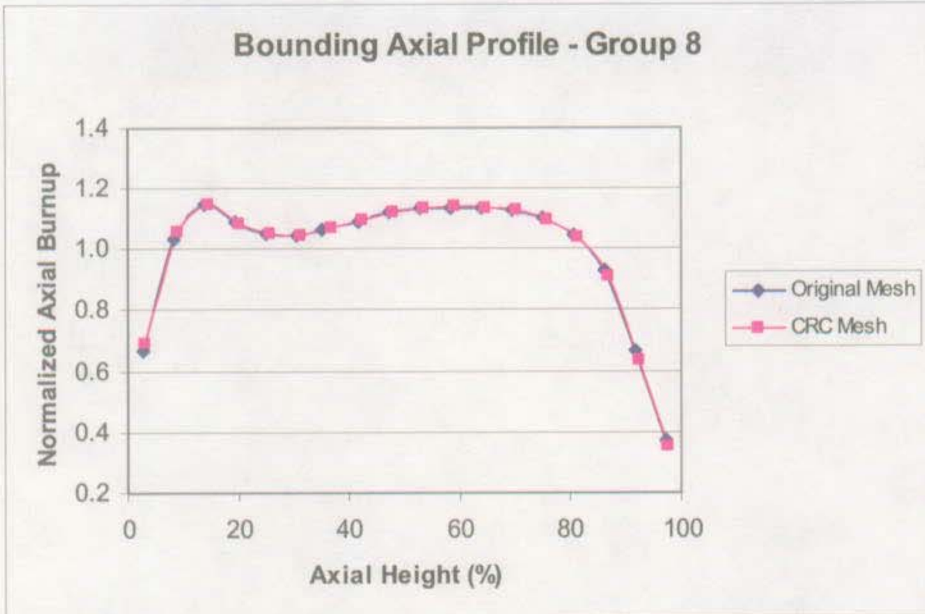

Figure A-20. Bounding Axial Profile Comparison for Burnup Group 8 – Original Mesh/CRC Mesh

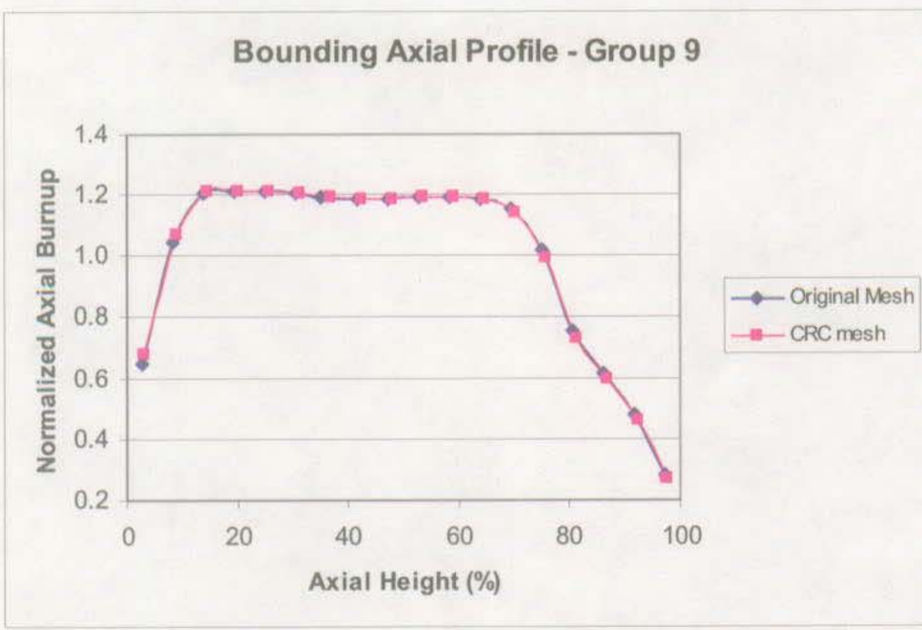

Figure A-21. Bounding Axial Profile Comparison for Burnup Group 9 – Original Mesh/CRC Mesh

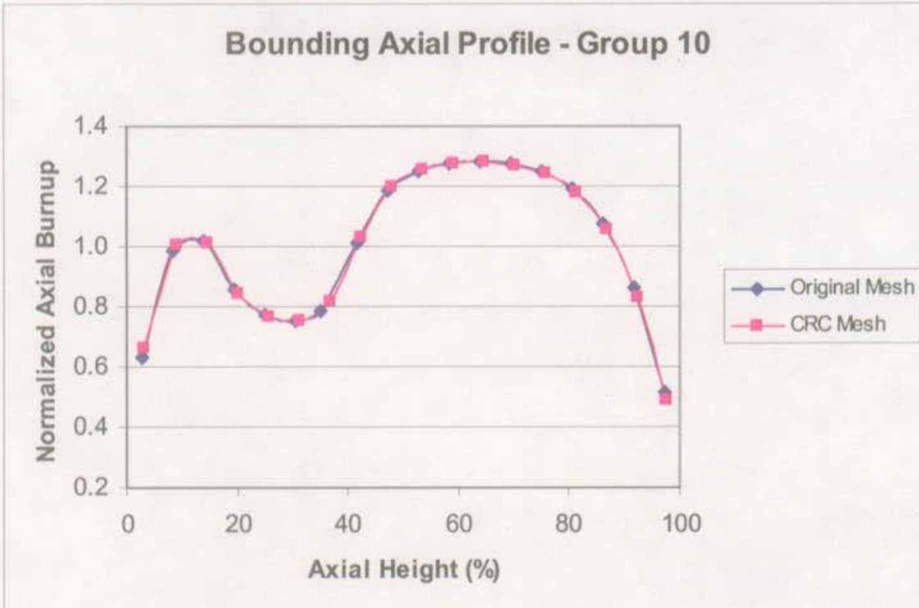

Figure A-22. Bounding Axial Profile Comparison for Burnup Group 10 – Original Mesh/CRC Mesh

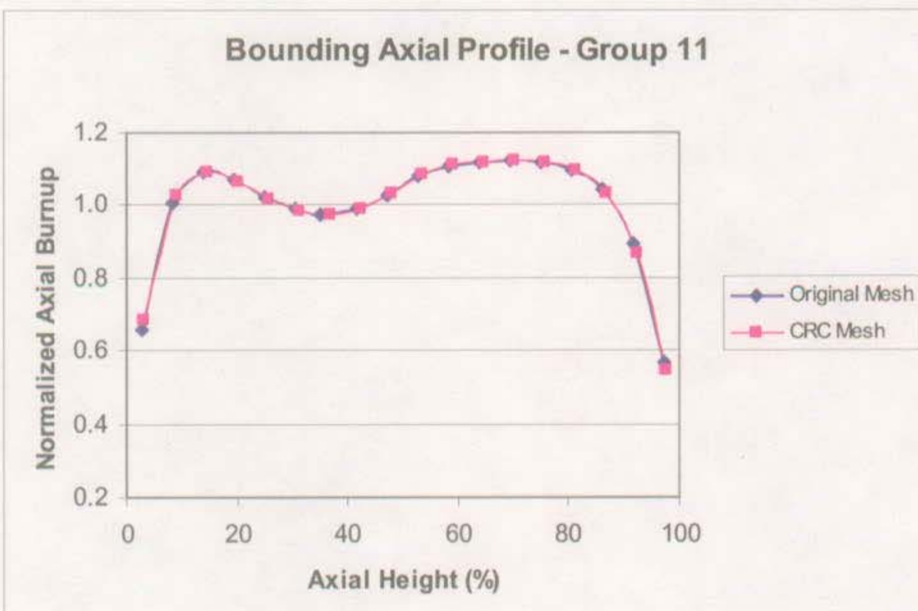

Figure A-23. Bounding Axial Profile Comparison for Burnup Group 11 – Original Mesh/CRC Mesh

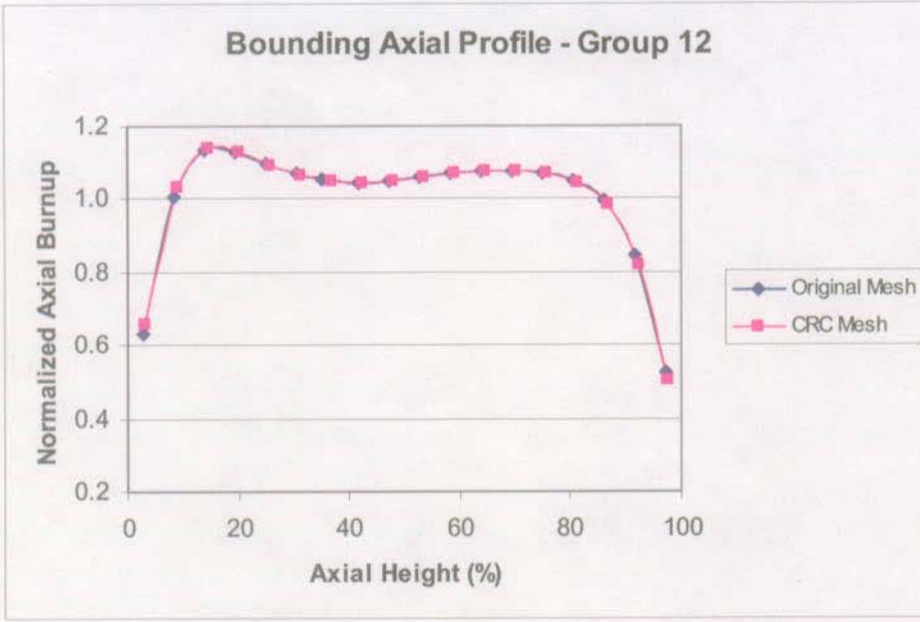

Figure A-24. Bounding Axial Profile Comparison for Burnup Group 12 – Original Mesh/CRC Mesh

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7. Document Number(s) ~~32-50337567~~ 32-5033756 HP 1-9-04	8. Version Designator 00
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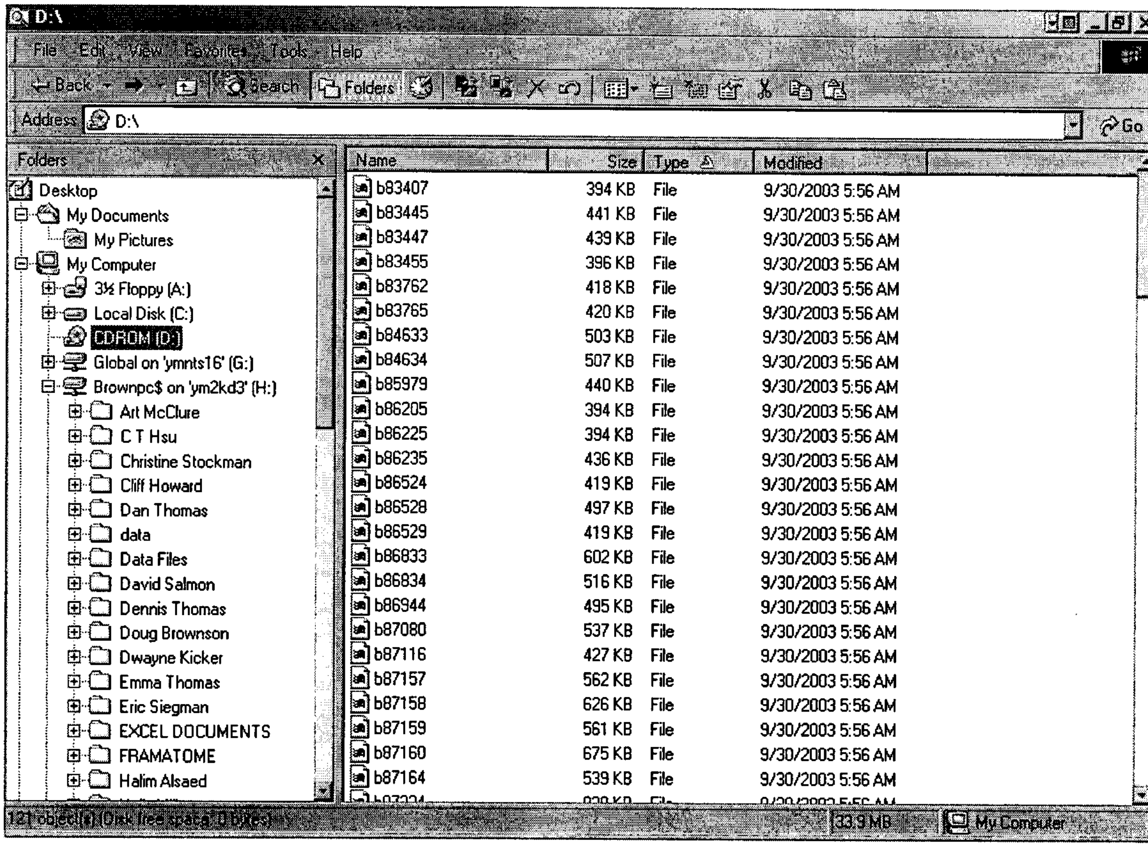
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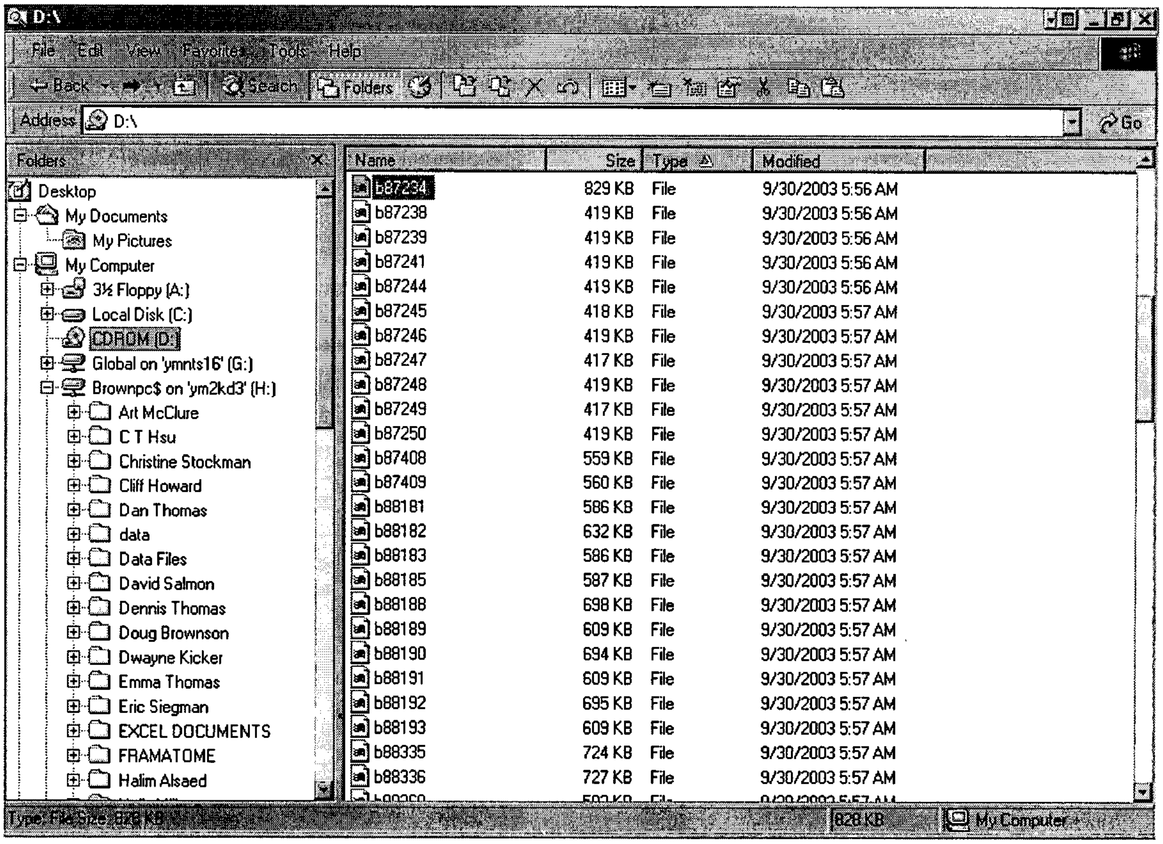
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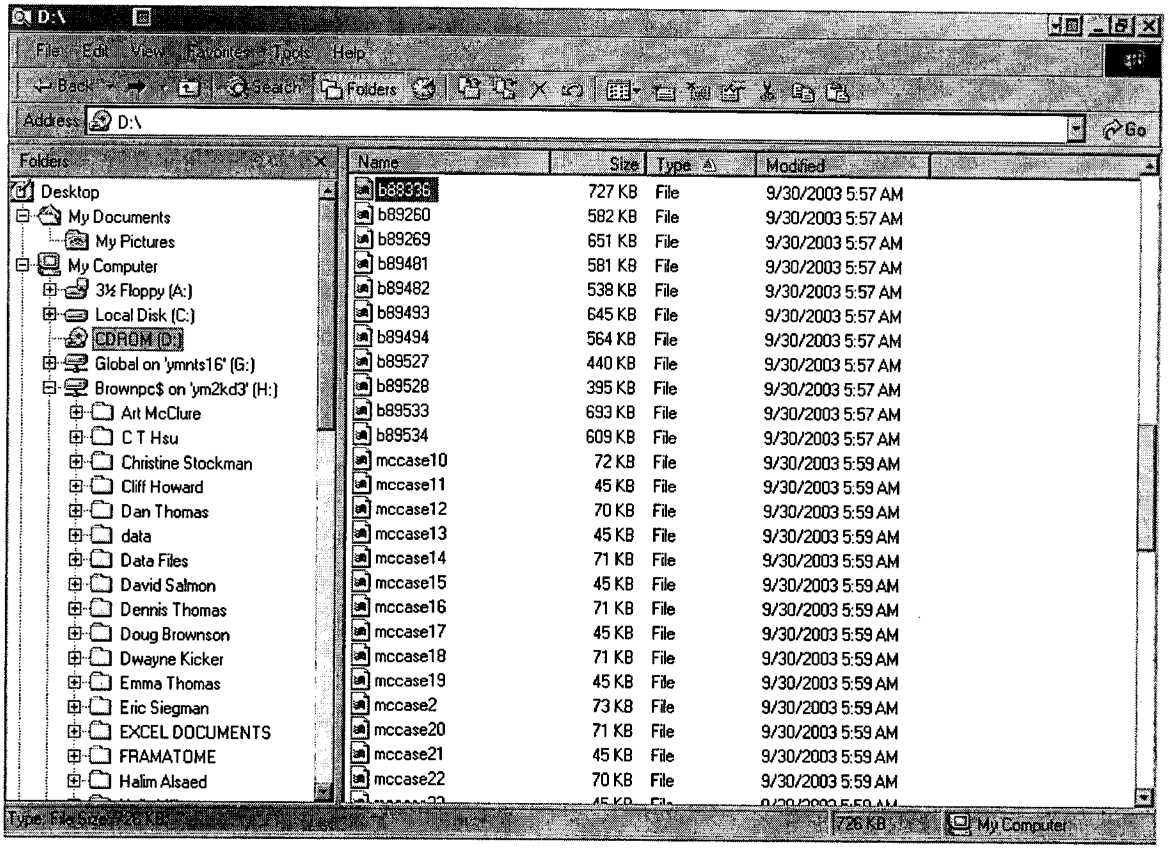
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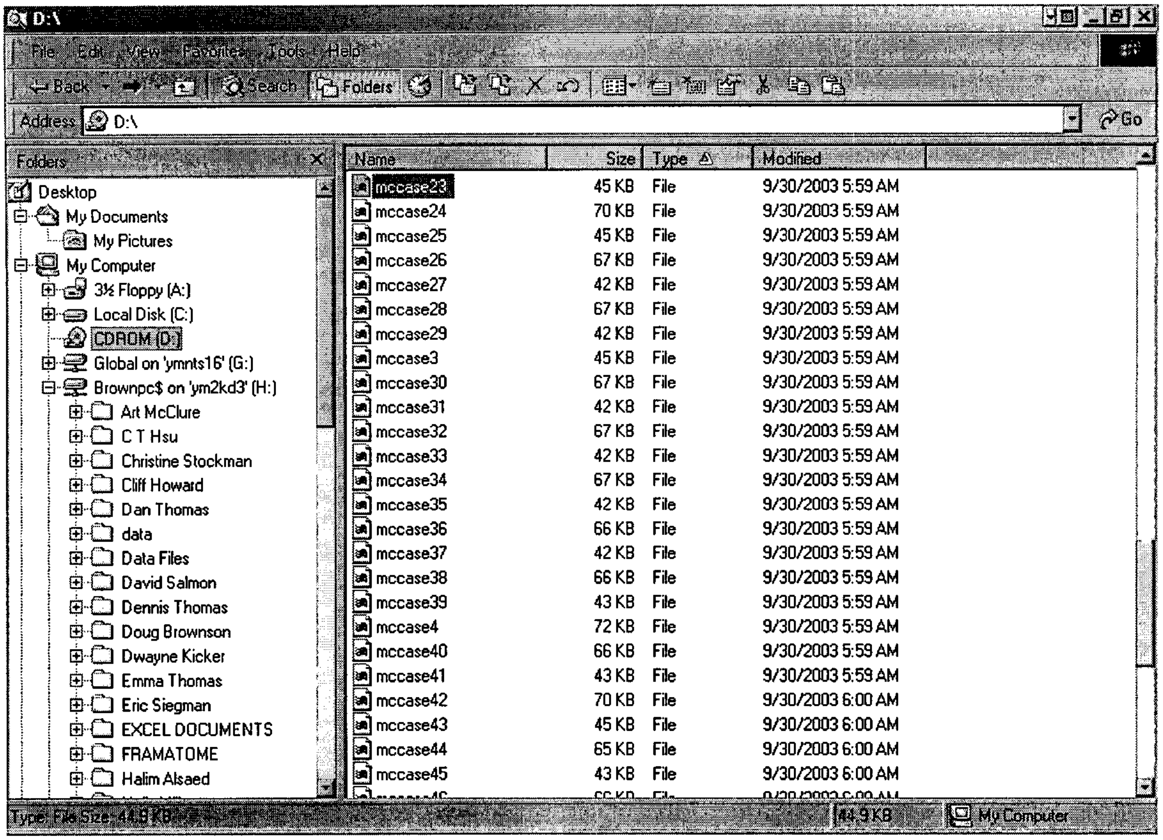

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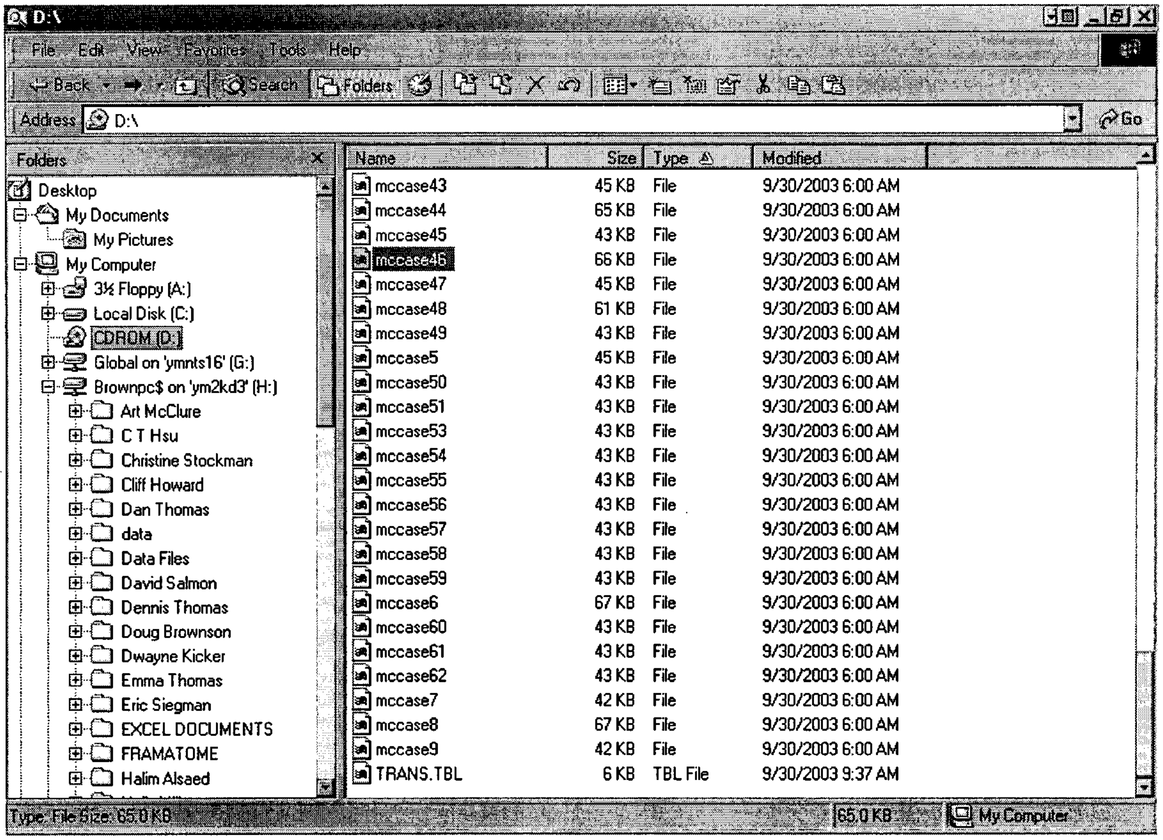
D:\
File Edit View Favorites Tools Help
Back Search Folders
Address D:\
Go
Folders
Desktop
My Documents
My Pictures
My Computer
3½ Floppy (A:)
Local Disk (C:)
CDROM (D:)
Global on 'ymnts16' (G:)
Brownpc$ on 'ym2kd3' (H:)
Art McClure
C T Hsu
Christine Stockman
Cliff Howard
Dan Thomas
data
Data Files
David Salmon
Dennis Thomas
Doug Brownson
Dwayne Kicker
Emma Thomas
Eric Siegman
EXCEL DOCUMENTS
FRAMATOME
Halim Alsaed
Name Size Type Modified
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My Computer