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Non-Q Design Analysis Cover Sheet

Complete only applicable items.

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13. Remarks

All of the attachments for this document have been moved to the reference - Section 5.26 and are now located in the RPC (BATCH NO. MOY-970327-03).
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1. Purpose

This analysis is prepared by the Mined Geologic Disposal System (MGDS) Waste Package Development Department (WPDD) to determine the viability of the UCF waste package concept with respect to criticality regulatory requirements in compliance with the goals of the Waste Package Implementation Plan[5.1] for conceptual design. These design calculations are performed in sufficient detail to provide a comprehensive comparison base with other design alternatives. The objectives of this evaluation are 1) to show the reactivity worth of burnup credit, 2) to show to what extent the concept meets the regulatory requirements or indicate additional measures that are required for the intact waste package, 3) to demonstrate time effects on criticality potential, 4) to demonstrate the effects of varied boron concentration in the control panels on criticality potential, and 5) to provide input for separate shielding calculations.

2. Quality Assurance

This is a scoping analysis performed to assist in reducing the number of options to be considered in future analyses and is considered a non-quality affecting document. The NAP procedures for Non-Q Analysis will be followed.

All design inputs which are identified in this document are for preliminary designs; some or all of these design inputs will require subsequent qualification (or superseding inputs) as the waste package design proceeds. This document will not directly support any construction, fabrication, or procurement activity and therefore does not require formal TBV (to be verified) tracking.

3. Method

The multiplication factor (k_{eff}) of the disposal packages is determined using the Monte Carlo neutron transport technique implemented in the MCNP[5.5] computer program. The combined average value of k_{eff} of the three estimates, as listed in the final generation summary in the MCNP output, is reported in this document.

4. Design Inputs

All design inputs are for preliminary designs; some or all of these design inputs will require subsequent qualification (or superseding inputs) as the waste package design proceeds. The [unqualified] design inputs identified and documented in Section 4 have been identified as TBV; but, will not be used to directly support any construction, fabrication, or procurement activity and therefore does not require formal TBV tracking.

4.1 Design Parameters

4.1.1 PWR Mechanical Parameters

The PWR fuel assembly upon which this calculation is based is the B&W 15 x 15 fuel assembly. The mechanical parameters for this assembly type are shown in the table below.

Table 4.1-1 Mechanical Parameters of B&W 15x15 Fuel Assembly

Parameter	Value	Units	Metric	Units	Radius (cm)	Ref
Fuel Rods	208	/assbly	208	/assbly		5.6
Fuel Rods on a Lattice Side	15	/side	15	/side		5.6
Guide Tubes	16	/assbly	16	/assbly		5.6
Instrumentation Tubes	1	/assbly	1	/assbly		5.6
Total Guide + Instrument Tubes	17	/assbly	17	/assbly		-
Clad/Tube Material	ZIRC-4		ZIRC-4			5.6
Fuel Pellet OD	0.3686	inches	0.936244	cm	0.468122	5.6
Fuel Stack Height	141.8	inches	360.172	cm		5.6
Mass of U	1023	lb	464	kg		5.7
Mass of UO_2	1160.64	lb	526.38	kg		5.6
Percent of Theoretical Density	95	%	95	%		5.6
Fuel Clad OD	0.430	inches	1.0922	cm	0.5461	5.6
Clad Thickness	0.0265	inches	0.06731	cm		5.6
Fuel Clad ID*	0.377	inches	0.95758	cm	0.47879	-
Fuel Rod Pitch	0.568	inches	1.44272	cm		5.6
Guide Tube OD	0.530	inches	1.3462	cm	0.6731	5.6
Guide Tube Thickness	0.016	inches	0.04064	cm		5.6
Guide Tube ID*	0.498	inches	1.26492	cm	0.63246	-

Parameter	Value	Units	Metric	Units	Radius (cm)	Ref
Instrumentation Tube OD	0.493	inches	1.25222	cm	0.62611	5.6
Fuel Assembly Envelope	8.536	inches	21.6814	cm		5.6

* The inner diameters (IDs) above are calculated by subtracting twice the thickness from the outer diameter (OD).

4.1.2 BWR Mechanical Parameters

The BWR fuel assembly upon which this calculation is based is the GE-5 8 x 8 fuel assembly. The mechanical parameters for this assembly type are shown in the table below.

Table 4.1.2-1 Mechanical Parameters of GE-5 8x8 Fuel Assembly

Parameter	Value	Units	Metric	Units	Radius (cm)	Ref
Fuel rods	62	/assbly	62	/assbly		5.7
Fuel rods on a lattice side	8	/side	8	/side		5.7
Clad/tube material	ZIRC-2		ZIRC-2			5.7
Fuel pellet OD	0.410	inches	1.0414	cm	0.5207	5.7
Fuel Stack height	150.0	inches	381.0	cm		5.7
Mass of U	403.45	lb	183	kgm		5.7
Percent of Theoretical Density	95	%	95	%		5.7
Fuel clad OD	0.483	inches	1.2268	cm	0.6134	5.7
Clad thickness	0.032	inches	0.08128	cm		5.7
Fuel clad ID*	0.419	inches	1.0643	cm	0.53215	-
Fuel rod pitch	0.640	inches	1.6256	cm		5.7
Fuel assembly shroud thickness	0.10	inches	0.254	cm		5.8
Fuel assembly Shroud outside flat-to-flat	5.415	inches	13.7541	cm		5.8

* The inner diameters (IDs) above are calculated by subtracting twice the thickness from the outer diameter (OD).

4.2 Criteria

This design analysis provides the repository criticality control design criteria for UCF Waste Packages, based upon criteria from requirement documents. The criteria cited in requirement documents that have bearing on this analysis include:

From May 1995, Revision 01 of the MGDS-Requirements Document (RD)[5.9];
"**3.2.2.6 Criticality Protection**

A. All systems for processing, transporting, handling, storing, retrieving, emplacing, and isolating radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor (k_{eff}) must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the methods of calculation. [10CFR60.131(b)(7)]"

From September 21, 1994 Revision 00, ICN 1 of the Engineered Barrier Design (EBD)-RD[5.10];
"**3.2.2.6 CRITICALITY PROTECTION**

A. The Engineered Barrier Segment shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor must be sufficiently below unity to show at least a five percent margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the methods of calculation. [MGDS-RD 3.2.2.6.A][10CFR60.131(b)(7)]"

From September 21, 1994 Revision 00, ICN 1 of the Engineered Barrier Design (EBD)-RD[5.10];
"**3.7.1.3 INTERNAL STRUCTURE REQUIREMENTS**

A. The internal structure shall provide separation of the waste forms such that nuclear criticality shall not be possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. The calculated effective multiplication factor (k_{eff}) must be sufficiently below unity to show at least a five percent margin after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the methods of calculation (TBD). [MGDS-RD 3.2.2.6.A][10CFR60.131(b)(7)]"

4.3 Assumptions

All assumptions identified in this section will require verification (or superseding assumptions) as the waste package design proceeds and should be treated as TBV items for preliminary design. For Pre-title II design (conceptual or preliminary), assumptions are identified and documented, but they are not subject to MGDS NLP-3-15.

4.3.1 Burnup credit is an acceptable criticality control mechanism for the waste package. (CDA Key 009)[5.11]. This assumption is based up encouraging interactions with the NRC staff through the Burnup Credit Committee, chaired by DOE headquarters. This assumption is used throughout Section 7.

4.3.2 The waste package will be emplaced in-drift in a horizontal mode (CDA Key 011)[5.11]. This assumption is based on a current program decision. This assumption is used throughout Section 7.

4.3.3 The design of the 21 PWR assembly UCF waste package is based on preliminary drawings BBA000000-01717-2100-15057[5.12], sheets 1 thru 4 (TBV). These drawings serve as the primary design control for the waste packages in WPDD. This assumption is used in Section 7.4.1.

4.3.4 The design of the 12 PWR assembly UCF waste package is based on preliminary drawings BBA000000-01717-2100-15022[5.13], sheets 1 thru 4 (TBV). These drawings serve as the primary design control for the waste packages in WPDD. This assumption is used in Section 7.5.1.

4.3.5 The design of the 44 BWR assembly UCF waste package is based on preliminary drawings BBA000000-01717-2100-15050[5.14], sheets 1 thru 4 (TBV). These drawings serve as the primary design control for the waste packages in WPDD. This assumption is used in Section 7.4.2.

4.3.6 The design of the 24 BWR assembly UCF waste package is based on preliminary drawings BBA000000-01717-2100-15029[5.15], sheets 1 thru 4 (TBV). These drawings serve as the primary design control for the waste packages in WPDD. This assumption is used in Section 7.5.2.

4.3.4 For SNF, the list of "Principal Isotopes" for long-term criticality control previously established[5.16] was used. The 30 principal isotopes are shown in Table 4.3-1. This assumption is used throughout Section 7.

4.3.6 The reference BWR fuel assembly selected for conceptual UCF development is the GE 8x8 fuel type, which has been established as one of the more reactive BWR fuel designs under intact fuel assembly and fixed MPC geometry conditions[5.17]. This assumption is used in Sections 7.4.2 and 7.5.2.

4.3.7 The reference PWR fuel assembly selected for conceptual UCF development is the B&W 15 x 15 fuel type, which has been established as one of the more reactive PWR fuel designs under intact fuel assembly and fixed MPC geometry conditions[5.17]. This assumption is used in Sections 7.4.1 and 7.5.1.

4.3.8 The fueled length of the PWR assembly is modeled as 406.2 cm rather than the actual length of 360.172[5.6] cm to conservatively cover most of the SNF inventory. This assumption is used in Sections 7.4.1 and 7.5.1.

4.3.9 The fresh fuel bias and uncertainty for MCNP is approximately 0.015[5.18]. The preliminary SNF bias and uncertainty is approximately 0.06[5.18]. These uncertainties were used in a prior unverified analysis. This assumption is used throughout Section 7.

4.3.10 The non-fuel material compositions are taken from a separate materials composition analysis[5.19]. This analysis was performed to provide a single QA'ed reference for material compositions. This assumption is used throughout Section 7.

4.3.11 The design basis BWR SNF characteristics used are: 3.0% U-235 enrichment, 20 GWd/MTU burnup, as established by the M&O[5.20]. This assumption is used in Sections 7.4.2 and 7.5.2.

4.3.12 The BWR SNF material compositions as a function of time are taken from a separate composition analysis[5.21]. This analysis was performed to provide a single reference for BWR compositions to be used in all disposal packages. This assumption is used in Sections 7.4.2 and 7.5.2.

4.3.13 The design basis PWR SNF characterisitics used are: 3.0% U-235 enrichment, 20 GWd/MTU burnup, as established by the M&O[5.20]. This assumption is used in Sections 7.4.1 and 7.5.1.

4.3.14 The PWR SNF material compositions as a function of time are taken from a separate composition analysis[5.22]. This analysis was performed to provide a single QA'ed reference for PWR compositions to be used in all disposal packages. This assumption is used in Sections 7.4.1 and 7.5.1.

4.3.15 The BWR fuel assembly is modeled as an 8x8 array (64) of fuel pins. This assumption is a conservatism included in the calculation since 2 of the positions in the array are typically burnable absorber rods or water holes as indicated in Table 4.1.2-1. This assumption is used in Sections 7.4.2 and 7.5.2.

4.3.16 The UO_2 is modeled as 96% of theoretical density and no account of the pellet chamfer is taken resulting in an overprediction of the fuel mass in an assembly. This assumption is a conservatism included in the calculation. This assumption is used throughout Section 7.

4.3.17 The zinc weight percent contained in the aluminum 6063 material composition used in the MCNP models was transferred to the aluminum balance material in the composition due to the lack of cross-section data for zinc.

4.3.18 The borated stainless steel (316B6A) composition used in the MCNP model contained a 20 percent reduced boron fraction with respect to the referenced material composition. The weight percent of the boron isotopes in the 316B6A composition were reduced by 20 percent and the code was allowed to renormalize the remaining isotopes in the composition based on the engineering judgement that the renormalization effect was negligible.

4.3.19 The 44 and 24 BWR UCF WP radial dimensions are assumed to be the same as the 21 and 12 PWR UCF WP dimensions, respectively.

Table 4.3-1 Principal Long-Term Burnup Credit Isotopes

O-16	Mo-95	Ru-101	Tc-99	Rh-103
Ag-109	Nd-143	Nd-145	Sm-147	Sm-149
Sm-150	Sm-151	Sm-152	Eu-151	Eu-153
Gd-155	U-233	U-234	U-235	U-236
U-238	Np-237	Pu-238	Pu-239	Pu-240
Pu-241	Pu-242	Am-241	Am-242m	Am-243

4.4 Codes and Standards

Not Applicable.

5. References

5.1 *Yucca Mountain Site Characterization Project Waste Package Implementation Plan*, YMP/92-11Q, REV 1.

5.2 Not Used.

5.3 Not Used.

5.4 Not Used.

5.5 Briesmeister, Judith F., Ed., "MCNP- A General Monte Carlo Code for Neutron and Photon Transport," LANL, LA-7396-M, Rev. 2, April 1991.

5.6 *Preliminary Waste Form Characteristics Report Version 1.0*, UCRL-ID-108314 Rev. 1, LLNL, page 2.1.2.2-6, December, 1994.

5.7 *Characteristics of Potential Repository Wastes*, DOE/RW-0184-R1, Volume 1, OCRWM, US Department of Energy, page 2A-8, July, 1992.

5.8 Primm, R. T. III, et al., *Reference Spent Fuel Characteristics for Plutonium Disposition Reactors*, Rev. 1, ORNL/MD/LTR-17, Oak Ridge National Laboratory, page 4, April, 1995.

5.9 *Office of Civilian Radioactive Waste Management Mined Geological Disposal System Requirements Document*, DOE/RW-0404P, DI: B00000000-00811-1708-00002 REV 01 DCN01.

5.10 *Yucca Mountain Site Characterization Project Engineered Barrier Design Requirements Document*, YMP/CM-0024, Rev 0, ICN 1.

5.11 *Controlled Design Assumptions (CDA) Document*, DI#:B00000000-01717-4600-00032 REV 01, CRWMS M&O.

5.12 "Waste Package Tube Design (21-PWR)," DI#: BBA000000-01717-2100-15057 REV 0A, Sheets 1 - 4, CRWMS M&O.

5.13 "Waste Package Tube Design (12-PWR)," DI#: BBA000000-01717-2100-15022 REV 0A, Sheets 1 - 4, CRWMS M&O.

5.14 "Waste Package Tube Design (44-BWR)," DI#: BBA000000-01717-2100-15050 REV 0A, Sheets 1 - 4, CRWMS M&O.

5.15 "Waste Package Tube Design (24-BWR)," DI#: BBA000000-01717-2100-15029 REV 0A, Sheets 1 - 4, CRWMS M&O.

5.16 "Disposal Criticality Analysis Technical Report," B00000000-01717-5705-00020 Rev 00.

5.17 "Multi-Purpose Canister (MPC) Implementation Program Conceptual Design Phase Report, Volume II A - MPC Conceptual Design Report," DI# A20000000-00811-5705-00002 Final Draft, CRWMS M&O, Page II.A.3-35,September 1993.

5.18 *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design*, DI#:B00000000-01717-5705-00015 REV 00, CRWMS M&O, pages 6-241, 6-203.

5.19 Thomas, D. A., "Material Compositions and Number Densities for Neutronic Calculations," DI# BBA000000-01717-0200-00002 Rev 00, CRWMS M&O.

5.20 Gottlieb, P., "Waste Package Design Basis Fuel Analysis," DI# B0000000-01717-0200-00121 Rev 01 Draft, CRWMS M&O.

5.21 IOC from J. W. Davis, "Incomplete BWR Compositions Analysis," LV.WP.JWD.01/97-003, CRWMS M&O.

5.22 Davis, J. W., "SAS2H Generated Isotopic Concentrations for a B&W 15x15 PWR

Assembly," DI# BBA00000-01717-0200-00012 Rev 00, CRWMS M&O.

5.23 *Office of Civilian Radioactive Waste Management Topical Report on Actinide-Only Burnup Credit for PWR Spent Nuclear Fuel Packages*, DOE/RW-0472.

5.24 Davis, J. W., "21 PWR Assembly MPC Waste Package Criticality Analysis," DI# BBABB000-01717-0200-00004 Rev 00, CRWMS M&O.

5.25 *Carpenter Neutrosorb Plus and Neutrosorb Borated Stainless Steels*, Cartech, Carpenter Technology Corporation, 1993.

5.26 Records Package containing all the listed attachments on pages 36-56. in the RPC (BATCH NO. MOY-970327-03) JWD 3/31/97 HHB 3/31/97

6. Use of Computer Software

6.1 Scientific and Engineering Software

MCNP 4.2 CSCI B00000000-01717-1200-30006 Rev 0. Hewlett Packard Apollo 9000, Series 735 Workstations

MCNP 4.2[5.5] is an appropriate tool to be utilized to determine the criticality safety of fresh and spent lattices of PWR assemblies. This software has been validated and was previously obtained from the SCM in accordance with appropriate procedures. An associated continuous energy cross-section set based on ENDF/B-V is utilized by MCNP.

There are biases and uncertainties associated with a criticality calculation. How these biases and uncertainties are treated in criticality calculations is covered in the American National Standard on "Criticality Safety Criteria for the Handling, Storage, and Transportation of LWR Fuel Outside Reactors" (ANSI/ANS-8.17). The fresh fuel bias and uncertainty for MCNP is approximately 0.015[5.18]. The preliminary SNF bias and uncertainty is approximately 0.06[5.18]. The SNF bias and uncertainty is higher due to additional factors such as isotopics and axial effects.

7. Design Analysis

To better define the pre- and postclosure issues and the methodology for addressing them, a Three Phased Approach for disposal criticality control was developed. The three time phases associated with the approach are: the Preclosure/Operations Phase, the Postclosure/ Containment Phase, and the Postclosure/Isolation Phase. This analysis is performed for the Preclosure/Operations Phase and for time effects on isotopic composition for intact conditions. No criticality events external to the waste package or major internal geometry changes are evaluated.

7.1 Background

The UCF container is designed to contain and store SNF and/or non-fuel-bearing hardware delivered from nuclear reactor sites to the repository. Non-fuel-bearing hardware is not of criticality concern and, therefore, is not considered in this report. The UCF is intended to handle intact or damaged SNF from both PWR and BWR reactor types shipped to the MGDS repository in transportation casks that are not MPC type containers. In addition, the UCF will handle fuel shipped in MPC type containers which does not meet disposal requirements as packaged in the MPC. The current analysis is limited to intact SNF.

The design of the UCF disposal container is performed by the M&O WPD. The UCF disposal container has different basket designs to handle PWR and BWR SNF.

7.2 Design Details and Evaluation

UCF conceptual designs incorporate boron neutron absorbers in the form of borated stainless steel (316B6A) control panels in fuel baskets to provide a criticality control function. The use of the borated stainless steel provides the capability to adjust the neutron absorber concentrations over a wide range to allow for variations in burnup, or it may be decreased for a basket intended to hold low enrichment first core fuel assemblies. The borated stainless steel is also corrosion resistant, allowing credit to be taken for it in criticality analyses for long time frames.

For the current analysis, credit is taken for the inherent neutron absorption capability of fixed structural components within the UCF internal basket array. No credit is taken for irradiated control rods or burnable poisons. Calculations are run with and without boron in the stainless steel and with and without the stainless steel basket material to demonstrate the reactivity worth of the materials. The duration of time that less than 25% of the stainless and/or boron is leached/corroded away is undetermined, and these results will allow evaluation in either case.

The criticality evaluations have been performed for a design basis SNF at 3.00% U-235 enrichment and 20 GWd/MTU burnup, as established by the M&O[5.8] for both BWR and PWR SNF. The fuel isotopic burnup and decay compositions are taken from separate SAS2H analyses[5.21, 5.22]. The assembly axial and radial burnup variations and differential loading effects have not been accounted for in the models. These effects could be significant for the BWR models and will be investigated in detail in the future. They are currently assumed to be covered in the applied bias and uncertainty.

7.3 Modeling

Each fuel assembly is treated as a heterogeneous system with the fuel pins, control rod guide tubes, and instrument guide tube modeled explicitly. The model consists of an array of pins and tubes placed into an assembly configuration. A cross-sectional view of a B&W 15x15 PWR assembly and a GE 8x8 assembly are shown in Figures 7.3-1 and 7.3-2, respectively. An array of these assemblies including the UCF SS basket is then placed into the UCF configuration. One-quarter of the UCF disposal container is modeled laterally and the assemblies and container are modeled from the centerline up (reflected on the centerline) axially. The fuel end fittings, water gaps, UCF WP spacers, and canister lids are modeled axially. Axial and radial cross-sectional views are included for each UCF configuration in their respective sections.

The "normal" condition in the repository, both within and surrounding the WP, is a dry environment. When an insufficient amount of water is present, insufficient neutrons are thermalized (slowed down to thermal energy levels) to bring a system critical. Values of k_{eff} for unmoderated canisters do not represent a criticality safety concern, but are needed for shielding calculations to account for subcritical multiplication of the spontaneous fission neutrons and alpha-n reactions.

The "accident" condition considers the repository and waste package as being flooded with water. Under flooded conditions, further detailed criticality evaluations of the system must be performed to determine k_{eff}. A waste package fully flooded with cool (1 g/cc) water is the standard waste package criticality evaluation condition. This is the condition assumed for most evaluations in this report.

A water reflector (air for "normal" case) 30 cm thick was placed above and around the outer barrier of the disposal container. Approximately 30 cm of water will isolate a package from any interaction with others. Based on mean free paths of neutrons in water, the 30 cm thickness provides the equivalent of an infinite reflector.

The volume of fuel assemblies and basket structure within the UCF WPs was modeled as being centered in the inner barrier of the waste package. The thicknesses of the gap between the inner and outer barrier lids were 0.5 cm for the 21 PWR UCF WP and 1.5 cm for the 12 PWR, 44 BWR, and 24 BWR UCF WPs.

7.4 Large UCF Calculations

This section provides the results of the analyses for PWR and BWR configurations. The 21 assembly PWR design requires both burnup credit and 316B6A control panels to meet acceptance criteria. The 44 assembly BWR design does meet acceptance criteria with burnup credit and 316B6A with a very low boron loading. The BWR design also meets acceptance criteria with control panels alone (no burnup credit). The time period in which credit for the control panels can be taken must be defined.

7.4.1 21 Assembly PWR

The 21 PWR fuel assembly basket is formed by 21 tubes stacked in an irregular array on a nominal 23.35-cm (9.19 inches) center-to-center spacing. The fuel cell opening provided is 22.35 cm (8.80 inches). The fuel cell tubes are formed from 0.5-cm (0.20-inch) thick borated stainless steel plates (316B6A). The assembly array is interrupted by 4 aluminum thermal shunts 1.0 cm (0.39 inches) thick running on all 4 sides of the central assembly position across the inner diameter of the inner barrier (cruciform pattern). Checking of this analysis revealed that the iron weight percent of 60.245 in the SS316 (316B6A) material composition should have been input as 60.445 weight percent. Based on engineering judgement the effect of the reduced iron weight percent on the calculation is negligible.

The cross-sectional view in the X-Y plane (radial view) of the physical MCNP model for the intact geometry was generated with the MCNP plotting capability and is shown in Figure 7.4.1-1. The cross-sectional view in the X-Y plane of the physical MCNP model for the collapsed geometry is shown in Figure 7.4.1-2. An axial view of the intact geometry model is shown in Figure 7.4.1-3.

7.4.1.1 Standard Evaluation

Calculations were performed for intact and collapsed geometries, with and without boron in the stainless steel, for the fresh and design basis SNF (3.00% U-235 Enrichment, 20 GWd/MTU) at five years decay. The k_{eff} ($\pm 2\sigma$) values calculated for the different cases are listed below. The combined average value of k_{eff} of the three estimates, as listed in the final generation summary in the MCNP output, is reported in this document.

Design Basis SNF, Intact, No Boron	-	1.0086 ± .0034
Fresh Fuel, Intact, No Boron	-	1.1907 ± .0029
Design Basis SNF, Intact, With Boron	-	0.8730 ± .0037
Fresh Fuel, Intact, With Boron	-	1.0245 ± .0041
Design Basis SNF, Collapsed, No Boron	-	1.0180 ± .0037
Fresh Fuel, Collapsed, No Boron	-	1.2081 ± .0029
Design Basis SNF, Collapsed, With Boron	-	0.8784 ± .0033
Fresh Fuel, Collapsed, With Boron	-	1.0231 ± .0043

The burnup credit reactivity worth { $(k_2 - k_1) / (k_1 * k_2)$ } is shown below for the four sets of cases along with the reactivity worth for comparisons between sets with the design basis SNF.

Intact, No Boron	-	-0.152 ± .004
Intact, With Boron	-	-0.169 ± .006
Collapsed, No Boron	-	-0.155 ± .004
Collapsed, With Boron	-	-0.161 ± .006

Intact, Boron vs. No Boron	-	-0.154 ± .006
Collapsed vs. Intact, No Boron	-	0.009 ± .005
Collapsed vs. Intact, With Boron	-	0.007 ± .006
Collapsed, Boron vs. No Boron	-	-0.156 ± .006

Note that both boron and burnup credit are required in order to meet limits. With biases applied, (0.06) the two cases with boron and burnup credit narrowly meet the 0.95 value limit established in 10 CFR 60.131(b)(7). Burnup credit appears to be slightly enhanced with the addition of boron. The boron worth for the intact and the collapsed cases is the same within the 95% confidence interval (±2σ). The worth of collapsing the array is the same within the 95% confidence interval whether or not boron is present.

To demonstrate the effect of fission products, two additional calculations were run corresponding to the intact, design basis SNF cases with and without boron for only actinides. The k_{eff} values for the Actinides Only cases are 1.0707 ± .0039 and 0.9274 ± .0045 for the no boron and boron cases, respectively. The corresponding reactivity worths for the Actinides Only cases are 0.058 ± .005 and 0.067 ± .007. To demonstrate the conservatism of the Actinide-Only Burnup Credit approach[5.23], two additional calculations were run with f_{BUC}'s applied. The k_{eff} values for the Actinides Only cases with f_{BUC}'s applied are 1.0996 ± .0046 and 0.9545 ± .0040 for the no boron and boron cases, respectively. The corresponding reactivity worths for the Actinides Only cases with f_{BUC}'s applied are 0.082 ± .005 and 0.098 ± .007.

Changes were made to the assumptions used and the calculation of isotopics between the MPC[5.24] analysis and the UCF analysis. To indicate the reactivity change due to altering the isotopes included in the "Principal Isotopes" list (by using SAS2H rather than the CDB to provide isotopics and including the KIDMAN fission product isotopes) an intact, no boron case was run using the approach indicated in the MPC analysis[5.24]. The k_{eff} value for this case is 1.0096 ± .0036, and the corresponding reactivity worth of the changes is less than the standard deviation in the results.

A minor error was found in the model after most of the calculations were completed. This error involved dimensioning the thickness of the A516 outer barrier lid as 1 cm rather than the correct 11 cm. This axial dimension is not significant to the criticality calculations performed in this analysis, but would have affected shielding calculations performed using this model. A corrected case was run corresponding to the design basis SNF, intact geometry, with no boron providing a k_{eff} value of 1.0079 ± .0044, which is the same value calculated previously within the standard deviation of the results.

7.4.1.2 Moderator Density Effects

The reactivity effect of reducing the moderator density was investigated by running a series of cases and plotting the results. The intact, unborated stainless steel basket case was used as a base and 10 cases were run with water densities ranging between 98% and 0%. The curve generated from these cases is shown in Figure 7.4.1.2-1. The values used to generate the curve are $k_{eff} + 2\sigma$. The k_{eff} is shown to drop with the moderator density. In order to demonstrate that borated stainless steel or collapsing of the array have no effect on this trend, the 98%, 95%, and 0% cases were repeated for the intact, borated case and the borated and unborated collapsed cases. The results are shown on the same curve and are identified on the legend. The k_{eff} ($\pm 2\sigma$) values calculated for the different cases are listed below. The 100% moderator density cases presented in the previous section were also plotted in Figure 7.4.1.2-1.

Design Basis SNF, Intact, No Boron, 98% Density	-	1.0044 ± .0034
Design Basis SNF, Intact, No Boron, 95% Density	-	0.9959 ± .0044
Design Basis SNF, Intact, No Boron, 90% Density	-	0.9870 ± .0055
Design Basis SNF, Intact, No Boron, 80% Density	-	0.9705 ± .0056
Design Basis SNF, Intact, No Boron, 60% Density	-	0.9115 ± .0042
Design Basis SNF, Intact, No Boron, 40% Density	-	0.8119 ± .0039
Design Basis SNF, Intact, No Boron, 20% Density	-	0.6332 ± .0051
Design Basis SNF, Intact, No Boron, 10% Density	-	0.4996 ± .0028
Design Basis SNF, Intact, No Boron, 5% Density	-	0.4100 ± .0030
Design Basis SNF, Intact, No Boron, 1% Density	-	0.3193 ± .0024
Design Basis SNF, Intact, No Boron, 0% Density	-	0.2934 ± .0017
Design Basis SNF, Intact, With Boron, 98% Density	-	0.8674 ± .0045
Design Basis SNF, Intact, With Boron, 95% Density	-	0.8597 ± .0034
Design Basis SNF, Intact, With Boron, 0% Density	-	0.2813 ± .0015
Design Basis SNF, Collapsed, No Boron, 98% Density	-	1.0152 ± .0030
Design Basis SNF, Collapsed, No Boron, 95% Density	-	1.0085 ± .0042
Design Basis SNF, Collapsed, No Boron, 0% Density	-	0.2975 ± .0014
Design Basis SNF, Collapsed, With Boron, 98% Density	-	0.8758 ± .0040
Design Basis SNF, Collapsed, With Boron, 95% Density	-	0.8647 ± .0052
Design Basis SNF, Collapsed, With Boron, 0% Density	-	0.2862 ± .0016

7.4.1.3 Time Effects

The long-term time effects on the criticality potential of SNF in a WP are a criticality concern unique to the MGDS. To calculate the time effect on criticality, isotopic composition information at different time steps was required. The required isotopic compositions for the fuel characteristics at 27 selected decay times were generated using the SAS2H sequence of SCALE4.2[5.22]. Output of the isotopic composition of the fuel at the 27 times were then used to generate number densities that were entered into MCNP model input files. Each time step for the fuel characteristics represents an MCNP model input file. The results from the MCNP runs are consolidated to form a plot of the change in the criticality of the UCF WP (k_{eff}) over time. The results ($k_{eff} + 2\sigma$) are shown in Figures 7.4.1.3-1, -2, -3 and -4 for the 3.00% U-235 Enrichment, 20 GWd/MTU design basis fuel in the different models, as indicated in the titles. The k_{eff} ($\pm 2\sigma$) values calculated for the different cases are listed below in Table 7.4.1.3-1.

Each of the four curves generated have the same basic behavior. For the first ~200 years after discharge, the criticality potential of SNF decreases as the Pu-241 (13.2-year half-life) fissile material decays. From ~200 years to ~10,000 - 20,000 years, the criticality potential of the SNF increases as Pu-240 (6,580-year half-life) and the medium half-life neutron absorbers decay. After the ~20,000-year local peak, the criticality potential of the SNF decreases again as the Pu-239 (24,400-year half-life) fissile material decays. In all cases the reactivity at 5 years decay is conservatively higher than the reactivity at all later times.

Table 7.4.1.3-1 Time Effects k_{eff} ($\pm 2\sigma$) Values for 21 PWR Assembly UCF WP in Different Configurations.

TIME (Years)	Intact No B	Intact With B	Collapsed No B	Collapsed With B
1	1.0211 ± .0039	0.8844 ± .0051	1.0372 ± .0035	0.8907 ± .0048
5	1.0086 ± .0034	0.8730 ± .0037	1.0180 ± .0037	0.8784 ± .0033
10	0.9947 ± .0042	0.8625 ± .0040	1.0047 ± .0028	0.8646 ± .0031
20	0.9767 ± .0033	0.8469 ± .0029	0.9914 ± .0034	0.8515 ± .0041
50	0.9616 ± .0031	0.8299 ± .0038	0.9768 ± .0031	0.8397 ± .0040
100	0.9602 ± .0033	0.8269 ± .0038	0.9700 ± .0041	0.8338 ± .0038
200	0.9613 ± .0027	0.8347 ± .0037	0.9694 ± .0037	0.8353 ± .0032
300	0.9606 ± .0033	0.8348 ± .0032	0.9711 ± .0031	0.8417 ± .0035
400	0.9673 ± .0037	0.8401 ± .0039	0.9733 ± .0033	0.8397 ± .0044
500	0.9646 ± .0039	0.8380 ± .0035	0.9787 ± .0041	0.8447 ± .0037
1000	0.9730 ± .0027	0.8381 ± .0032	0.9839 ± .0043	0.8483 ± .0034
4000	0.9775 ± .0035	0.8455± .0041	0.9934 ± .0036	0.8527 ± .0039

TIME (Years)	Intact No B	Intact With B	Collapsed No B	Collapsed With B
8000	0.9888 ± .0030	0.8548 ± .0034	0.9966 ± .0032	0.8556 ± .0043
10000	0.9849 ± .0045	0.8521 ± .0032	0.9965 ± .0042	0.8565 ± .0043
14000	0.9903 ± .0032	0.8546 ± .0036	1.0000 ± .0036	0.8557 ± .0046
18000	0.9902 ± .0034	0.8482 ± .0042	0.9988 ± .0036	0.8583 ± .0036
22000	0.9844 ± .0037	0.8505 ± .0037	1.0009 ± .0034	0.8526 ± .0032
26000	0.9834 ± .0035	0.8485 ± .0031	0.9980 ± .0040	0.8535 ± .0044
30000	0.9851 ± .0032	0.8484 ± .0037	0.9964 ± .0032	0.8496 ± .0036
36000	0.9794 ± .0033	0.8430 ± .0034	0.9935 ± .0032	0.8426 ± .0042
45000	0.9715 ± .0031	0.8389 ± .0035	0.9854 ± .0032	0.8389 ± .0034
60000	0.9640 ± .0033	0.8276 ± .0043	0.9786 ± .0027	0.8296 ± .0040
70000	0.9603 ± .0038	0.8263 ± .0043	0.9763 ± .0037	0.8293 ± .0032
100000	0.9543 ± .0034	0.8222 ± .0041	0.9696 ± .0031	0.8202 ± .0034
250000	0.9545 ± .0038	0.8171 ± .0047	0.9649 ± .0031	0.8188 ± .0033
500000	0.9536 ± .0027	0.8206 ± .0034	0.9692 ± .0031	0.8210 ± .0044
999999	0.9555 ± .0029	0.8182 ± .0049	0.9720 ± .0035	0.8212 ± .0036

7.4.1.4 Control Panel Loading

The stainless steel base used for fabrication of the baskets can contain up to 2.25 percent boron by weight in the stainless steel 316B (SS-B) material[5.25]. To retain near peak mechanical properties, boron contents ≤ 1.75 weight percent are preferred. This corresponds to a 316B6A grade with a nominal boron weight percent of 1.6.

Without long-term material tests to confirm the removal rate of boron, some initial engineering estimates have been made for the loss rate of B-10[5.18]. These evaluations indicate that ~20 percent of the B-10 could be removed from the 316B6A over the 10,000 years of disposal isolation. Based on this estimate and the materials considerations listed above, the previous calculations which contained 316B6A were performed with a nominal 1.6 weight percent loading minus 20% of the boron.

In order to demonstrate the effect of changing the boron loading in the 316B6A, a series of calculations were performed varying the loading from 0.4 to 2.0 percent of natural boron using the intact array model. The curve generated from these results ($k_{eff} + 2\sigma$) is shown in Figure 7.4.1.4-1. The concentration indicated on the x-axis is the actual loading; these concentrations have not been reduced by the 20% loss factor for 10,000 years. The k_{eff} ($\pm 2\sigma$) values calculated for the different cases are listed below. Checking of the analysis revealed that the iron weight percent in the SS316 (316B4A) material of the 1.0 percent natural boron loaded case (input filename: ucb21b3; corresponding attachment: CXXXVIII) should have been 60.045 weight percent instead of 60.445 weight percent as input. Based on engineering judgement the effect of the increased iron weight percent on the calculation results is negligible.

The change in reactivity which can be determined from this curve would be equally applicable to the collapsed array cases, as indicated by the results presented in section 7.4.1.1. Based on this curve, approximately 1.2 weight percent natural boron is required in the stainless steel basket material for the collapsed array model to meet the 0.95 limit when the bias and uncertainty is applied. This indicates that a minimum initial boron loading of 1.5 weight percent is required for the 21 PWR assembly UCF waste package when the 20 percent loss margin is applied. Note that this analysis was performed for an intact 0.5 cm tube thickness (1 cm 316B6A between assemblies). Future analysis will need to account for loss of the stainless steel as well as the boron.

Design Basis SNF, Intact, 0.4 wt% B	-	0.9213 ± .0046
Design Basis SNF, Intact, 0.87 wt% B	-	0.8874 ± .0051
Design Basis SNF, Intact, 1.0 wt% B	-	0.8833 ± .0035
Design Basis SNF, Intact, 1.2 wt% B	-	0.8755 ± .0042
Design Basis SNF, Intact, 1.6 wt% B	-	0.8655 ± .0040
Design Basis SNF, Intact, 2.0 wt% B	-	0.8560 ± .0033

7.4.2 44 Assembly BWR

The 44 BWR fuel assembly basket is formed by 11 tubes stacked in a square array in each quarter of the waste package on a nominal 16.00-cm (6.30 inches) center-to-center spacing. The array is interrupted along the center line on the X and Y axes by an aluminum thermal shunt 2.0 cm (0.79 inches) thick. The fuel cell opening provided is 15.3 cm (6.02 inches). The fuel cell tubes are formed from 0.35-cm (0.14-inch) thick borated stainless steel plates (316B6A). Checking of this analysis revealed that the iron weight percent of 64.545 in the SS316L material composition should have been input as 65.545 weight percent. Based on engineering judgement the effect of the reduced iron weight percent on the calculation is negligible.

The cross-sectional view in the X-Y plane of the physical MCNP model was generated with the MCNP plotting capability and is shown in Figure 7.4.2-1. The cross-sectional view in the X-Y plane of the physical MCNP model for the collapsed geometry is shown in Figure 7.4.2-2. An axial view of the intact geometry model is shown in Figure 7.4.2-3.

The assembly axial and radial burnup variations and differential loading effects have not been accounted for in the models. These effects could be significant for the BWR models and will be thoroughly investigated in the future.

7.4.2.1 Standard Evaluation

Calculations were performed for intact and collapsed geometries, with and without boron in the stainless steel, for the fresh fuel and design basis SNF (3.00% U-235 Enrichment, 20 GWd/MTU) at five years decay. The k_{eff} ($\pm 2\sigma$) values calculated for the different cases are as follow:

Design Basis SNF, Intact, No Boron	-	0.8622 ± .0033
Fresh Fuel, Intact, No Boron	-	1.0575 ± .0032
Design Basis SNF, Intact, With Boron	-	0.6774 ± .0039
Fresh Fuel, Intact, With Boron	-	0.8335 ± .0048
Design Basis SNF, Collapsed, No Boron	-	0.9114 ± .0024
Fresh Fuel, Collapsed, No Boron	-	1.1273 ± .0038
Design Basis SNF, Collapsed, With Boron	-	0.6895 ± .0043
Fresh Fuel, Collapsed, With Boron	-	0.8582 ± .0043

The burnup credit reactivity worth { $(k_2 - k_1) / (k_1 * k_2)$ } is shown below for the four sets of cases along with the reactivity worth for comparisons between sets with the design basis SNF.

Intact, No Boron	-	-0.214 ± .005
Intact, With Boron	-	-0.276 ± .011
Collapsed, No Boron	-	-0.210 ± .004
Collapsed, With Boron	-	-0.285 ± .011

Intact, Boron vs. No Boron	-	-0.316 ± .010
Collapsed vs. Intact, No Boron	-	0.063 ± .005
Collapsed vs. Intact, With Boron	-	0.026 ± .012
Collapsed, Boron vs. No Boron	-	-0.353 ± .009

Note that some boron credit is required with burnup credit in order to meet limits for the collapsed arrays but only one or the other is required for intact arrays. Burnup credit is not required with full boron credit in either the intact or collapsed arrays. With biases applied, (0.06) the two cases with boron and burnup credit meet the 0.95 value limit established in 10 CFR 60.131(b)(7) by a significant margin. Burnup credit appears to be slightly enhanced with the addition of boron. Collapsing the array appears to slightly enhance the effectiveness of the boron. The worth of collapsing the array appears to be reduced by 50% with boron present and burnup credit.

The change in reactivity in going from the 21 PWR assembly to the 44 BWR assembly design for each of the four models with the design basis fuel (DBF) is indicated below.

Intact, No Boron	-	-0.168 ± .006
Intact, With Boron	-	-0.331 ± .010
Collapsed, No Boron	-	-0.115 ± .005
Collapsed, With Boron	-	-0.312 ± .010

To demonstrate the effect of fission products, two additional calculations were run corresponding to the intact, design basis SNF cases with and without boron for only actinides. The k_{eff} values for the Actinides Only cases are 0.9139 ± .0035 and 0.7122 ± .0034 for the no boron and boron cases, respectively. The corresponding reactivity values for the Actinides Only cases are 0.066 ± .006 and 0.072 ± .011.

The assembly shroud (Zircaloy-2) was included in the models. The reactivity effect of the shrouds was investigated by running a set of additional cases for the DBF at 5 years decay with the shrouds replaced by water. For the collapsed models with and without boron, an additional case was run in which the basket was collapsed into the space which would normally be occupied by the shroud. The results for each of these cases is indicated below. Within the 95% confidence interval of the data, the results are essentially the same except for the intact, no boron case. The most significant difference is between the intact, no boron cases where the change in reactivity is approximately -1.5%.

Intact, No Boron	-	0.8509 ± .0031
Intact, With Boron	-	0.6753 ± .0034
Collapsed, No Boron	-	0.9103 ± .0027
Collapsed, With Boron	-	0.6950 ± .0039
Collapsed, No Boron, extra collapse	-	0.9134 ± .0026
Collapsed, With Boron,extra collapse	-	0.6905 ± .0044

7.4.2.2 Moderator Density Effects

The reactivity effect of reducing the moderator density was investigated by running a series of cases and plotting the results. The intact, unborated stainless steel basket case was used as a base and 10 cases were run with water densities ranging between 98% and 0%. The curve generated from these cases is shown in Figure 7.4.2.2-1. The values used to generate the curve are $k_{eff} + 2\sigma$. The k_{eff} is shown to drop with the moderator density. In order to demonstrate that borated stainless steel or collapsing of the array have no effect on this trend, the 98%, 95%, and 0% cases were repeated for the intact, borated case and the borated and unborated collapsed cases. The results are shown on the same curve and are identified on the legend. The k_{eff} ($\pm 2\sigma$) values calculated for the different cases are listed below. The 100% moderator density cases presented in the previous section were also plotted in Figure 7.4.2.2-1.

Design Basis SNF, Intact, No Boron, 98% Density	-	0.8576 ± .0033
Design Basis SNF, Intact, No Boron, 95% Density	-	0.8541 ± .0043
Design Basis SNF, Intact, No Boron, 90% Density	-	0.8551 ± .0032
Design Basis SNF, Intact, No Boron, 80% Density	-	0.8436 ± .0035
Design Basis SNF, Intact, No Boron, 60% Density	-	0.8092 ± .0029
Design Basis SNF, Intact, No Boron, 40% Density	-	0.7424 ± .0034
Design Basis SNF, Intact, No Boron, 20% Density	-	0.6029 ± .0025
Design Basis SNF, Intact, No Boron, 10% Density	-	0.4695 ± .0022
Design Basis SNF, Intact, No Boron, 5% Density	-	0.3746 ± .0024
Design Basis SNF, Intact, No Boron, 1% Density	-	0.2904 ± .0013
Design Basis SNF, Intact, No Boron, 0% Density	-	0.2749 ± .0013

Design Basis SNF, Intact, With Boron, 98% Density	-	0.6693 ± .0033
Design Basis SNF, Intact, With Boron, 95% Density	-	0.6660 ± .0040
Design Basis SNF, Intact, With Boron, 0% Density	-	0.2575 ± .0012
Design Basis SNF, Collapsed, No Boron, 98% Density	-	0.9091 ± .0038
Design Basis SNF, Collapsed, No Boron, 95% Density	-	0.9030 ± .0031
Design Basis SNF, Collapsed, No Boron, 0% Density	-	0.2854 ± .0011
Design Basis SNF, Collapsed, With Boron, 98% Density	-	0.6867 ± .0041
Design Basis SNF, Collapsed, With Boron, 95% Density	-	0.6803 ± .0038
Design Basis SNF, Collapsed, With Boron, 0% Density	-	0.2689 ± .0013

7.4.2.3 Time Effects

The long-term time effects for the design basis BWR fuel are similar to those described in Section 7.4.1.3 for the 21 PWR assembly UCF WP. The design basis U-235 enrichments and burnup are essentially the same, and only neutron spectrum effects will contribute to differences, producing slightly higher plutonium inventories in the BWR. The required isotopic compositions for the fuel characteristics at 27 selected decay times were generated using the SAS2H sequence of SCALE4.2[5.21] and used in MCNP cases to generate the results. The results ($k_{eff} + 2\sigma$) are shown in Figures 7.4.2.3-1, -2, -3, and -4 for the 3.00% U-235 Enrichment, 20 GWd/MTU design basis fuel in the different models, as indicated in the titles. The k_{eff} ($\pm 2\sigma$) values calculated for the different cases are listed in Table 7.4.2.3-1.

Each of the four curves generated have the same basic behavior. For the first ~200 years after discharge, the criticality potential of SNF decreases as the Pu-241 (13.2-year half-life) fissile material decays. From ~200 years to ~10,000 years, the criticality potential of the SNF increases as Pu-240 (6,580-year half-life) and the medium half-life neutron absorbers decay. After the ~10,000-year local peak, the criticality potential of the SNF decreases again as the Pu-239 (24,400-year half-life) fissile material decays. In all cases the reactivity at 5 years decay is conservatively higher than the reactivity at all later times. The curves, in general, follow the trends identified for the 21 assembly PWR design with the exceptions of a narrower, slightly earlier, secondary peak and a slight rise in k_{eff} from 100,000 year out to 1,000,000 years. The troughs in the BWR curve are not as pronounced as those in the PWR curve. The BWR local peaks are slightly closer to the 5 year decay value than those for the PWR design.

Table 7.4.2.3-1 Time Effects k_{eff} ($\pm 2\sigma$) Values for 44 BWR Assembly UCF WP in Different Configurations.

TIME (Years)	Intact No B	Intact With B	Collapsed No B	Collapsed With B
1	0.8735 ± .0040	0.6851 ± .0033	0.9206 ± .0035	0.7029 ± .0045
5	0.8622 ± .0033	0.6774 ± .0039	0.9114 ± .0024	0.6895 ± .0043
10	0.8503 ± .0037	0.6694 ± .0032	0.8983 ± .0043	0.6861 ± .0033
20	0.8355 ± .0035	0.6565 ± .0033	0.8817 ± .0028	0.6708 ± .0036
50	0.8269 ± .0031	0.6476 ± .0034	0.8773 ± .0033	0.6640 ± .0035
100	0.8214 ± .0036	0.6423 ± .0045	0.8739 ± .0047	0.6637 ± .0035
200	0.8251 ± .0030	0.6481 ± .0035	0.8712 ± .0035	0.6666 ± .0037
300	0.8290 ± .0043	0.6509 ± .0039	0.8789 ± .0035	0.6650 ± .0033
400	0.8292 ± .0035	0.6538 ± .0038	0.8769 ± .0028	0.6656 ± .0043
500	0.8373 ± .0037	0.6565 ± .0038	0.8808 ± .0032	0.6667 ± .0029
1000	0.8348 ± .0033	0.6630 ± .0037	0.8857 ± .0037	0.6690 ± .0036
4000	0.8434 ± .0032	0.6589 ± .0040	0.8874 ± .0037	0.6760 ± .0035
8000	0.8429 ± .0037	0.6609 ± .0041	0.8937 ± .0034	0.6762 ± .0041
10000	0.8463 ± .0032	0.6584 ± .0038	0.8920 ± .0032	0.6760 ± .0039
14000	0.8444 ± .0025	0.6615 ± .0036	0.8959 ± .0022	0.6698 ± .0025
18000	0.8377 ± .0034	0.6536 ± .0029	0.8910 ± .0039	0.6645 ± .0035
22000	0.8326 ± .0027	0.6494 ± .0044	0.8895 ± .0041	0.6620 ± .0032
26000	0.8319 ± .0042	0.6490 ± .0038	0.8860 ± .0032	0.6601 ± .0038
30000	0.8314 ± .0035	0.6466 ± .0038	0.8834 ± .0044	0.6589 ± .0028
36000	0.8256 ± .0036	0.6433 ± .0031	0.8801 ± .0028	0.6536 ± .0031
45000	0.8140 ± .0037	0.6331 ± .0051	0.8677 ± .0026	0.6474 ± .0040
60000	0.8106 ± .0041	0.6327 ± .0034	0.8657 ± .0029	0.6418 ± .0030

TIME (Years)	Intact No B	Intact With B	Collapsed No B	Collapsed With B
70000	0.8106 ± .0041	0.6301 ± .0038	0.8637 ± .0036	0.6400 ± .0035
100000	0.8122 ± .0036	0.6289 ± .0028	0.8654 ± .0028	0.6385 ± .0041
250000	0.8108 ± .0032	0.6294 ± .0039	0.8663 ± .0035	0.6398 ± .0031
500000	0.8151 ± .0034	0.6330 ± .0030	0.8673 ± .0031	0.6421 ± .0036
999999	0.8143 ± .0036	0.6337 ± .0037	0.8670 ± .0035	0.6440 ± .0031

7.4.2.4 Control Panel Loading

In order to demonstrate the effect of changing the boron loading in the 316B6A, a series of calculations were performed varying the loading from 0.4 to 2.0 percent of natural boron using the intact array model with DBF. The curve generated from these results ($k_{eff} + 2\sigma$) is shown in Figure 7.4.2.4-1. The concentration indicated on the x-axis is the actual loading; these concentrations have not been reduced by the 20% loss factor for 10,000 years. The k_{eff} ($\pm 2\sigma$) values calculated for the different cases are listed below. The change in reactivity which can be determined from this curve would be equally applicable to the collapsed array cases, as indicated by the results presented in section 7.4.2.1. Based on this curve, approximately 0.08 weight percent boron is required in the stainless steel basket material for the collapsed array model with DBF to meet the 0.95 limit when the bias and uncertainty is applied. This indicates that a minimum initial loading of 0.10 weight percent is required for the 44 BWR assembly UCF waste package when the 20 percent loss margin is applied. The 0.10 weight percent boron is less than 10% of that required for the 21 PWR design.

Design Basis SNF, Intact, 0.4 wt% B	-	0.7353 ± .0034
Design Basis SNF, Intact, 0.87 wt% B	-	0.6965 ± .0042
Design Basis SNF, Intact, 1.0 wt% B	-	0.6878 ± .0033
Design Basis SNF, Intact, 1.2 wt% B	-	0.6794 ± .0039
Design Basis SNF, Intact, 1.6 wt% B	-	0.6653 ± .0037
Design Basis SNF, Intact, 2.0 wt% B	-	0.6521 ± .0040

Checking of the analysis revealed that the iron weight percent in the SS316 (316B4A) material of the 1.0 percent natural boron loaded case (input filename: ucb44b3; corresponding attachment: CCXC) should have been 60.045 weight percent instead of 60.445 weight percent as input. Based on engineering judgement the effect of the increased iron weight percent on the calculation results is negligible.

7.5 Small UCF Calculations

This section provides the results of the analyses for PWR and BWR configurations. The calculations performed for the small UCF designs are a subset of those for the large designs. The basket arrays and materials are the same between large and small design, so the size of the package is the most significant effect. Changes to parameters such as boron loading in the basket, control rods, moderator density, or burnup credit would cause a similar change in reactivity in both the large and small packages.

The 12 assembly PWR design does meet acceptance criteria without additional criticality control measures beyond burnup credit and 316B6A control panels. The 24 assembly BWR design, like the 44 assembly BWR design, meets acceptance criteria with control panels alone. Boron loading in the stainless steel control panels is not required to supplement burnup credit in order to meet acceptance criteria for the 24 BWR design. The reactivity worth in going from the large to the small package is approximately 4% and 5% for the PWR and BWR packages, respectively.

7.5.1 12 Assembly PWR

The 12 PWR fuel assembly basket is formed by 3 tubes stacked in a square array in each quarter of the waste package on a nominal 23.35-cm (9.19 inches) center-to-center spacing. The array is interrupted along the centerline on the X and Y axes by an aluminum thermal shunt 1.0 cm (0.39 inches) thick. Checking of this analysis revealed that the aluminum thermal shunt was modeled as 2.0 cm thick instead of 1.0 cm thick. Based on engineering judgement the extra thickness of the aluminum thermal shunt does not significantly effect the results of the calculation. The fuel cell opening provided is 22.35 cm (8.80 inches). The fuel cell tubes are formed from 0.5-cm (0.20 inch) thick borated stainless steel plates (316B6A). Checking of this analysis revealed that the iron weight percent of 60.245 in the SS316 (316B6A) material composition should have been input as 60.445 weight percent. Based on engineering judgement the effect of the reduced iron weight percent on the calculation is negligible.

The cross-sectional view in the X-Y plane of the physical MCNP model for the 12 assembly PWR UCF waste package was generated with the MCNP plotting capability and is shown in Figure 7.5.1-1. The cross-sectional view in the X-Y plane of the physical MCNP model for the collapsed geometry is shown in Figure 7.5.1-2. An axial view of the intact geometry model is shown in Figure 7.5.1-3.

7.5.1.1 Standard Evaluation

Calculations were performed for intact and collapsed geometries, with and without boron in the stainless steel, for the design basis SNF (3.00% U-235 Enrichment, 20 GWd/MTU) at five years decay. The k_{eff} ($\pm 2\sigma$) values calculated for the different cases are as follow:

Design Basis SNF, Intact, No Boron	-	0.9706 ± .0037
Design Basis SNF, Intact, With Boron	-	0.8513 ± .0048
Design Basis SNF, Collapsed, No Boron	-	0.9828 ± .0039
Design Basis SNF, Collapsed, With Boron	-	0.8488 ± .0056

The reactivity worth { $(k_2 - k_1) / (k_1 * k_2)$ } for comparisons between sets is shown below.

Intact, Boron vs. No Boron	-	-0.144 ± .008
Collapsed vs. Intact, No Boron	-	0.013 ± .006
Collapsed vs. Intact, With Boron	-	0.003 ± .010
Collapsed, Boron vs. No Boron	-	-0.161 ± .009

With biases applied (0.06), the two cases with boron and burnup credit meet the 0.95 value limit established in 10 CFR 60.131(b)(7) by a significant margin. The boron worth for the intact and the collapsed cases is the same within the 95% confidence interval ($\pm 2\sigma$). The worth of collapsing the array is approximately the same whether or not boron is present. The reactivity worths indicated above are consistent with those presented for the 21 assembly PWR UCF waste package. The change in reactivity in going from the 21 assembly to the 12 assembly design for each of the four models is indicated in the values listed below.

Intact, No Boron	-	-0.039 ± .005
Intact, With Boron	-	-0.029 ± .008
Collapsed, No Boron	-	-0.035 ± .005
Collapsed, With Boron	-	-0.040 ± .009

7.5.1.2 Moderator Density Effects

The reactivity effect of reducing the moderator density was investigated for the 21 assembly UCF waste package in section 7.4.1.2. The results are applicable to the small package as well.

7.5.1.3 Time Effects

The required isotopic compositions for the fuel characteristics at 16 selected decay times were obtained from the same SAS2H calculations[5.22] used for the 21 assembly waste package analysis and were used in MCNP cases to generate the results. The results (k_{eff} + 2σ) are shown in Figures 7.5.1.3-1, -2, -3, and -4 for the 3.00% U-235 Enrichment, 20 GWd/MTU design basis fuel in the different models, as indicated in the titles. These curves are smoother than those presented for the 21 PWR assembly UCF design because fewer decay times were used for the 12 assembly design. The purpose of these curves is to demonstrate the same basic behavior shown for the larger UCF design. The k_{eff} (±2σ) values calculated for the different cases are listed below in Table 7.5.1.3-1.

Each of the four curves generated have the same basic behavior. For the first ~200 years after discharge, the criticality potential of SNF decreases as the Pu-241 (13.2-year half-life) fissile material decays. From ~200 years to ~10,000 - 20,000 years, the criticality potential of the SNF increases as Pu-240 (6,580-year half-life) and the medium half-life neutron absorbers decay. After the ~20,000-year local peak, the criticality potential of the SNF decreases again as the Pu-239 (24,400-year half-life) fissile material decays. In all cases the reactivity at 5 years decay is conservatively higher than the reactivity at all later times.

Table 7.5.1.3-1 Time Effects k_{eff} (±2σ) Values for 12 PWR Assembly UCF WP in Different Configurations.

TIME (Years)	Intact No B	Intact With B	Collapsed No B	Collapsed With B
1	0.9853 ± .0028	0.8595 ± .0046	0.9999 ± .0034	0.8617 ± .0038
5	0.9706 ± .0037	0.8513 ± .0048	0.9828 ± .0039	0.8488 ± .0056
10	-	-	-	-
20	0.9442 ± .0034	0.8248 ± .0031	0.9585 ± .0031	0.8272 ± .0050
50	0.9237 ± .0037	0.8068 ± .0036	0.9387 ± .0039	0.8079 ± .0031
100	0.9246 ± .0044	0.8043 ± .0042	0.9360 ± .0049	0.8092 ± .0040
200	-	-	-	-
300	0.9239 ± .0033	0.8051 ± .0035	0.9388 ± .0041	0.8123 ± .0037
400	-	-	-	-

TIME (Years)	Intact No B	Intact With B	Collapsed No B	Collapsed With B
500	-	-	-	-
1000	0.9375 ± .0039	0.8155 ± .0042	0.9513 ± .0036	0.8197 ± .0038
4000	0.9445 ± .0038	0.8219 ± .0033	0.9590 ± .0035	0.8293 ± .0035
8000	0.9523 ± .0048	0.8287 ± .0045	0.9661 ± .0039	0.8255 ± .0043
10000	-	-	-	-
14000	0.9566 ± .0033	0.8264 ± .0040	0.9663 ± .0033	0.8280 ± .0050
18000	-	-	-	-
22000	0.9516 ± .0040	0.8266 ± .0036	0.9690 ± .0039	0.8262 ± .0031
26000	-	-	-	-
30000	-	-	-	-
36000	0.9424 ± .0040	0.8181 ± .0031	0.9599 ± .0035	0.8196 ± .0048
45000	-	-	-	-
60000	0.9298 ± .0030	0.8016 ± .0045	0.9426 ± .0040	0.8081 ± .0037
70000	-	-	-	-
100000	0.9177 ± .0035	0.7954 ± .0038	0.9358 ± .0039	0.7930 ± .0035
250000	0.9166 ± .0040	0.7917 ± .0041	0.9359 ± .0036	0.7906 ± .0047
500000	-	-	-	-
999999	0.9219 ± .0033	0.7972 ± .0037	0.9346 ± .0028	0.7965 ± .0037

7.5.1.4 Control Panel Loading

The use of control panels containing boron has a similar percentage effect on k_{eff} as that reported for the 21 assembly PWR UCF in Section 7.4.1.4, as shown in Figure 7.4.1.4-1.

7.5.2 24 Assembly BWR

The 24 BWR fuel assembly basket is formed by 6 tubes stacked in a square array in each quarter of the waste package on a nominal 16.00-cm (6.30 inches) center-to-center spacing.

The array is interrupted along the center line on the X and Y axes by an aluminum thermal shunt 1.0 cm (0.39 inches) thick. The fuel cell opening provided is 15.3 cm (6.02 inches). The fuel cell tubes are formed from 0.35-cm (0.14-inch) thick borated stainless steel plates (316B6A). Checking of this analysis revealed that the iron weight percent of 64.545 in the SS316L material composition should have been input as 65.545 weight percent. Based on engineering judgement the effect of the reduced iron weight percent on the calculation is negligible.

The cross-sectional view in the X-Y plane of the physical MCNP model for the 24 assembly BWR UCF waste package was generated with the MCNP plotting capability and is shown in Figure 7.5.2-1. The cross-sectional view in the X-Y plane of the physical MCNP model for the collapsed geometry is shown in Figure 7.5.2-2. An axial view of the intact geometry model is shown in Figure 7.5.2-3.

7.5.2.1 Standard Evaluation

Calculations were performed for intact and collapsed geometries, with and without boron in the stainless steel, for the design basis SNF (3.00% U-235 Enrichment, 20 GWd/MTU) at five years decay. The k_{eff} ($\pm 2\sigma$) values calculated for the different cases are as follow:

Design Basis SNF, Intact, No Boron	-	0.8290 ± .0028
Design Basis SNF, Intact, With Boron	-	0.6519 ± .0042
Design Basis SNF, Collapsed, No Boron	-	0.8714 ± .0031
Design Basis SNF, Collapsed, With Boron	-	0.6625 ± .0038

The reactivity worth { $(k_2 - k_1) / (k_1 * k_2)$ } for comparisons between sets is shown below.

Intact, Boron vs. No Boron	-	-0.328 ± .011
Collapsed vs. Intact, No Boron	-	0.059 ± .006
Collapsed vs. Intact, With Boron	-	0.025 ± .013
Collapsed, Boron vs. No Boron	-	-0.362 ± .010

With biases applied (0.06), all the cases with burnup credit meet the 0.95 value limit established in 10 CFR 60.131(b)(7) by a significant margin. The worth of collapsing the array appears to be higher with no boron in the stainless steel. The reactivity worths indicated above are consistent within 1.5 percent with those presented for the 44 assembly BWR UCF waste package. The change in reactivity in going from the 44 assembly to the 24 assembly design for each of the four models is indicated below.

Intact, No Boron	-	-0.046 ± .006
Intact, With Boron	-	-0.058 ± .013
Collapsed, No Boron	-	-0.050 ± .005
Collapsed, With Boron	-	-0.059 ± .013

7.5.2.2 Moderator Density Effects

The reactivity effect of reducing the moderator density was investigated for the 44 assembly UCF waste package in section 7.4.2.2. The results are applicable to the small package as well.

7.5.2.3 Time Effects

The required isotopic compositions for the fuel characteristics at 16 selected decay times were obtained from the SAS2H calculations used for the 44 assembly waste package analysis[5.21] and were used in MCNP cases to generate the results. The results (k_{eff} + 2σ) are shown in Figures 7.5.2.3-1, -2, -3, and -4 for the 3.00% U-235 Enrichment, 20 GWd/MTU design basis fuel in the different models, as indicated in the titles. These curves are smoother than those presented for the 44 BWR assembly UCF design because fewer decay times were used for the 24 assembly design. The purpose of these curves is to demonstrate the same basic behavior shown for the larger UCF design. The k_{eff} (±2σ) values calculated for the different cases are listed below in Table 7.5.2.3-1.

Each of the four curves generated have the same basic behavior. For the first ~200 years after discharge, the criticality potential of SNF decreases as the Pu-241 (13.2-year half-life) fissile material decays. From ~200 years to ~10,000 - 20,000 years, the criticality potential of the SNF increases as Pu-240 (6,580-year half-life) and the medium half-life neutron absorbers decay. After the ~20,000-year local peak, the criticality potential of the SNF decreases again as the Pu-239 (24,400-year half-life) fissile material decays. In all cases the reactivity at 5 years decay is conservatively higher than the reactivity at all later times.

Table 7.5.2.3-1 Time Effects k_{eff} ($\pm 2\sigma$) Values for 24 BWR Assembly UCF WP in Different Configurations.

TIME (Years)	Intact No B	Intact With B	Collapsed No B	Collapsed With B
1	0.8390 ± .0040	0.6619 ± .0037	0.8839 ± .0037	0.6709 ± .0030
5	0.8290 ± .0028	0.6519 ± .0042	0.8714 ± .0031	0.6625 ± .0038
10	-	-	-	-
20	0.8019 ± .0035	0.6331 ± .0034	0.8427 ± .0035	0.6450 ± .0034
50	0.7983 ± .0037	0.6248 ± .0044	0.8392 ± .0035	0.6338 ± .0039
100	0.7982 ± .0034	0.6241 ± .0040	0.8369 ± .0032	0.6372 ± .0027
200	-	-	-	-
300	0.7984 ± .0042	0.6265 ± .0040	0.8404 ± .0040	0.6400 ± .0036
400	-	-	-	-
500	-	-	-	-
1000	0.8085 ± .0036	0.6342 ± .0030	0.8463 ± .0029	0.6434 ± .0032
4000	0.8108 ± .0034	0.6359 ± .0028	0.8535 ± .0034	0.6443 ± .0027
8000	0.8172 ± .0041	0.6368 ± .0037	0.8535 ± .0032	0.6498 ± .0035
10000	-	-	-	-
14000	0.8146 ± .0034	0.6370 ± .0039	0.8583 ± .0036	0.6437 ± .0033
18000	-	-	-	-
22000	0.8035 ± .0029	0.6291 ± .0034	0.8490 ± .0027	0.6369 ± .0033
26000	-	-	-	-
30000	-	-	-	-
36000	0.7955 ± .0029	0.6227 ± .0035	0.8401 ± .0035	0.6268 ± .0026
45000	-	-	-	-
60000	0.7872 ± .0038	0.6127 ± .0040	0.8327 ± .0030	0.6112 ± .0028

TIME (Years)	Intact No B	Intact With B	Collapsed No B	Collapsed With B
70000	-	-	-	-
100000	0.7864 ± .0031	0.6093 ± .0033	0.8289 ± .0031	0.6111 ± .0033
250000	0.7846 ± .0033	0.6110 ± .0029	0.8314 ± .0033	0.6114 ± .0028
500000	-	-	-	-
999999	0.7888 ± .0030	0.6134 ± .0031	0.8318 ± .0035	0.6138 ± .0033

7.5.2.4 Control Panel Loading

The reactivity effects of varying the boron concentration in the control panels is expected to be similar to those discussed for the 44 BWR UCF disposal containers.

8. Conclusions

With burnup credit and intact 316B6A control panels, the 21 PWR assembly UCF waste package meets the 0.95 (0.89 with bias and uncertainty) value limit established in Title 10 CFR Part 60.131 (b)(7). The 44 BWR assembly waste package meets acceptance criteria with burnup credit and a very low boron loading (0.1 wt% B) in the control panels. The 44 BWR assembly waste package also meets acceptance criteria with highly loaded intact control panels and no burnup credit. The time period in which credit for the control panels can be taken must be defined through detailed probabalistic analyses. The burnup credit reactivity worth is -0.15 and -0.21 for the intact PWR and BWR design basis SNF, respectively. For both the PWR and BWR cases, full density moderation resulted in the highest k_{eff} calculated when varying moderator density.

The 12 assembly PWR design does meet acceptance criteria without additional criticality control measures beyond burnup credit and 316B6A control panels. The 24 assembly BWR design, like the 44 assembly BWR design, meets acceptance criteria with control panels alone. Boron loading in the stainless steel control panels is not required to supplement burnup credit in order to meet acceptance criteria for the 24 BWR design. The reactivity worth in going from the large to the small package is approximately 4% and 5% for the PWR and BWR packages, respectively.

The effect of collapsing the basket array is a positive increase in the values of k_{eff}. An extensive parametric analysis needs to be performed to determine the configuration which provides the highest value of k_{eff} in the waste package.

9. Attachments

The following attachments are case output files as listed. The name of the file is listed in parenthesis. There are a total of 418 MCNP case output files in these attachments. However, the total number of attachment identifiers is 423. The discrepancy between the 418 output files and the 423 attachment identifiers is that the attachment identifiers CCXXIV through CCXXVIII were omitted in the numbering sequence. The discontinuous attachment numbering was maintained with the 5 attachment identifiers omitted.

I. 21 PWR, DBF, Intact, No Boron (ucf21b.O) June 28, 1995; 29 pages
II. 21 PWR , 0 GWd/MTHM, Intact, No Boron (ucf21fro) October 2, 1995; 27 pages
III. 21 PWR, DBF, Intact, With Boron (ucb21b.O) June 30, 1995; 30 pages
IV. 21 PWR , 0 GWd/MTHM, Intact, With Boron (ucb21fro) September 29, 1995; 27 pages
V. 21 PWR, DBF, Collapsed, No Boron (ucx21b.O) June 28, 1995; 26 pages
VI. 21 PWR , 0 GWd/MTHM, Collapsed, No Boron (ucx21fro) October 2, 1995; 24 pages
VII. 21 PWR, DBF, Collapsed, With Boron (ucy21b.O) July 3, 1995; 27 pages
VIII. 21 PWR , 0 GWd/MTHM, Collapsed, With Boron (ucy21fro) October 2, 1995; 24 pages
IX. 21 PWR, DBF, Intact, With Boron, Actinide Only (ucb21baO) July 8, 1995; 28 pages
X. 21 PWR, DBF, Intact, No Boron, Actinide Only (ucf21baO) July 9, 1995; 28 pages
XI. 21 PWR, DBF, Intact, No Boron, CDB Based Isotopics (ucf21b.o.cdb) May 25, 1995; 29 pages
XII. 21 PWR, DBF, Intact, No Boron, 98% H_2O Density (u21ldk.O) October 4, 1995; 29 pages
XIII. 21 PWR, DBF, Intact, No Boron, 95% H_2O Density (u21lda.O) June 26, 1995; 29 pages
XIV. 21 PWR, DBF, Intact, No Boron, 90% H_2O Density (u21ldb.O) June 26, 1995; 29 pages
XV. 21 PWR, DBF, Intact, No Boron, 80% H_2O Density (u21ldc.O) June 26, 1995; 29 pages
XVI. 21 PWR, DBF, Intact, No Boron, 60% H_2O Density (u21ldd.O) June 26, 1995; 29 pages
XVII. 21 PWR, DBF, Intact, No Boron, 40% H_2O Density (u21lde.O) June 26, 1995;

29 pages

XVIII. 21 PWR, DBF, Intact, No Boron, 20% H_2O Density (u21ldf.O) June 27, 1995; 29 pages

XIX. 21 PWR, DBF, Intact, No Boron, 10% H_2O Density (u21ldg.O) June 27, 1995; 29 pages

XX. 21 PWR, DBF, Intact, No Boron, 5% H_2O Density (u21ldh.O) June 27, 1995; 29 pages

XXI. 21 PWR, DBF, Intact, No Boron, 1% H_2O Density (u21ldi.O) June 27, 1995; 29 pages

XXII. 21 PWR, DBF, Intact, No Boron, 0% H_2O Density (u21ldj.O) June 27, 1995; 29 pages

XXIII. 21 PWR, DBF, Intact, With Boron, 98% H_2O Density (b21ldk.O) October 4, 1995; 30 pages

XXIV. 21 PWR, DBF, Intact, With Boron, 95% H_2O Density (b21lda.O) October 4, 1995; 30 pages

XXV. 21 PWR, DBF, Intact, With Boron, 0% H_2O Density (b21ldj.O) October 4, 1995; 30 pages

XXVI. 21 PWR, DBF, Collapsed, No Boron, 98% H_2O Density (x21ldk.O) October 4, 1995; 26 pages

XXVII. 21 PWR, DBF, Collapsed, No Boron, 95% H_2O Density (x21lda.O) Ocotber 4, 1995; 26 pages

XXVIII. 21 PWR, DBF, Collapsed, No Boron, 0% H_2O Density (x21ldj.O) October 4, 1995; 26 pages

XXIX. 21 PWR, DBF, Collapsed, With Boron, 98% H_2O Density (y21ldk.O) October 4, 1995; 27 pages

XXX. 21 PWR, DBF, Collapsed, With Boron, 95% H_2O Density (y21lda.O) October 4, 1995; 27 pages

XXXI. 21 PWR, DBF, Collapsed, With Boron, 0% H_2O Density (y21ldj.O) October 4, 1995; 27 pages

XXXII. 21 PWR, 1 year decay, Intact, No Boron (ucf21a.O) June 30, 1995; 29 pages

XXXIII. 21 PWR, 10 year decay, Intact, No Boron (ucf21c.O) June 28, 1995; 29 pages

XXXIV. 21 PWR, 20 year decay, Intact, No Boron (ucf21d.O) June 28, 1995; 29 pages

XXXV. 21 PWR, 50 year decay, Intact, No Boron (ucf21e.O) June 28, 1995; 29 pages

XXXVI. 21 PWR, 100 year decay, Intact, No Boron (ucf21f.O) June 28, 1995; 29 pages

XXXVII. 21 PWR, 200 year decay, Intact, No Boron (ucf21g.O) June 28, 1995; 29 pages

XXXVIII. 21 PWR, 300 year decay, Intact, No Boron (ucf21h.O) June 28, 1995; 29 pages

XXXIX. 21 PWR, 400 year decay, Intact, No Boron (ucf21i.O) June 28, 1995; 29 pages

XL. 21 PWR, 500 year decay, Intact, No Boron (ucf21j.O) June 29, 1995; 29 pages

XLI. 21 PWR, 1000 year decay, Intact, No Boron (ucf21k.O) June 29, 1995;

29 pages

XLII. 21 PWR, 4000 year decay, Intact, No Boron (ucf21l.O) June 29, 1995; 29 pages

XLIII. 21 PWR, 8000 year decay, Intact, No Boron (ucf21m.O) June 29, 1995; 29 pages

XLIV. 21 PWR, 10,000 year decay, Intact, No Boron (ucf21n.O) June 29, 1995; 29 pages

XLV. 21 PWR, 14,000 year decay, Intact, No Boron (ucf21o.O) June 29, 1995; 29 pages

XLVI. 21 PWR, 18,000 year decay, Intact, No Boron (ucf21p.O) June 29, 1995; 29 pages

XLVII. 21 PWR, 22,000 year decay, Intact, No Boron (ucf21q.O) June 29, 1995; 29 pages

XLVIII. 21 PWR, 26,000 year decay, Intact, No Boron (ucf21r.O) June 29, 1995; 29 pages

IL. 21 PWR, 30,000 year decay, Intact, No Boron (ucf21s.O) June 29, 1995; 29 pages

L. 21 PWR, 36,000 year decay, Intact, No Boron (ucf21t.O) June 29, 1995; 29 pages

LI. 21 PWR, 45,000 year decay, Intact, No Boron (ucf21u.O) June 30, 1995; 29 pages

LII. 21 PWR, 60,000 year decay, Intact, No Boron (ucf21v.O) June 30, 1995; 29 pages

LIII. 21 PWR, 70,000 year decay, Intact, No Boron (ucf21aaO) June 30, 1995; 29 pages

LIV. 21 PWR, 100,000 year decay, Intact, No Boron (ucf21w.O) June 30, 1995; 29 pages

LV. 21 PWR, 250,000 year decay, Intact, No Boron (ucf21x.O) June 30, 1995; 29 pages

LVI. 21 PWR, 500,000 year decay, Intact, No Boron (ucf21y.O) June 30, 1995; 29 pages

LVII. 21 PWR, 999,999 year decay, Intact, No Boron (ucf21z.O) June 30, 1995; 29 pages

LVIII. 21 PWR, 1 year decay, Intact, With Boron (ucb21a.O) June 30, 1995; 30 pages

LIX. 21 PWR, 10 year decay, Intact, With Boron (ucb21c.O) June 30, 1995; 30 pages

LX. 21 PWR, 20 year decay, Intact, With Boron (ucb21d.O) July 3, 1995; 30 pages

LXI. 21 PWR, 50 year decay, Intact, With Boron (ucb21e.O) July 1, 1995; 30 pages

LXII. 21 PWR, 100 year decay, Intact, With Boron (ucb21f.O) July 1, 1995;

30 pages

LXIII. 21 PWR, 200 year decay, Intact, With Boron (ucb21g.O) July 1, 1995; 30 pages

LXIV. 21 PWR, 300 year decay, Intact, With Boron (ucb21h.O) July 3, 1995; 30 pages

LXV. 21 PWR, 400 year decay, Intact, With Boron (ucb21i.O) July 1, 1995; 30 pages

LXVI. 21 PWR, 500 year decay, Intact, With Boron (ucb21j.O) July 1, 1995; 30 pages

LXVII. 21 PWR, 1000 year decay, Intact, With Boron (ucb21k.O) July 1, 1995; 30 pages

LXVIII. 21 PWR, 4000 year decay, Intact, With Boron (ucb21l.O) July 1, 1995; 30 pages

LXIX. 21 PWR, 8000 year decay, Intact, With Boron (ucb21m.O) July 1, 1995; 30 pages

LXX. 21 PWR, 10,000 year decay, Intact, With Boron (ucb21n.O) July 1, 1995; 30 pages

LXXI. 21 PWR, 14,000 year decay, Intact, With Boron (ucb21o.O) July 1, 1995; 30 pages

LXXII. 21 PWR, 18,000 year decay, Intact, With Boron (ucb21p.O) July 1, 1995; 30 pages

LXXIII. 21 PWR, 22,000 year decay, Intact, With Boron (ucb21q.O) July 1, 1995; 29 pages

LXXIV. 21 PWR, 26,000 year decay, Intact, With Boron (ucb21r.O) July 1, 1995; 29 pages

LXXV. 21 PWR, 30,000 year decay, Intact, With Boron (ucb21s.O) July 1, 1995; 29 pages

LXXVI. 21 PWR, 36,000 year decay, Intact, With Boron (ucb21t.O) July 1, 1995; 29 pages

LXXVII. 21 PWR, 45,000 year decay, Intact, With Boron (ucb21u.O) July 1, 1995; 29 pages

LXXVIII. 21 PWR, 60,000 year decay, Intact, With Boron (ucb21v.O) July 2, 1995; 29 pages

LXXIX. 21 PWR, 70,000 year decay, Intact, With Boron (ucb21aaO) June 30, 1995; 29 pages

LXXX. 21 PWR, 100,000 year decay, Intact, With Boron (ucb21w.O) July 2, 1995; 29 pages

LXXXI. 21 PWR, 250,000 year decay, Intact, With Boron (ucb21x.O) July 2, 1995; 29 pages

LXXXII. 21 PWR, 500,000 year decay, Intact, With Boron (ucb21y.O) July 2, 1995; 29 pages

LXXXIII. 21 PWR, 999,999 year decay, Intact, With Boron (ucb21z.O) July 2, 1995; 29 pages

LXXXIV. 21 PWR, 1 year decay, Collapsed, No Boron (ucx21a.O) July 3, 1995; 26 pages

LXXXV. 21 PWR, 10 year decay, Collapsed, No Boron (ucx21c.O) July 3, 1995; 26 pages

LXXXVI. 21 PWR, 20 year decay, Collapsed, No Boron (ucx21d.O) July 3, 1995; 26 pages

LXXXVII. 21 PWR, 50 year decay, Collapsed, No Boron (ucx21e.O) July 3, 1995; 26 pages

LXXXVIII. 21 PWR, 100 year decay, Collapsed, No Boron (ucx21f.O) July 3, 1995; 26 pages

LXXXIX. 21 PWR, 200 year decay, Collapsed, No Boron (ucx21g.O) July 4, 1995; 26 pages

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CCCXIII. 12 PWR, 1 year decay, Intact, With Boron (ucb12a.O) October 11, 1995; 29 pages

CCCXIV. 12 PWR, 20 year decay, Intact, With Boron (ucb12d.O) October 11, 1995; 29 pages

CCCXV. 12 PWR, 50 year decay, Intact, With Boron (ucb12e.O) October 11, 1995; 29 pages

CCCXVI. 12 PWR, 100 year decay, Intact, With Boron (ucb12f.O) October 11, 1995; 29 pages

CCCXVII. 12 PWR, 300 year decay, Intact, With Boron (ucb12h.O) October 11, 1995; 29 pages

CCCXVIII. 12 PWR, 1000 year decay, Intact, With Boron (ucb12k.O) October 11, 1995; 29 pages

CCCXIX. 12 PWR, 4000 year decay, Intact, With Boron (ucb12l.O) October 11, 1995; 29 pages

CCCXX. 12 PWR, 8000 year decay, Intact, With Boron (ucb12m.O) October 11, 1995; 29 pages

CCCXXI. 12 PWR, 14,000 year decay, Intact, With Boron (ucb12o.O) October 11, 1995; 29 pages

CCCXXII. 12 PWR, 22,000 year decay, Intact, With Boron (ucb12q.O) October 11, 1995; 29 pages

CCCXXIII. 12 PWR, 36,000 year decay, Intact, With Boron (ucb12t.O) October 11, 1995; 29 pages

CCCXXIV. 12 PWR, 60,000 year decay, Intact, With Boron (ucb12v.O) October 11, 1995; 29 pages

CCCXXV. 12 PWR, 100,000 year decay, Intact, With Boron (ucb12w.O) October 11, 1995; 29 pages

CCCXXVI. 12 PWR, 250,000 year decay, Intact, With Boron (ucb12x.O) October 11, 1995; 29 pages

CCCXXVII. 12 PWR, 999,999 year decay, Intact, With Boron (ucb12z.O) October 11, 1995; 29 pages

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CCCXXIX. 12 PWR, 20 year decay, Collapsed, No Boron (ucx12d.O) July 8, 1995; 26 pages

CCCXXX. 12 PWR, 50 year decay, Collapsed, No Boron (ucx12e.O) July 8, 1995; 26 pages

CCCXXXI. 12 PWR, 100 year decay, Collapsed, No Boron (ucx12f.O) July 8, 1995; 26 pages
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CCCXXXVI. 12 PWR, 14,000 year decay, Collapsed, No Boron (ucx12o.O) July 8, 1995; 26 pages
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CCCXXXVIII. 12 PWR, 36,000 year decay, Collapsed, No Boron (ucx12t.O) July 9, 1995; 26 pages
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CCCXLI. 12 PWR, 250,000 year decay, Collapsed, No Boron (ucx12x.O) July 9, 1995; 26 pages
CCCXLII. 12 PWR, 999,999 year decay, Collapsed, No Boron (ucx12z.O) July 9, 1995; 26 pages
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CCCXLV. 12 PWR, 50 year decay, Collapsed, With Boron (ucy12e.O) July 9, 1995; 26 pages
CCCXLVI. 12 PWR, 100 year decay, Collapsed, With Boron (ucy12f.O) July 9, 1995; 26 pages
CCCXLVII. 12 PWR, 300 year decay, Collapsed, With Boron (ucy12h.O) July 9, 1995; 26 pages
CCCXLVIII. 12 PWR, 1000 year decay, Collapsed, With Boron (ucy12k.O) July 9, 1995; 26 pages
CCCIL. 12 PWR, 4000 year decay, Collapsed, With Boron (ucy12l.O) July 9, 1995; 26 pages
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26 pages

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CCCLII. 12 PWR, 22,000 year decay, Collapsed, With Boron (ucy12q.O) July 10, 1995; 26 pages

CCCLIII. 12 PWR, 36,000 year decay, Collapsed, With Boron (ucy12t.O) July 10, 1995; 26 pages

CCCLIV. 12 PWR, 60,000 year decay, Collapsed, With Boron (ucy12v.O) July 10, 1995; 26 pages

CCCLV. 12 PWR, 100,000 year decay, Collapsed, With Boron (ucy12w.O) July 10, 1995; 26 pages

CCCLVI. 12 PWR, 250,000 year decay, Collapsed, With Boron (ucy12x.O) July 10, 1995; 26 pages

CCCLVII. 12 PWR, 999,999 year decay, Collapsed, With Boron (ucy12z.O) July 10, 1995; 26 pages

CCCLVIII. 24 BWR, DBF, Intact, No Boron (ucf24b.O) July 21, 1995; 29 pages

CCCLIX. 24 BWR, DBF, Intact, With Boron (ucb24b.O) October 17, 1995; 29 pages

CCCLX. 24 BWR, DBF, Collapsed, No Boron (ucx24b.O) October 5, 1995; 27 pages

CCCLXI. 24 BWR, DBF, Collapsed, With Boron (ucy24b.O) October 5, 1995; 28 pages

CCCLXII. 24 BWR, 1 year decay, Intact, No Boron (ucf24a.O) July 21, 1995; 29 pages

CCCLXIII. 24 BWR, 20 year decay, Intact, No Boron (ucf24d.O) July 21, 1995; 29 pages

CCCLXIV. 24 BWR, 50 year decay, Intact, No Boron (ucf24e.O) July 21, 1995; 29 pages

CCCLXV. 24 BWR, 100 year decay, Intact, No Boron (ucf24f.O) July 21, 1995; 29 pages

CCCLXVI. 24 BWR, 300 year decay, Intact, No Boron (ucf24h.O) July 21, 1995 29 pages

CCCLXVII. 24 BWR, 1000 year decay, Intact, No Boron (ucf24k.O) October 5, 1995; 29 pages

CCCLXVIII. 24 BWR, 4000 year decay, Intact, No Boron (ucf24l.O) July 21, 1995; 29 pages

CCCLXIX. 24 BWR, 8000 year decay, Intact, No Boron (ucf24m.O) July21, 1995; 29 pages

CCCLXX. 24 BWR, 14,000 year decay, Intact, No Boron (ucf24o.O) October 5, 1995; 28 pages

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CCCLXXIII. 24 BWR, 60,000 year decay, Intact, No Boron (ucf24v.O) July 22, 1995; 28 pages

CCCLXXIV. 24 BWR, 100,000 year decay, Intact, No Boron (ucf24w.O) July 22, 1995;

28 pages

CCCLXXV. 24 BWR, 250,000 year decay, Intact, No Boron (ucf24x.O) July 22, 1995; 28 pages

CCCLXXVI. 24 BWR, 999,999 year decay, Intact, No Boron (ucf24z.O) July 22, 1995; 28 pages

CCCLXXVII. 24 BWR, 1 year decay, Intact, With Boron (ucb24a.O) October 17, 1995; 29 pages

CCCLXXVIII. 24 BWR, 20 year decay, Intact, With Boron (ucb24d.O) October 17, 1995; 29 pages

CCCLXXIX. 24 BWR, 50 year decay, Intact, With Boron (ucb24e.O) October 17, 1995; 29 pages

CCCLXXX. 24 BWR, 100 year decay, Intact, With Boron (ucb24f.O) October 17, 1995; 29 pages

CCCLXXXI. 24 BWR, 300 year decay, Intact, With Boron (ucb24h.O) October 17, 1995; 29 pages

CCCLXXXII. 24 BWR, 1000 year decay, Intact, With Boron (ucb24k.O) October 17, 1995; 29 pages

CCCLXXXIII. 24 BWR, 4000 year decay, Intact, With Boron (ucb24l.O) October 17, 1995; 29 pages

CCCLXXXIV. 24 BWR, 8000 year decay, Intact, With Boron (ucb24m.O) October 17, 1995; 29 pages

CCCLXXXV. 24 BWR, 14,000 year decay, Intact, With Boron (ucb24o.O) October 17, 1995; 28 pages

CCCLXXXVI. 24 BWR, 22,000 year decay, Intact, With Boron (ucb24q.O) October 17, 1995; 29 pages

CCCLXXXVII. 24 BWR, 36,000 year decay, Intact, With Boron (ucb24t.O) October 17, 1995; 29 pages

CCCLXXXVIII. 24 BWR, 60,000 year decay, Intact, With Boron (ucb24v.O) October 17, 1995; 29 pages

CCCLXXXIX. 24 BWR, 100,000 year decay, Intact, With Boron (ucb24w.O) October 17, 1995; 29 pages

CCCXC. 24 BWR, 250,000 year decay, Intact, With Boron (ucb24x.O) October 17, 1995; 29 pages

CCCXCI. 24 BWR, 999,999 year decay, Intact, With Boron (ucb24z.O) October 17, 1995; 28 pages

CCCXCII. 24 BWR, 1 year decay, Collapsed, No Boron (ucx24a.O) October 5, 1995; 28 pages

CCCXCIII. 24 BWR, 20 year decay, Collapsed, No Boron (ucx24d.O) October 5, 1995; 28 pages

CCCXCIV. 24 BWR, 50 year decay, Collapsed, No Boron (ucx24e.O) October 5, 1995; 28 pages

CCCXCV. 24 BWR, 100 year decay, Collapsed, No Boron (ucx24f.O) October 5, 1995; 28 pages

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CCCXCVII. 24 BWR, 1000 year decay, Collapsed, No Boron (ucx24k.O) October 5, 1995; 28 pages

CCCXCVIII. 24 BWR, 4000 year decay, Collapsed, No Boron (ucx24l.O) October 5, 1995; 28 pages

CCCIC. 24 BWR, 8000 year decay, Collapsed, No Boron (ucx24m.O) October 5, 1995; 28 pages

CD. 24 BWR, 14,000 year decay, Collapsed, No Boron (ucx24o.O) October 5, 1995; 27 pages

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CDIII. 24 BWR, 60,000 year decay, Collapsed, No Boron (ucx24v.O) October 5, 1995; 27 pages

CDIV. 24 BWR, 100,000 year decay, Collapsed, No Boron (ucx24w.O) October 5, 1995; 27 pages

CDV. 24 BWR, 250,000 year decay, Collapsed, No Boron (ucx24x.O) October 5, 1995; 27 pages

CDVI. 24 BWR, 999,999 year decay, Collapsed, No Boron (ucx24z.O) October 5, 1995; 27 pages

CDVII. 24 BWR, 1 year decay, Collapsed, With Boron (ucy24a.O) October 5, 1995; 28 pages

CDVIII. 24 BWR, 20 year decay, Collapsed, With Boron (ucy24d.O) October 5, 1995; 28 pages

CDIX. 24 BWR, 50 year decay, Collapsed, With Boron (ucy24e.O) October 5, 1995; 28 pages

CDX. 24 BWR, 100 year decay, Collapsed, With Boron (ucy24f.O) October 5, 1995; 28 pages

CDXI. 24 BWR, 300 year decay, Collapsed, With Boron (ucy24h.O) October 5, 1995; 28 pages

CDXII. 24 BWR, 1000 year decay, Collapsed, With Boron (ucy24k.O) October 5, 1995; 28 pages

CDXIII. 24 BWR, 4000 year decay, Collapsed, With Boron (ucy24l.O) October 5, 1995;

28 pages

CDXIV. 24 BWR, 8000 year decay, Collapsed, With Boron (ucy24m.O)
October 5, 1995; 28 pages

CDXV. 24 BWR, 14,000 year decay, Collapsed, With Boron (ucy24o.O)
October 5, 1995; 27 pages

CDXVI. 24 BWR, 22,000 year decay, Collapsed, With Boron (ucy24q.O)
October 5, 1995; 28 pages

CDXVII. 24 BWR, 36,000 year decay, Collapsed, With Boron (ucy24t.O)
October 5. 1995; 28 pages

CDXVIII. 24 BWR, 60,000 year decay, Collapsed, With Boron (ucy24v.O)
October 5, 1995; 27 pages

CDXIX. 24 BWR, 100,000 year decay, Collapsed, With Boron (ucy24w.O)
October 5, 1995; 28 pages

CDXX. 24 BWR, 250,000 year decay, Collapsed, With Boron (ucy24x.O)
October 5, 1995; 28 pages

CDXXI. 24 BWR, 999,999 year decay, Collapsed, With Boron (ucy24z.O)
October 5, 1995; 27 pages

CDXXII. 21 PWR, DBF, Intact, No Boron, Actinide Only with f_{BUC}'s (ucf21bvO)
July 9, 1995; 28 pages

CDXXIII. 21 PWR, DBF, Intact, With Boron, Actinide Only with f_{BUC}'s (ucb21bvO)
July 8, 1995; 28 pages

11/01/95 07:38:25
UCF - B&W 15x15 FUEL, 21
ASSEMBLY 3.00%/20 GWD/5 year
(ucf21b) sas2h
probid = 11/01/95 07:36:29
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(.000000, 1.000000, .000000)
origin:
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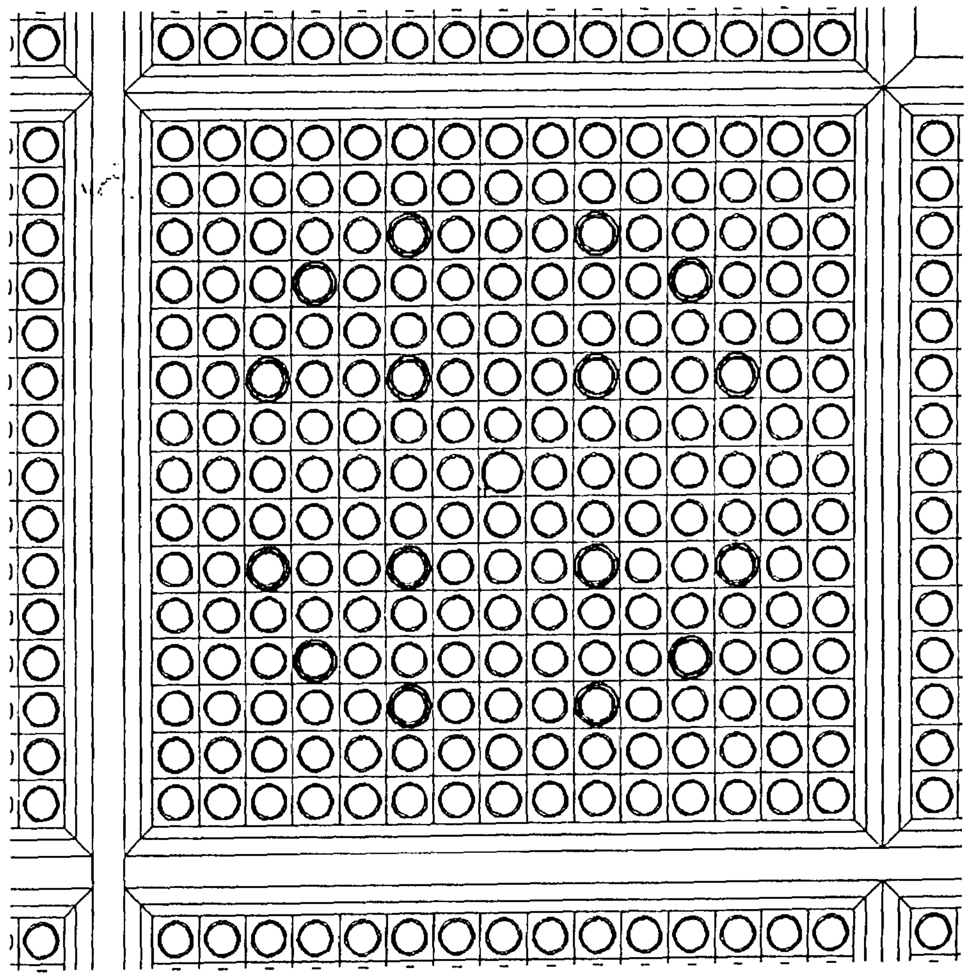

Figure 7.3-1. MCNP Cross-Sectional View of a B&W 15x15 PWR Fuel Assembly in the UCF Basket.

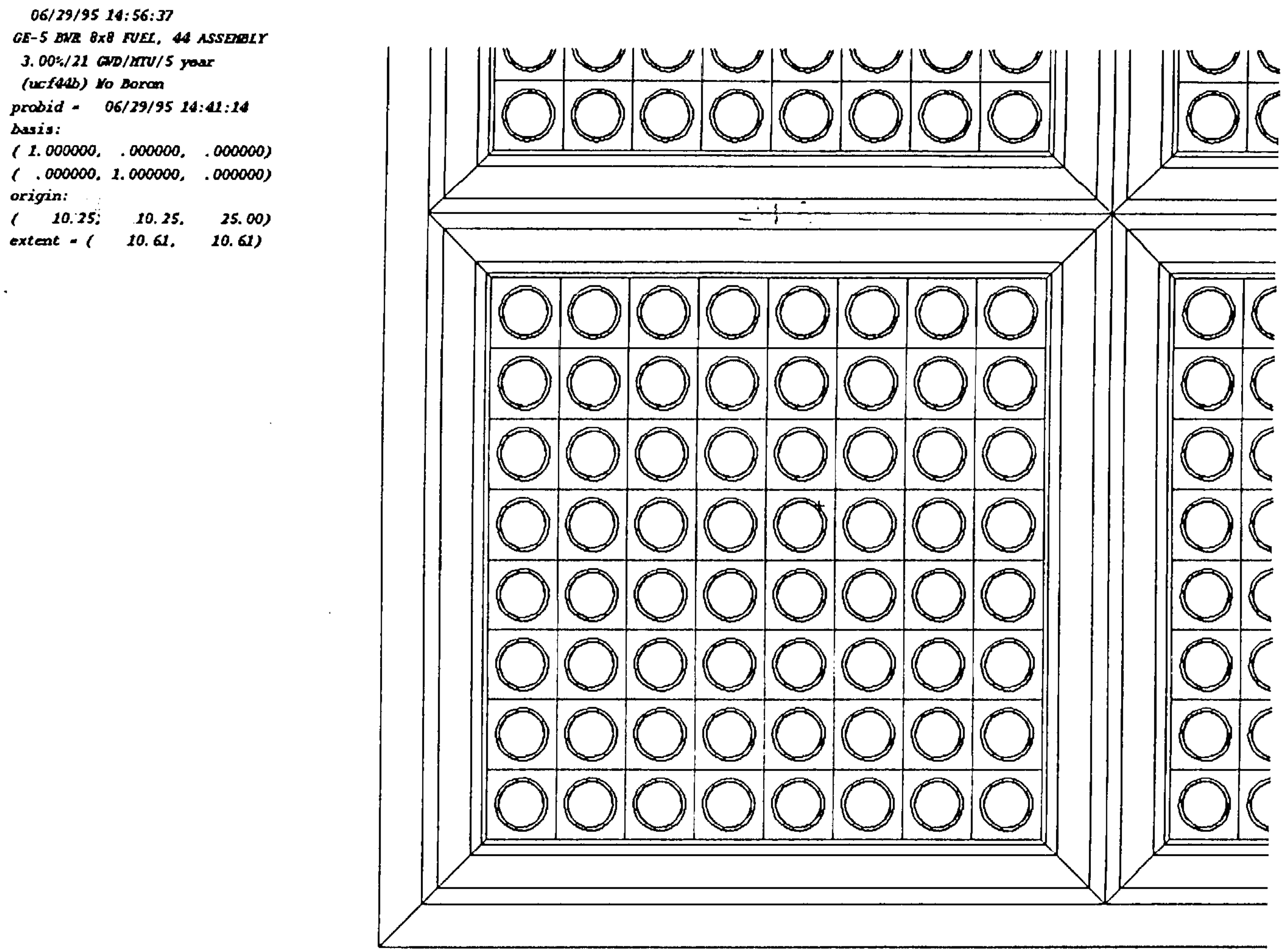

Figure 7.3-2. MCNP Cross-Sectional View of a GE 8x8 BWR Fuel Assembly in the UCF Basket.

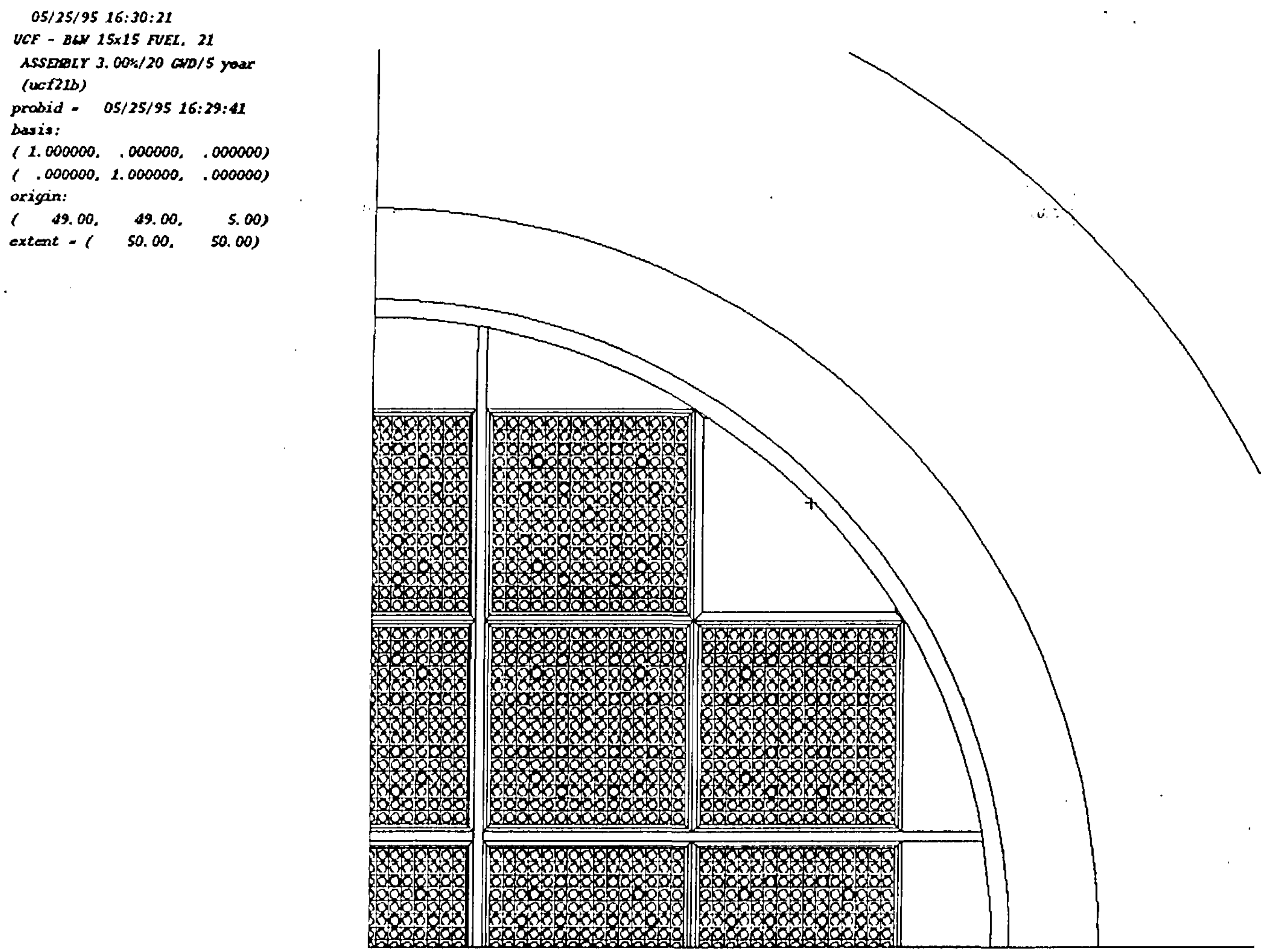

Figure 7.4.1-1. MCNP Cross-Sectional View of the 21 PWR Assembly UCF WP.

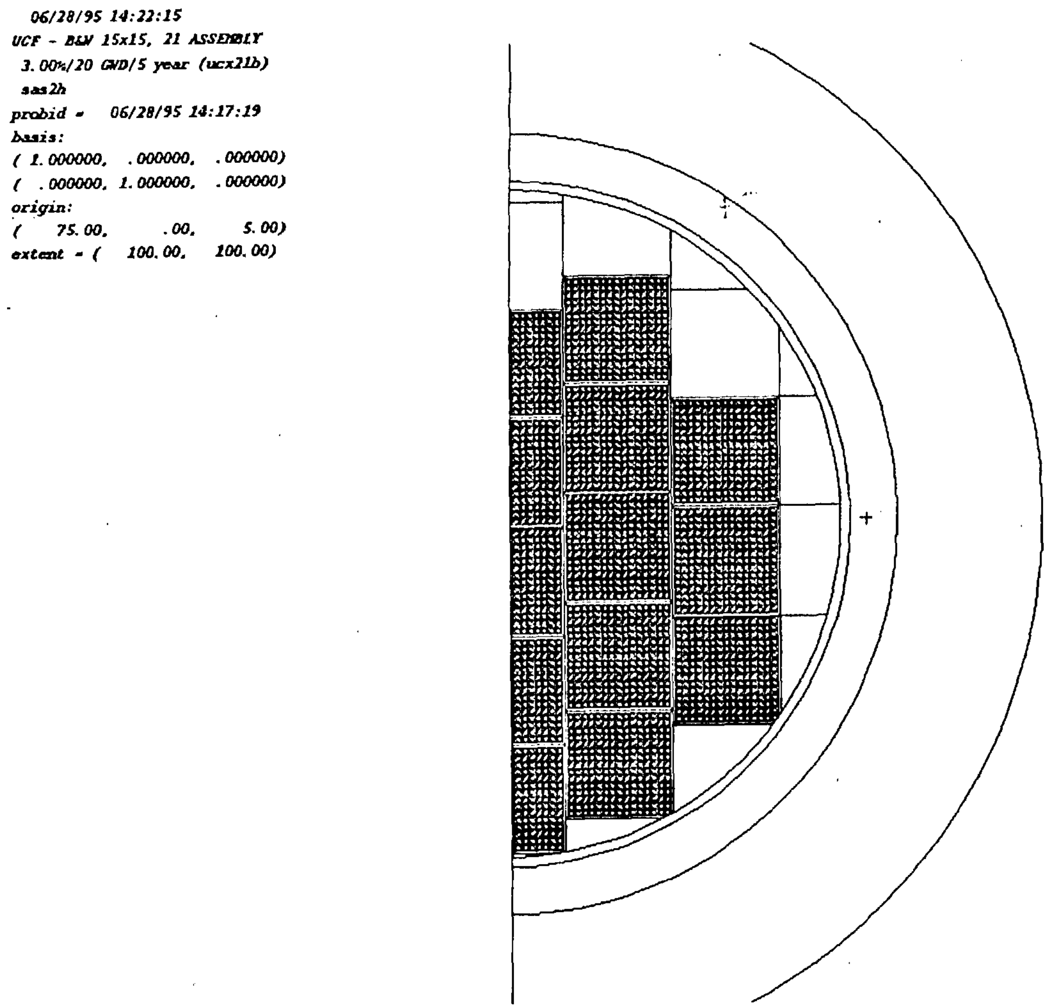

Figure 7.4.1-2. MCNP Cross-Sectional View of the 21 PWR Assembly Collapsed Array UCF WP.

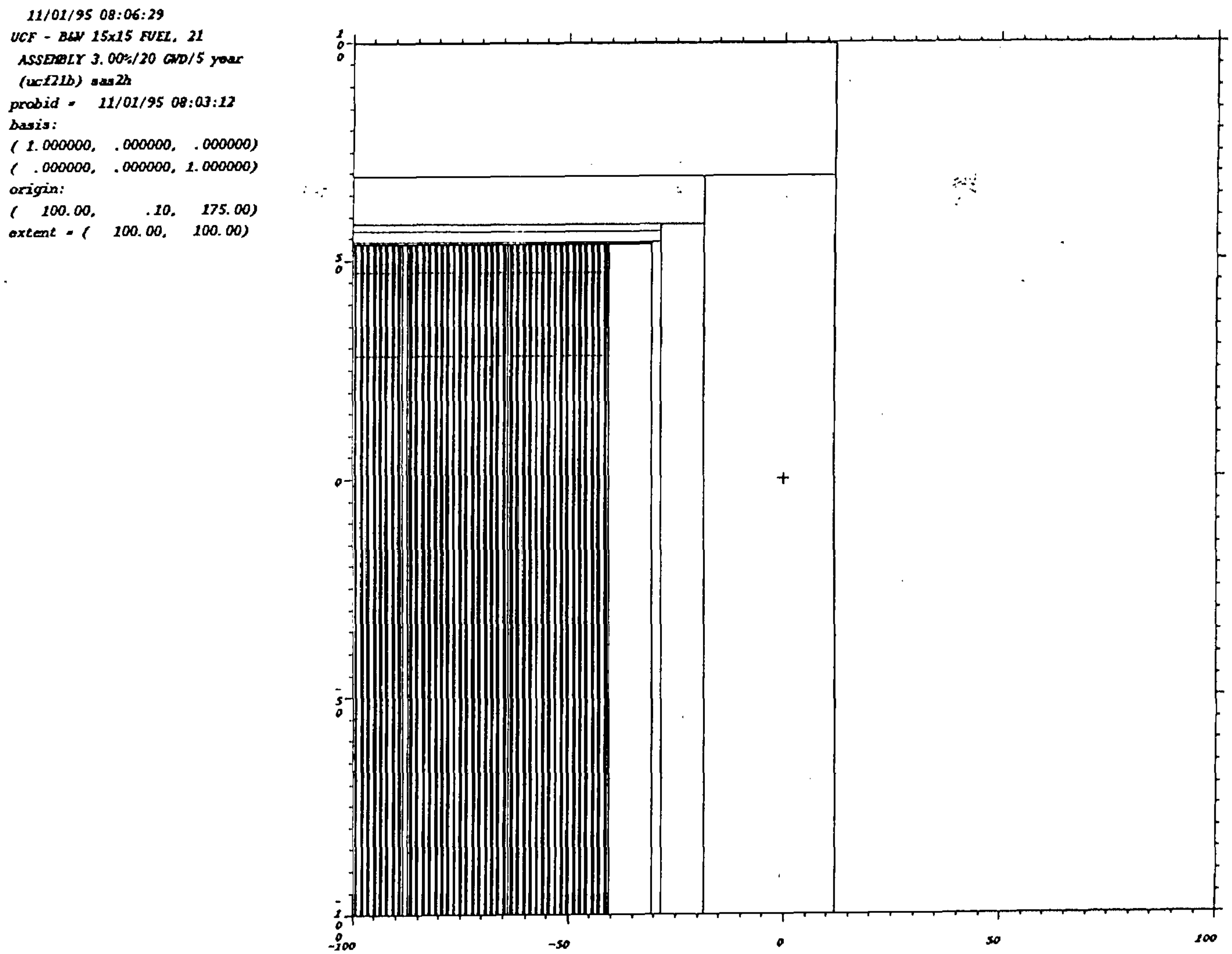

Figure 7.4.1-3. MCNP Axial View of the 21 PWR Assembly UCF WP.

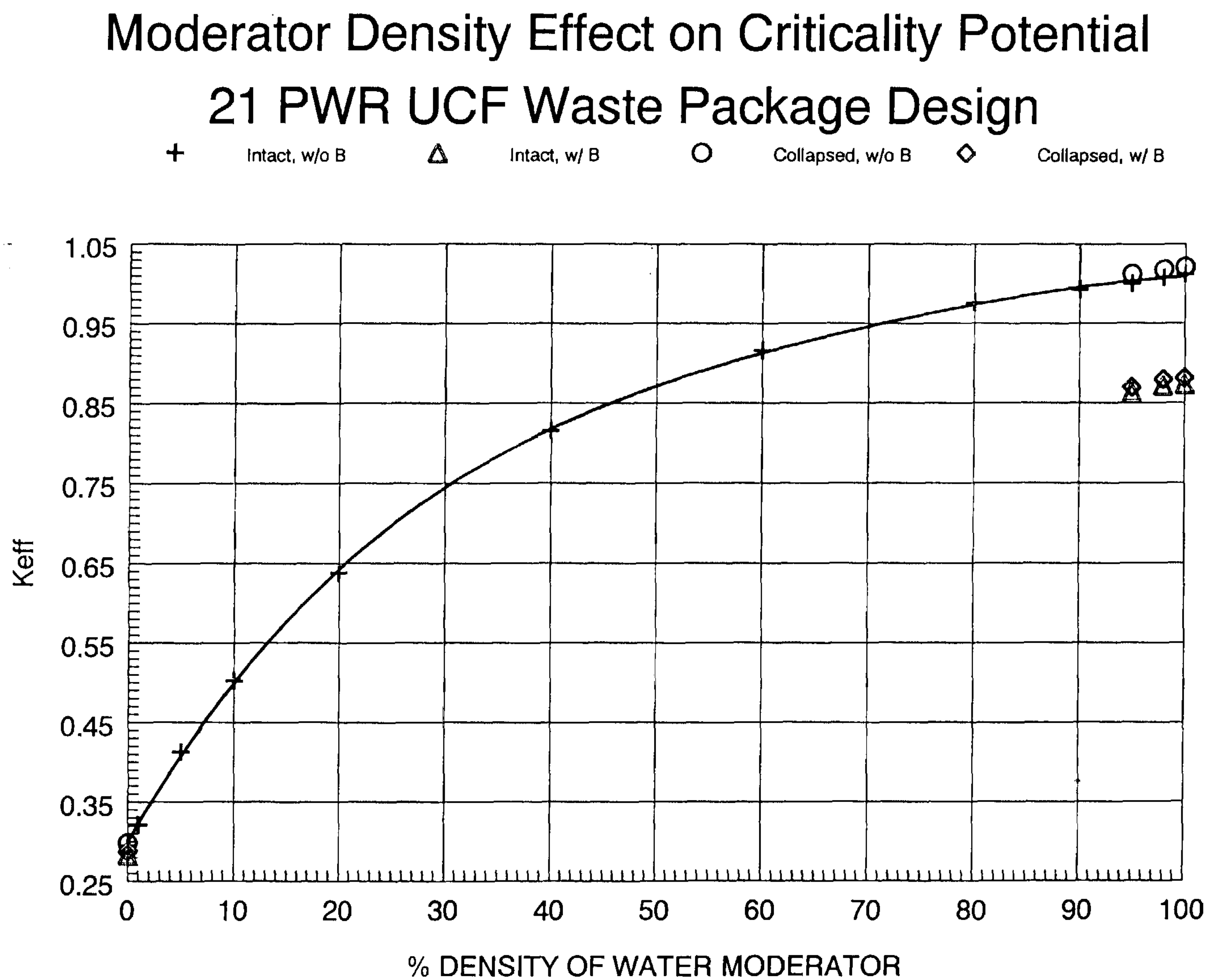

Figure 7.4.1.2-1. Moderator Density Effect on Criticality Potential for the 21 PWR Assembly UCF WP.

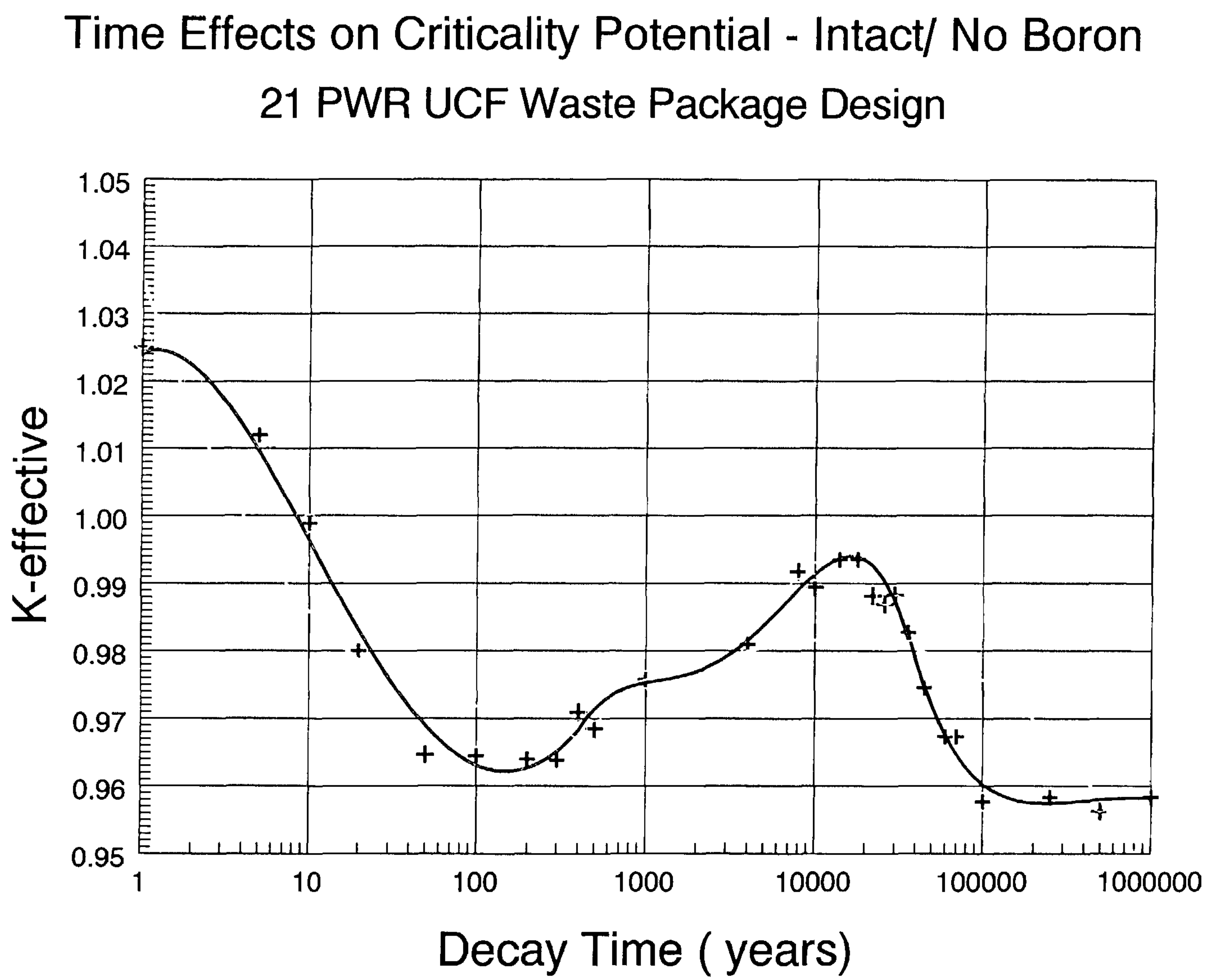

Figure 7.4.1.3-1. Time Effects on Criticality Potential, 21 PWR UCF WP, Intact Array, SS Panels.

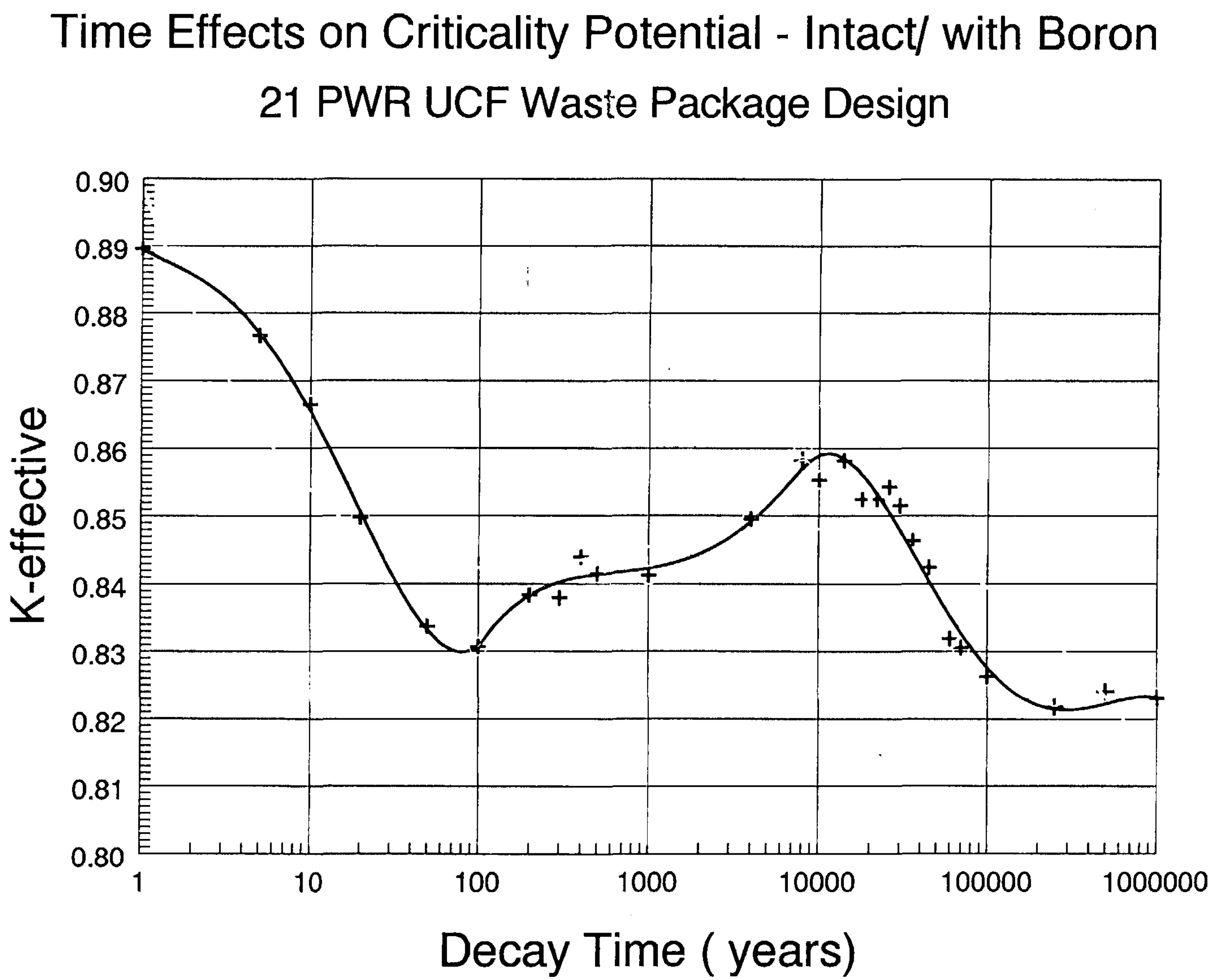

Figure 7.4.1.3-2. Time Effects on Criticality Potential, 21 PWR UCF WP, Intact Array, 316B6A Panels.

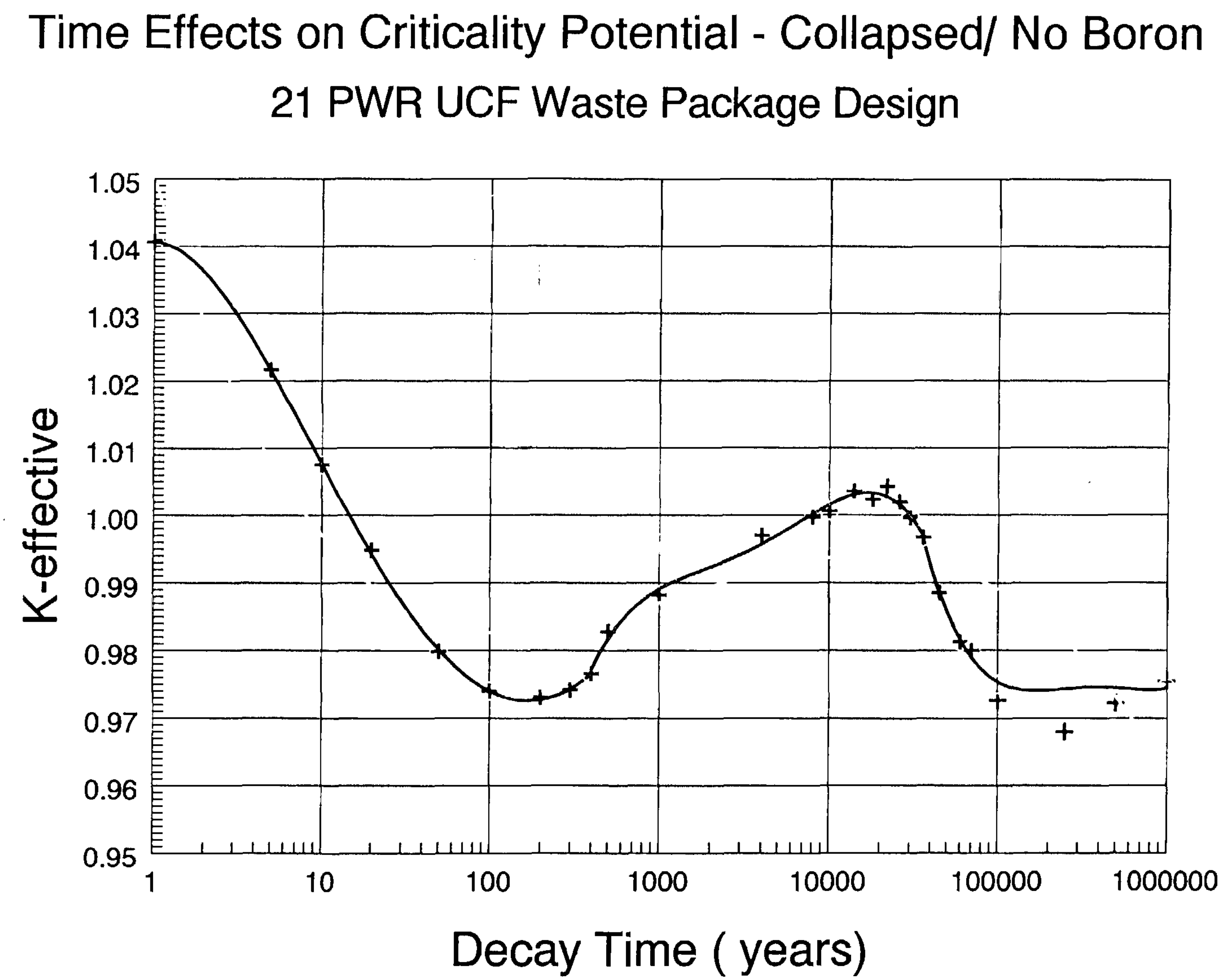

Figure 7.4.1.3-3. Time Effects on Criticality Potential, 21 PWR UCF WP, Collapsed Array, SS Panels.

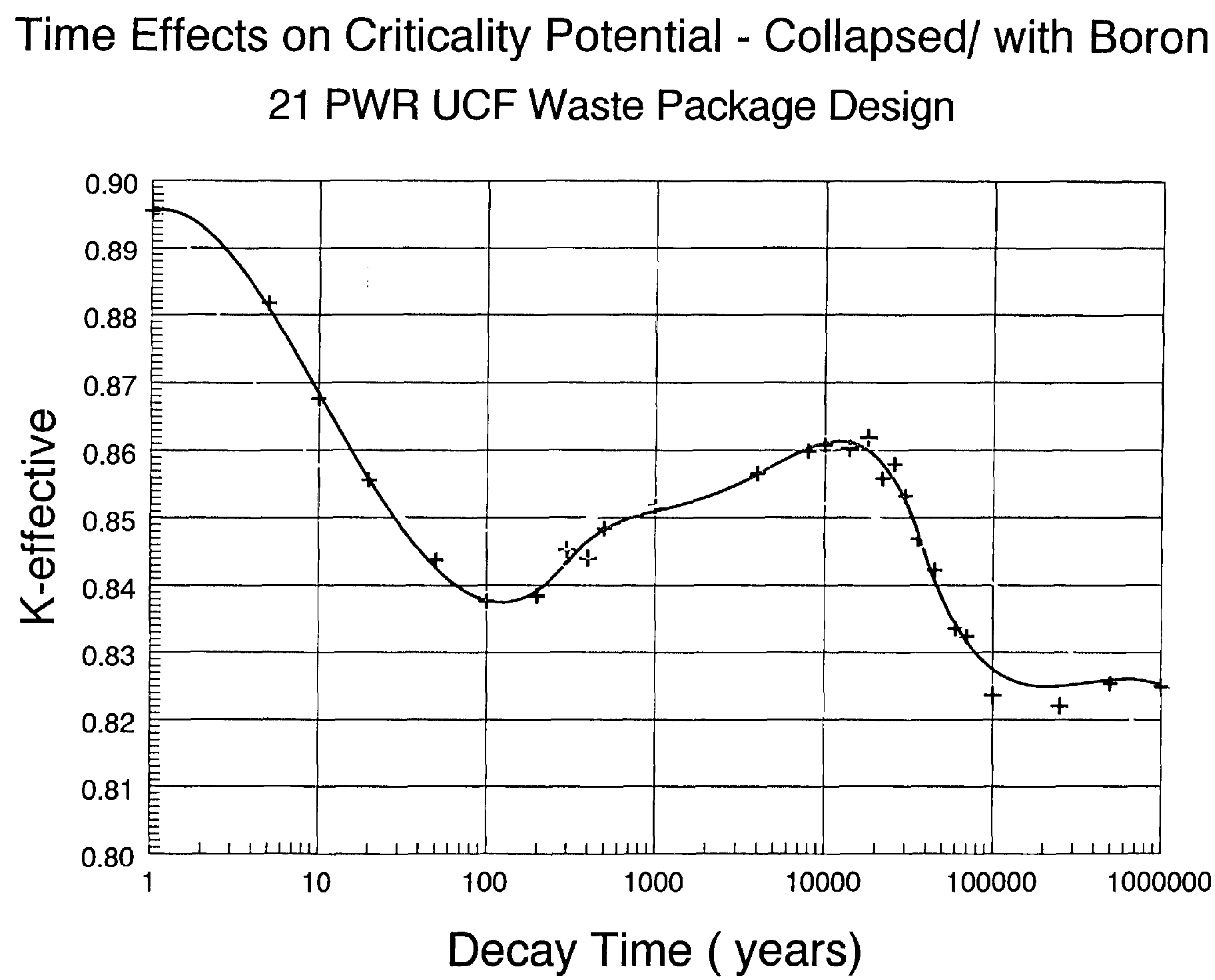

Figure 7.4.1.3-4. Time Effects on Criticality Potential, 21 PWR UCF WP, Collapsed Array, 316B6A Panels.

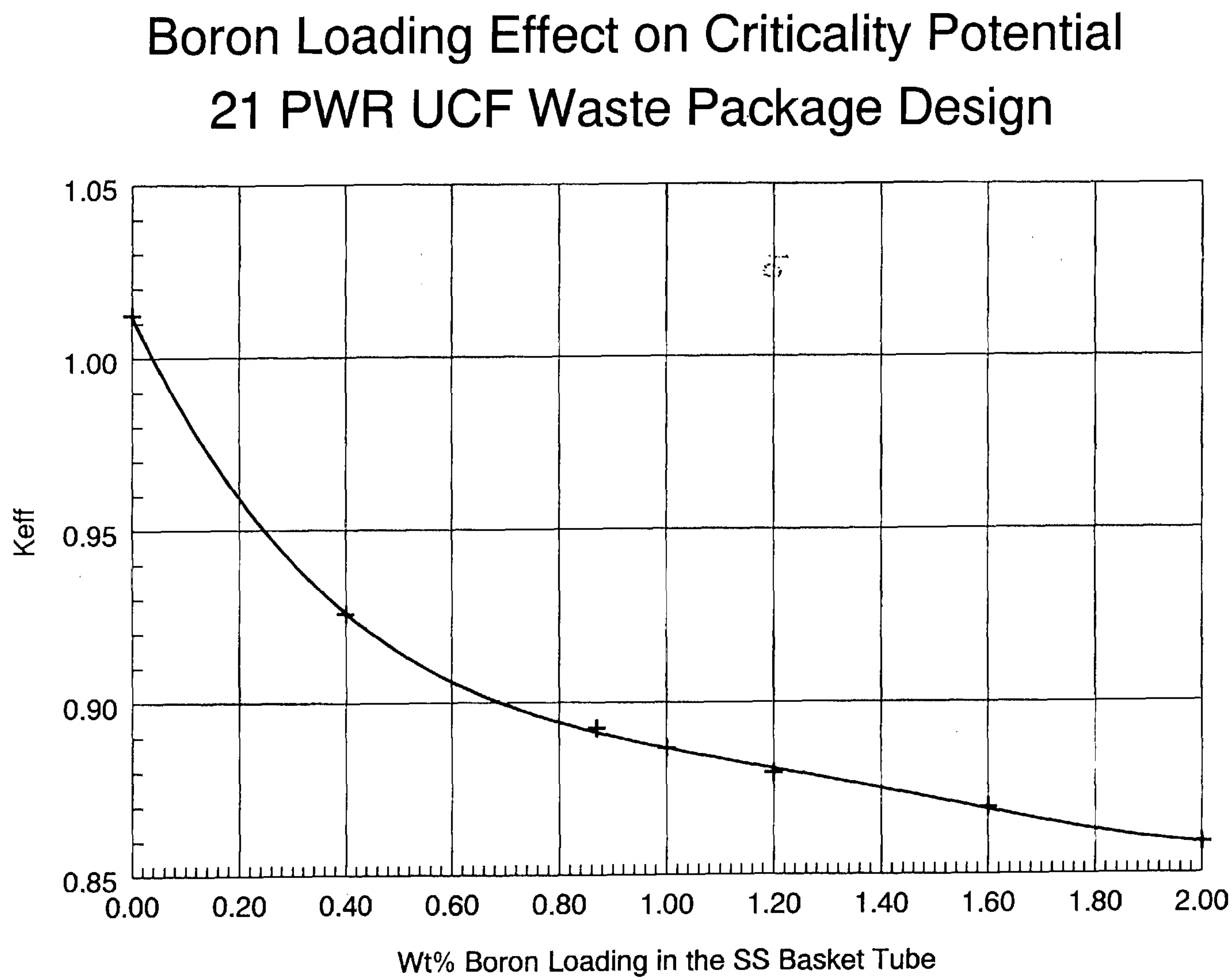

Figure 7.4.1.4-1. Control Panel Boron Loading Effect on Criticality Potential, 21 PWR UCF WP.

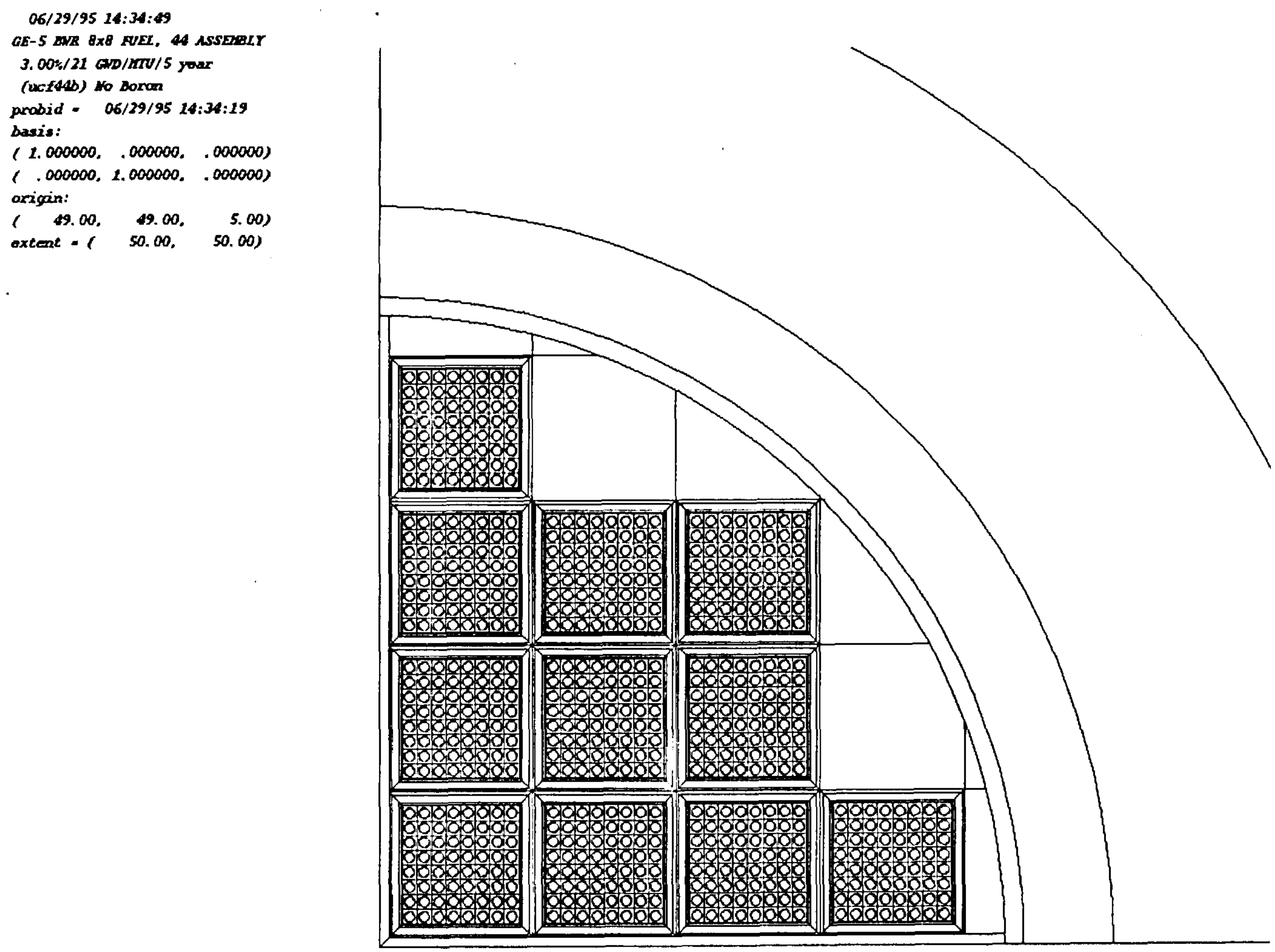

Figure 7.4.2-1. MCNP Cross-Sectional View of the 44 BWR Assembly UCF WP.

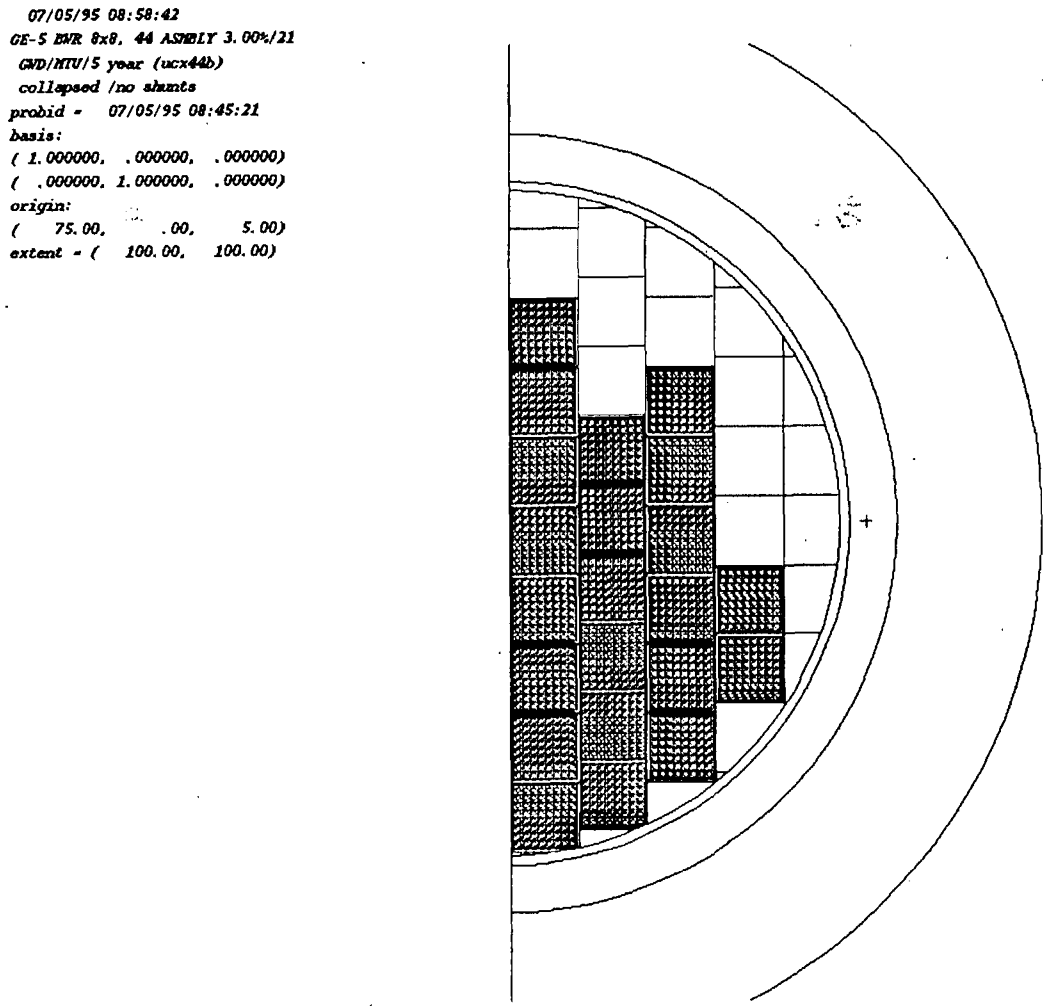

Figure 7.4.2-2. MCNP Cross-Sectional View of the 44 BWR Assembly Collapsed Array UCF WP.

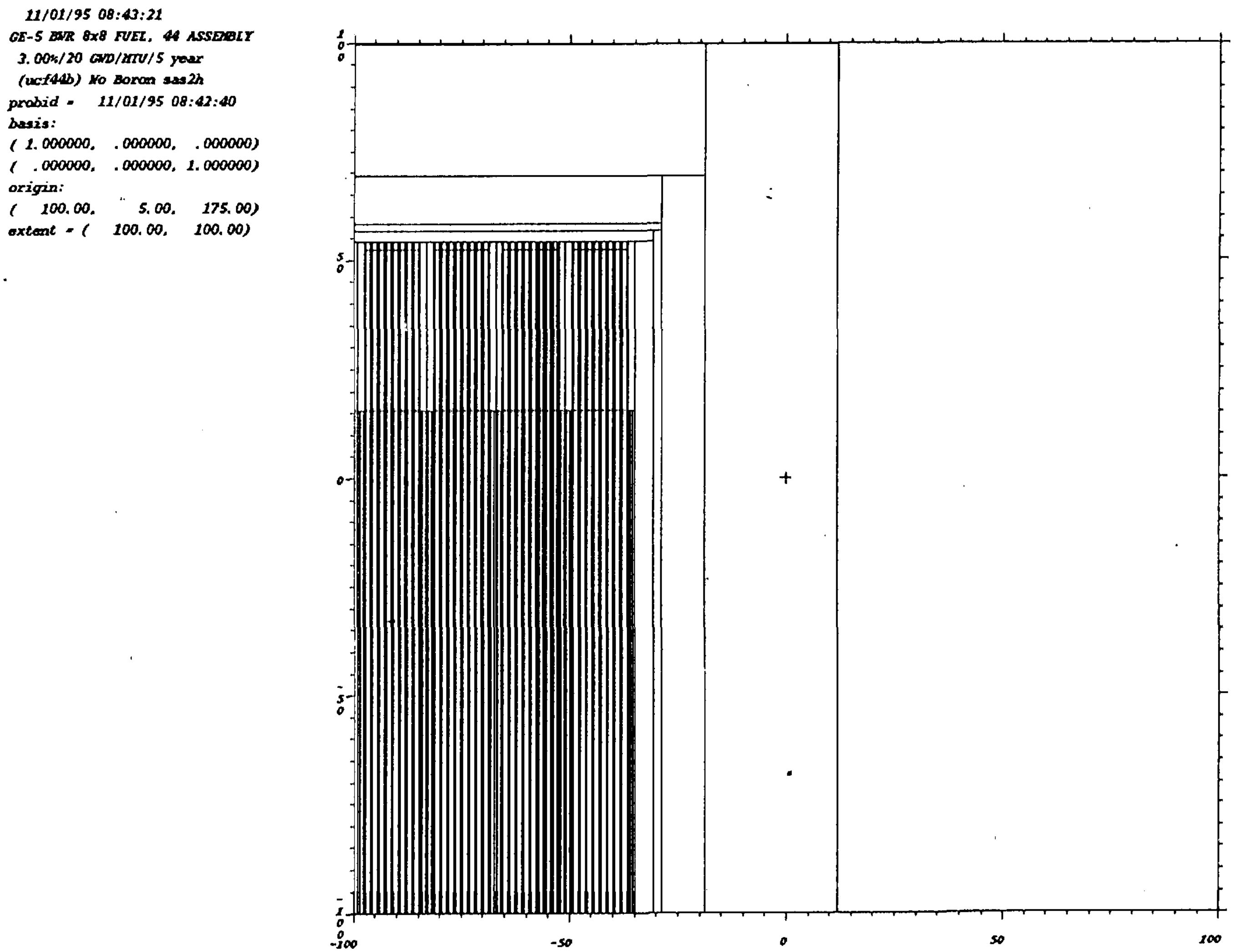

Figure 7.4.2-3. MCNP Axial View of the 44 BWR Assembly UCF WP.

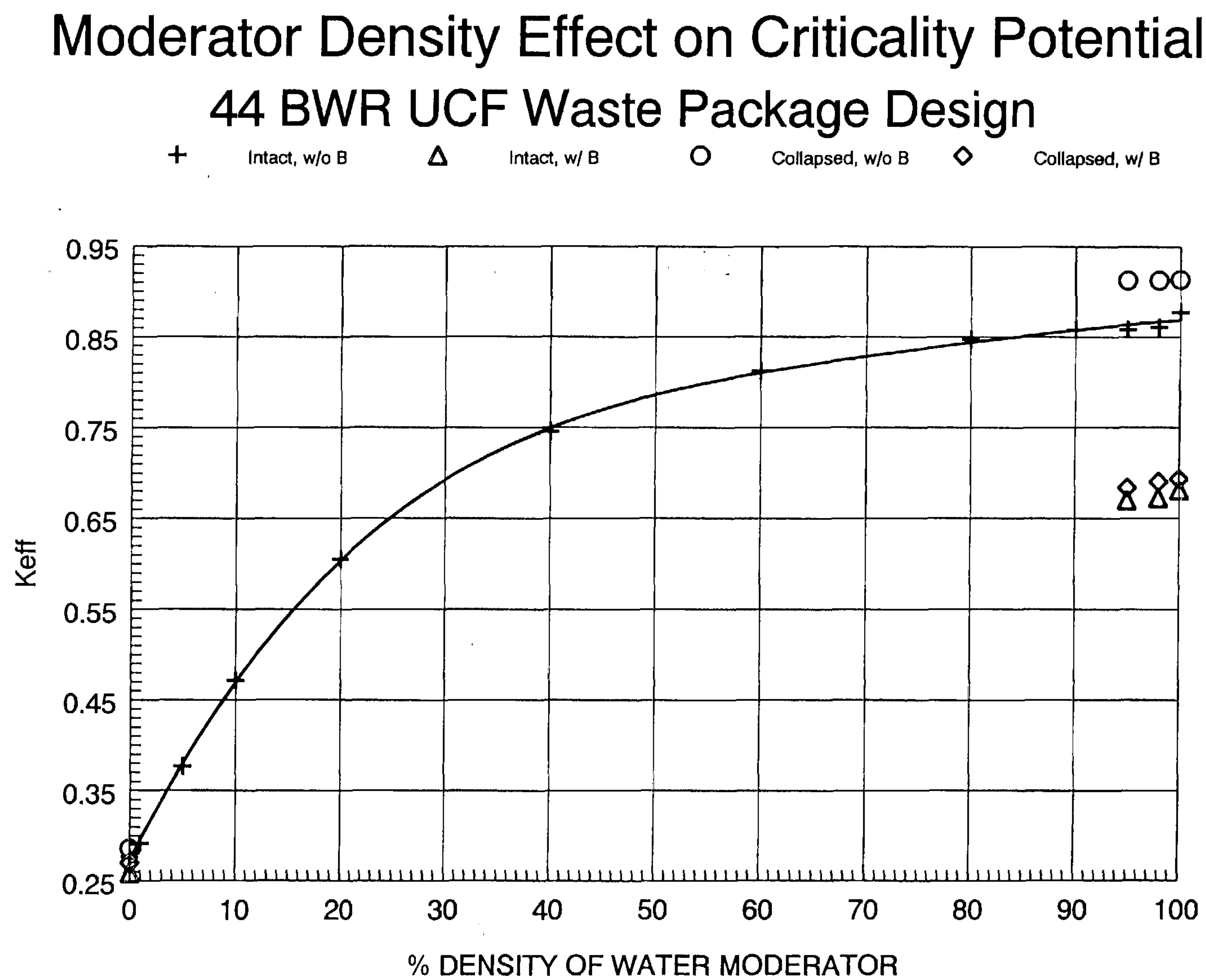

Figure 7.4.2.2-1. Moderator Density Effect on Criticality Potential for the 44 BWR Assembly UCF WP.

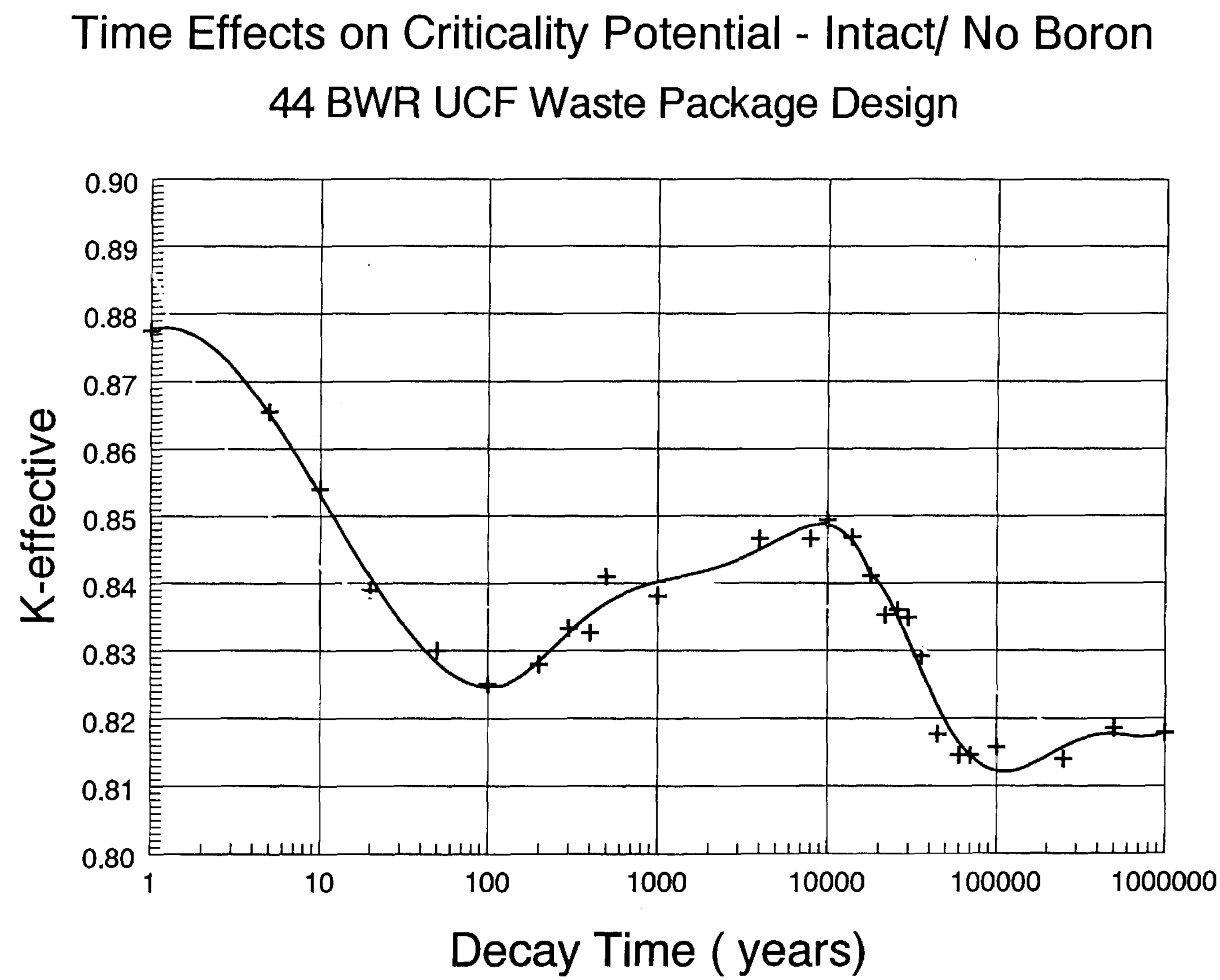

Figure 7.4.2.3-1. Time Effects on Criticality Potential, 44 BWR UCF WP, Intact Array, SS Panels.

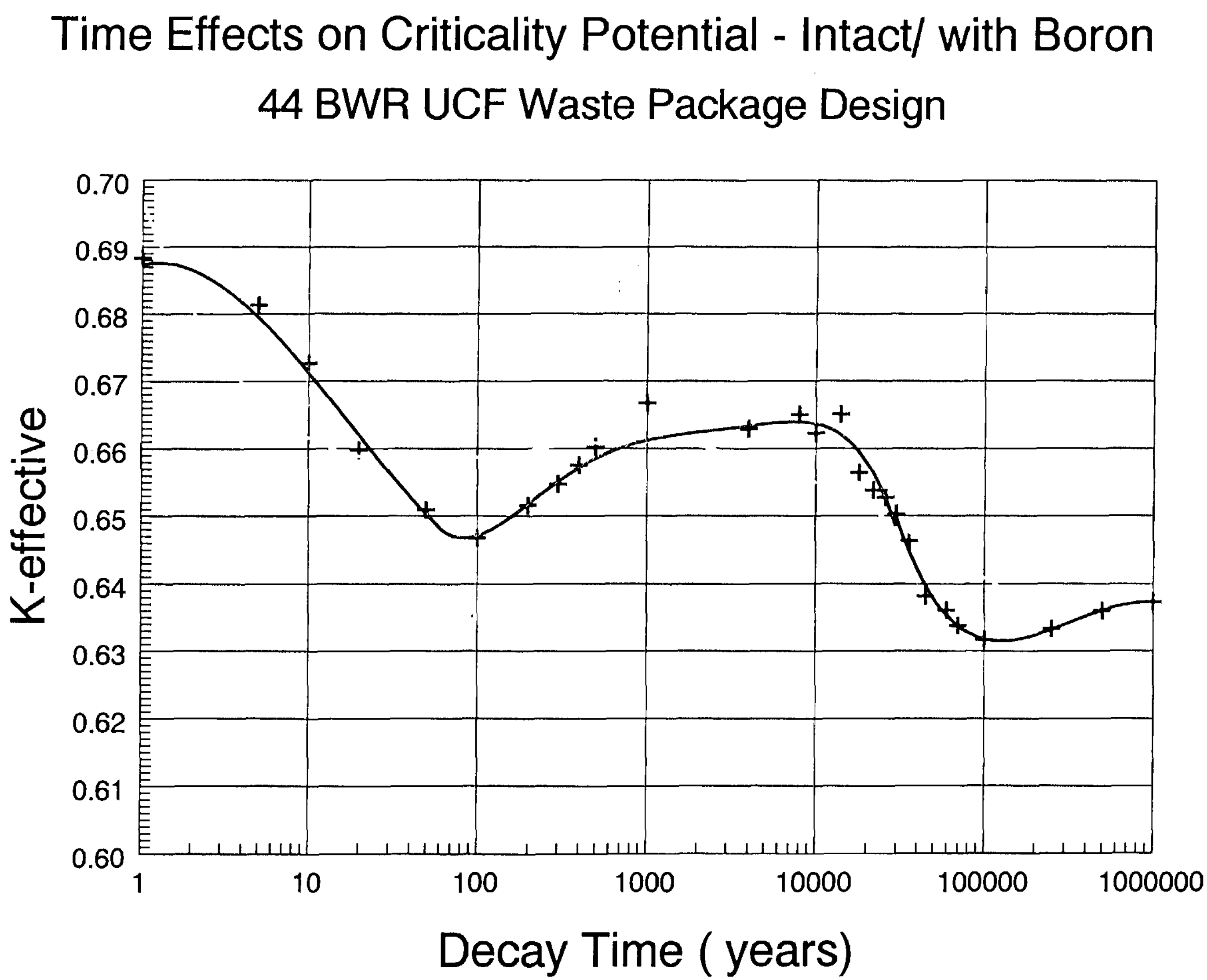

Figure 7.4.2.3-2. Time Effects on Criticality Potential, 44 BWR UCF WP, Intact Array, 316B6A Panels.

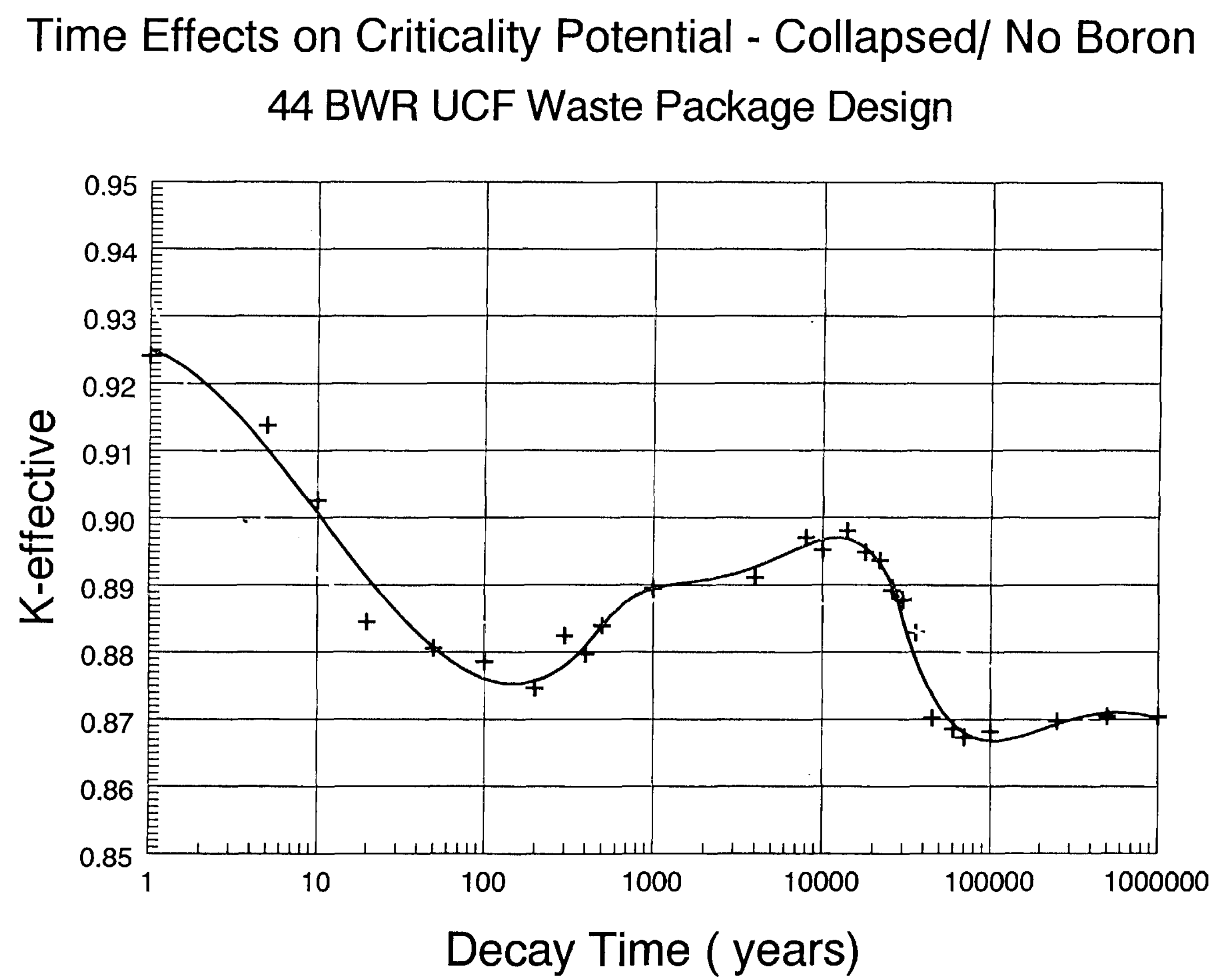

Figure 7.4.2.3-3. Time Effects on Criticality Potential, 44 BWR UCF WP, Collapsed Array, SS Panels.

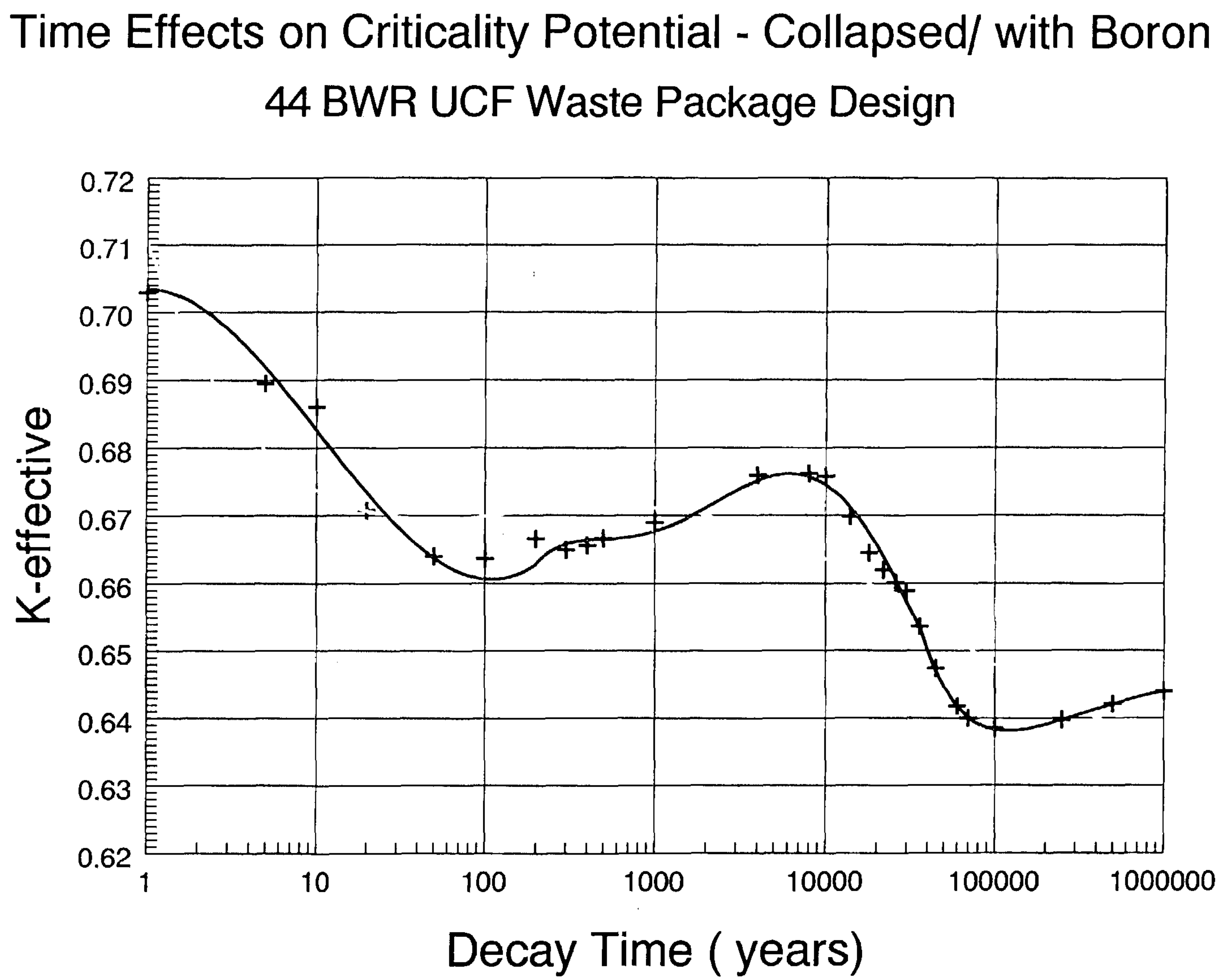

Figure 7.4.2.3-4. Time Effects on Criticality Potential, 44 BWR UCF WP, Collapsed Array, 316B6A Panels.

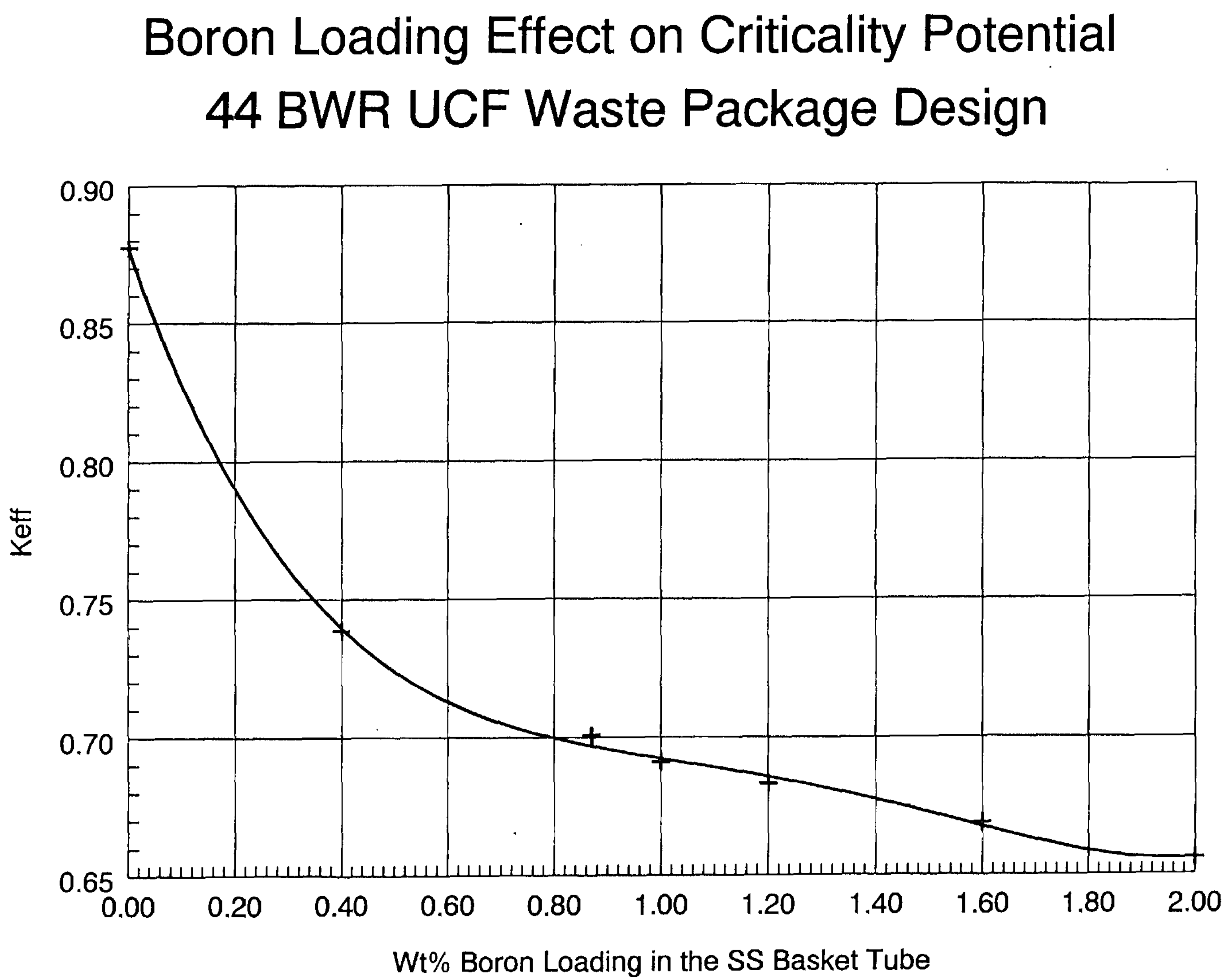

Figure 7.4.2.4-1. Control Panel Boron Loading Effect on Criticality Potential, 44 BWR UCF WP.

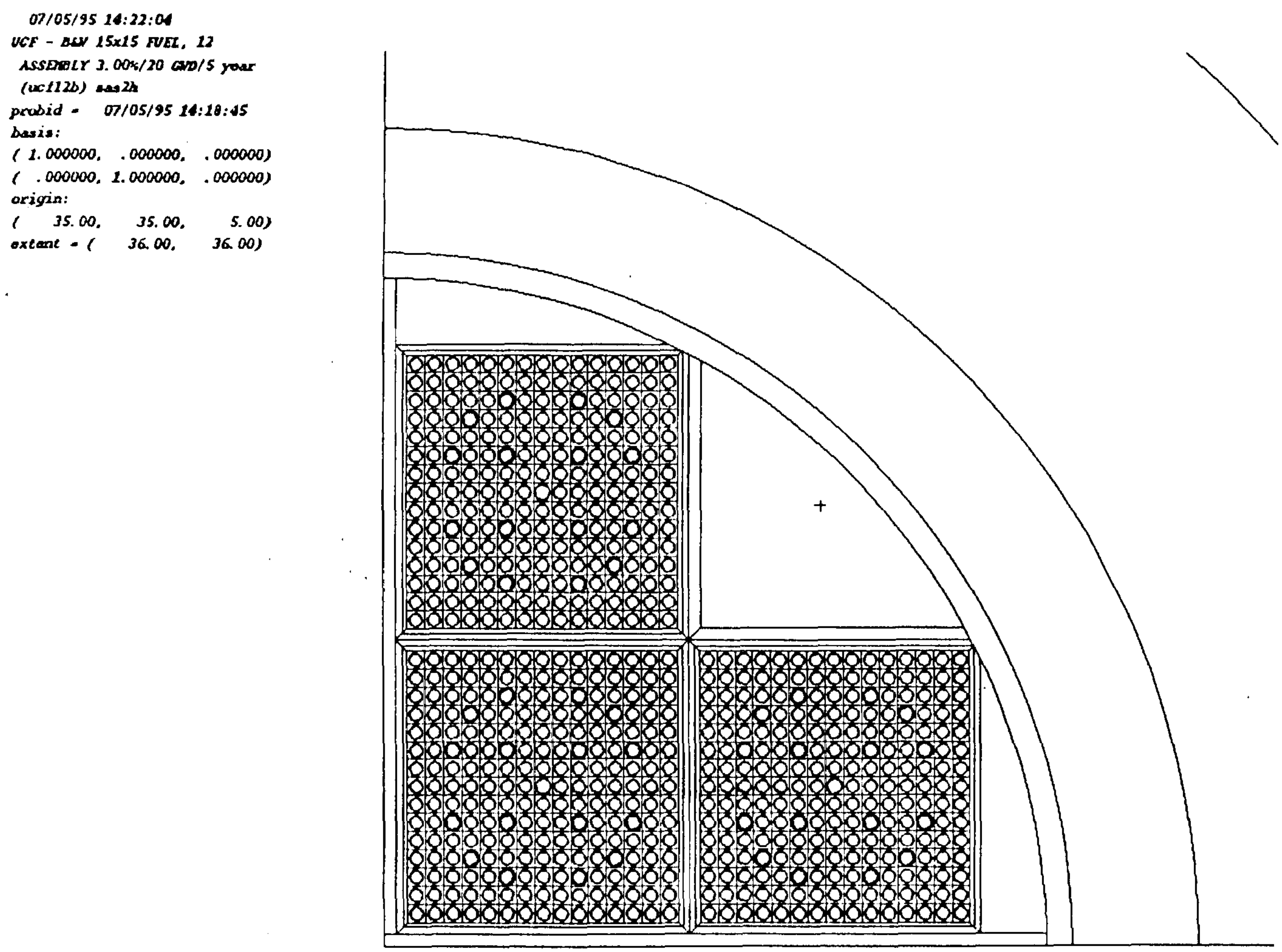

Figure 7.5.1-1. MCNP Cross-Sectional View of the 12 PWR Assembly UCF WP.

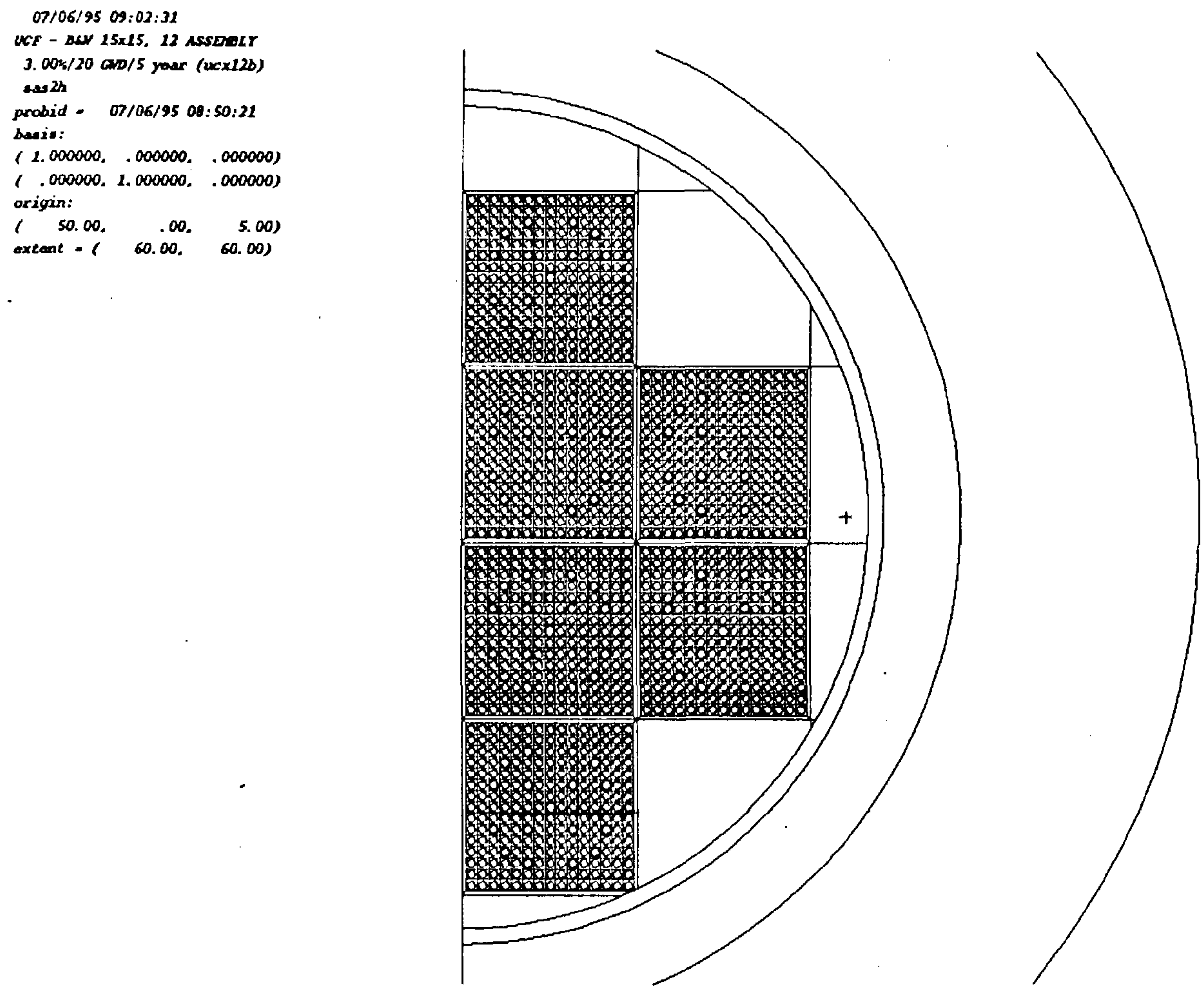

Figure 7.5.1-2. MCNP Cross-Sectional View of the 12 PWR Assembly Collapsed Array UCF WP.

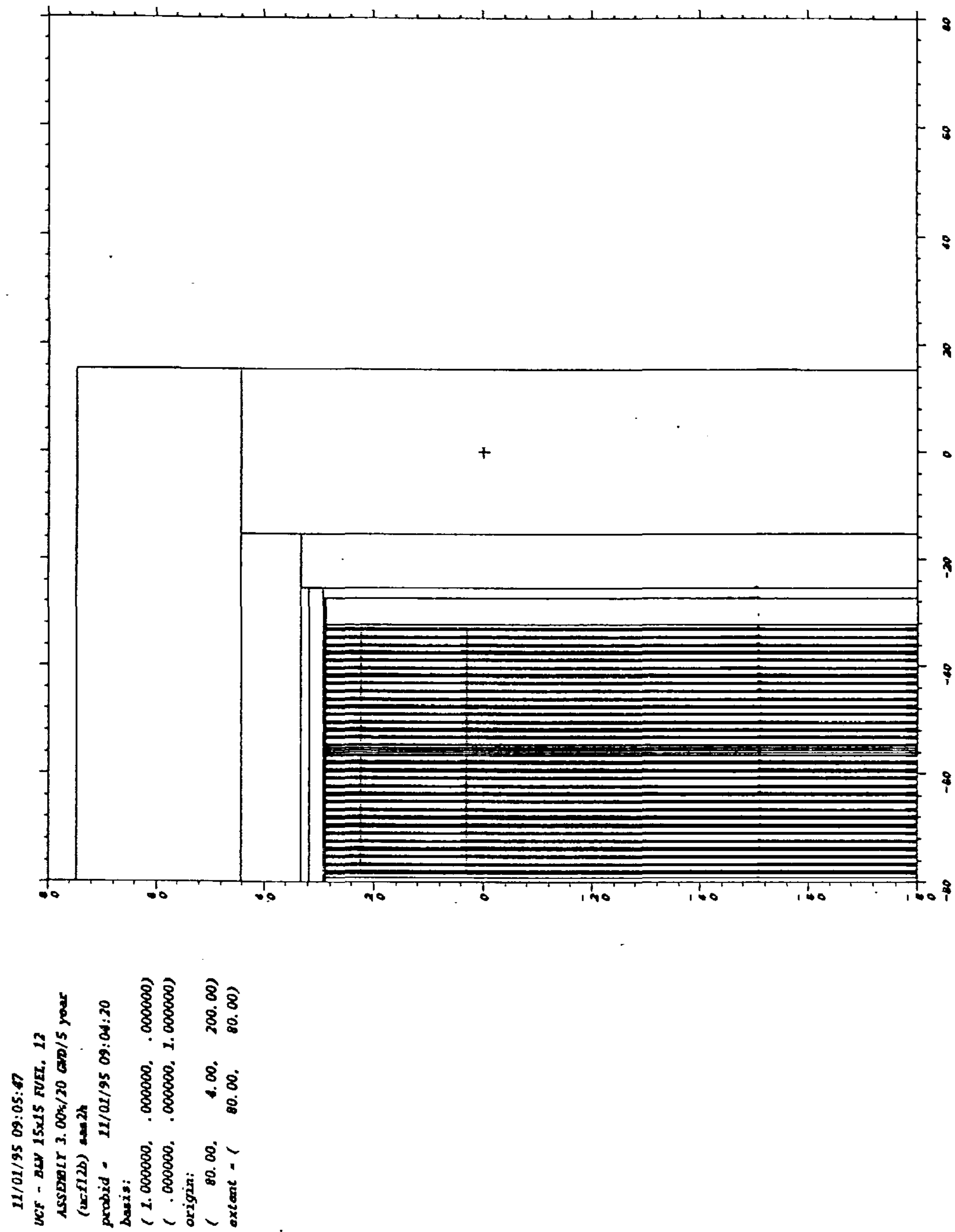

Figure 7.5.1-3. MCNP Axial View of the 12 PWR Assembly UCF WP

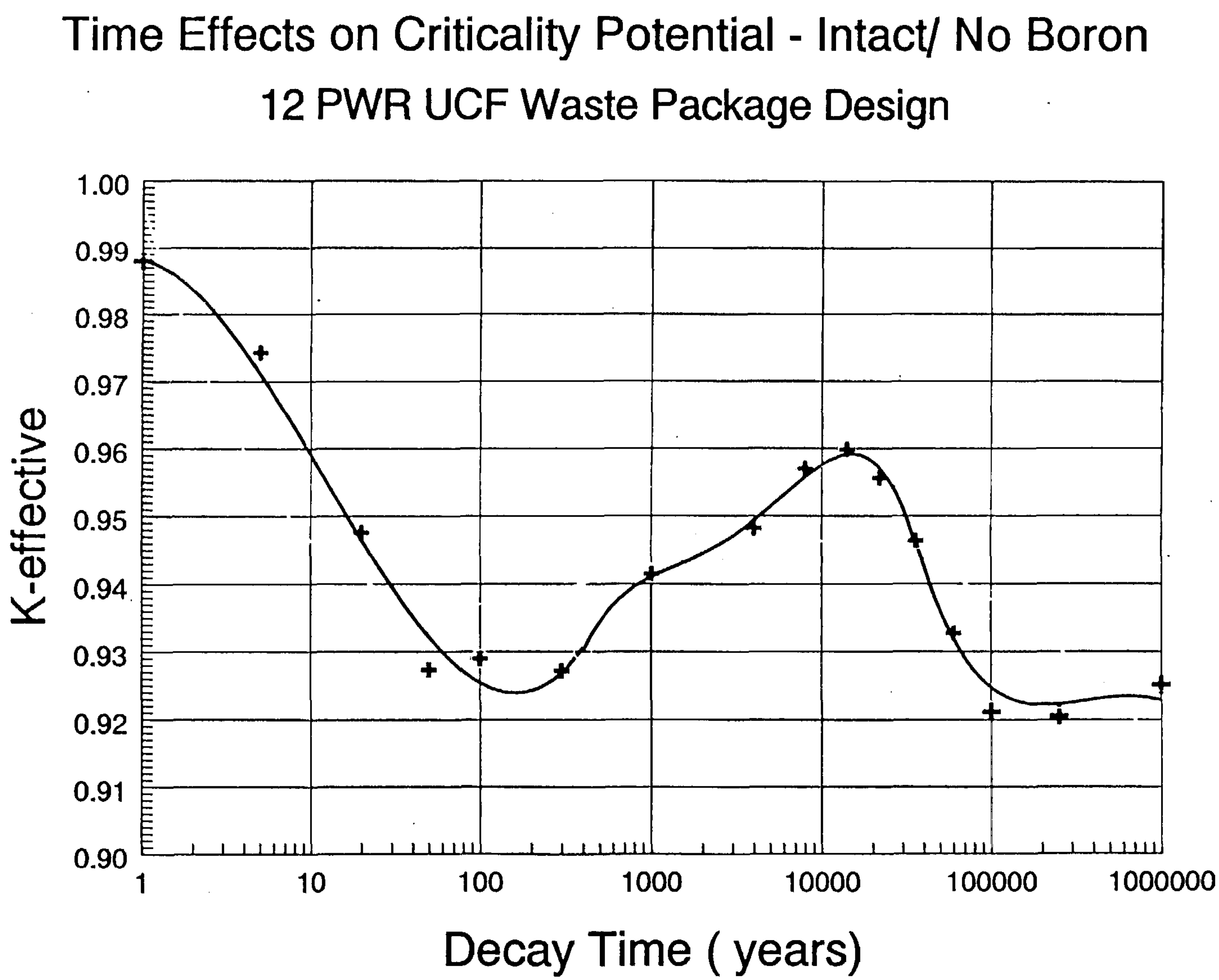

Figure 7.5.1.3-1. Time Effects on Criticality Potential, 12 PWR UCF WP, Intact Array, SS Panels.

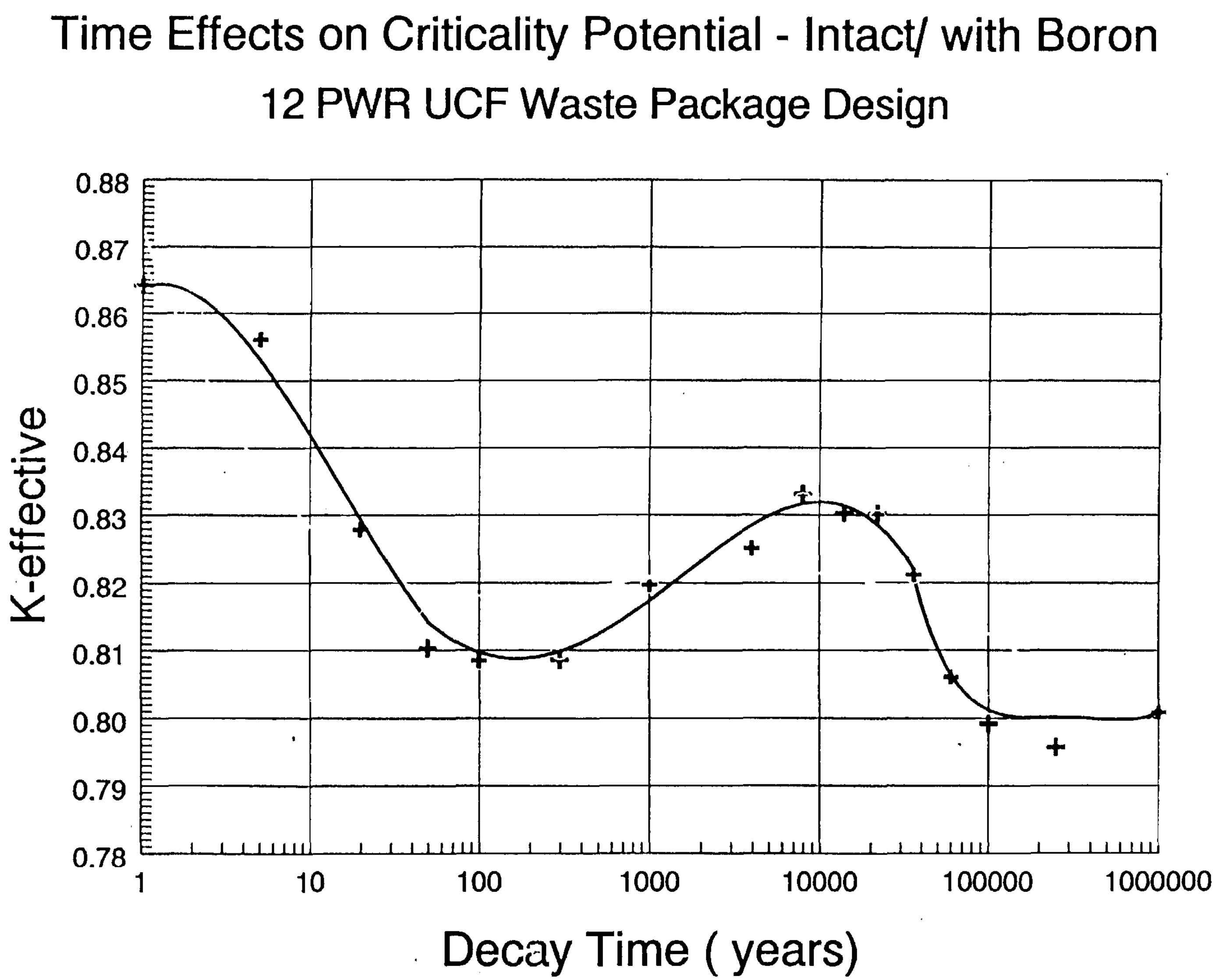

Figure 7.5.1.3-2. Time Effects on Criticality Potential, 12 PWR UCF WP, Intact Array, 316B6A Panels.

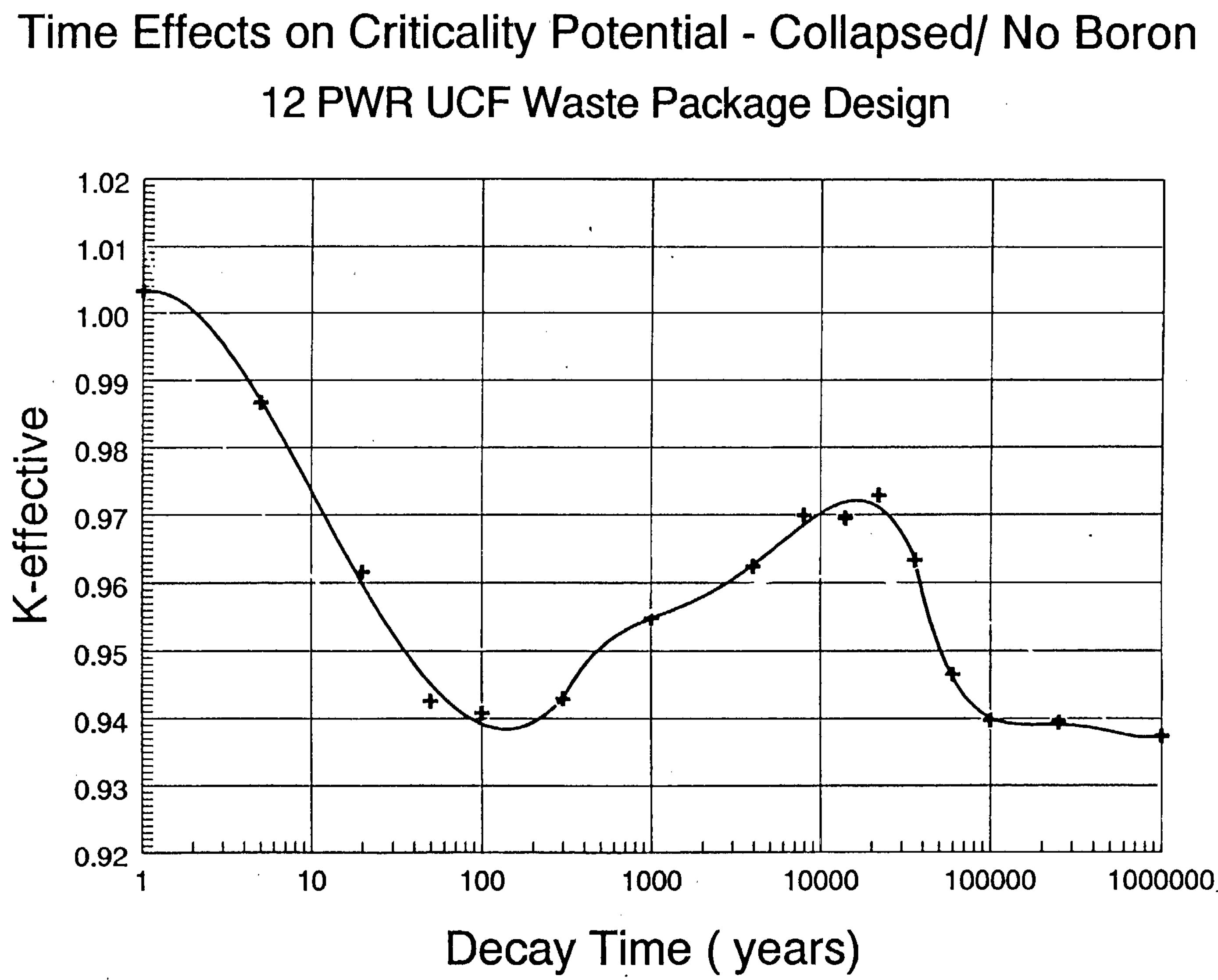

Figure 7.5.1.3-3. Time Effects on Criticality Potential, 12 PWR UCF WP, Collapsed Array, SS Panels.

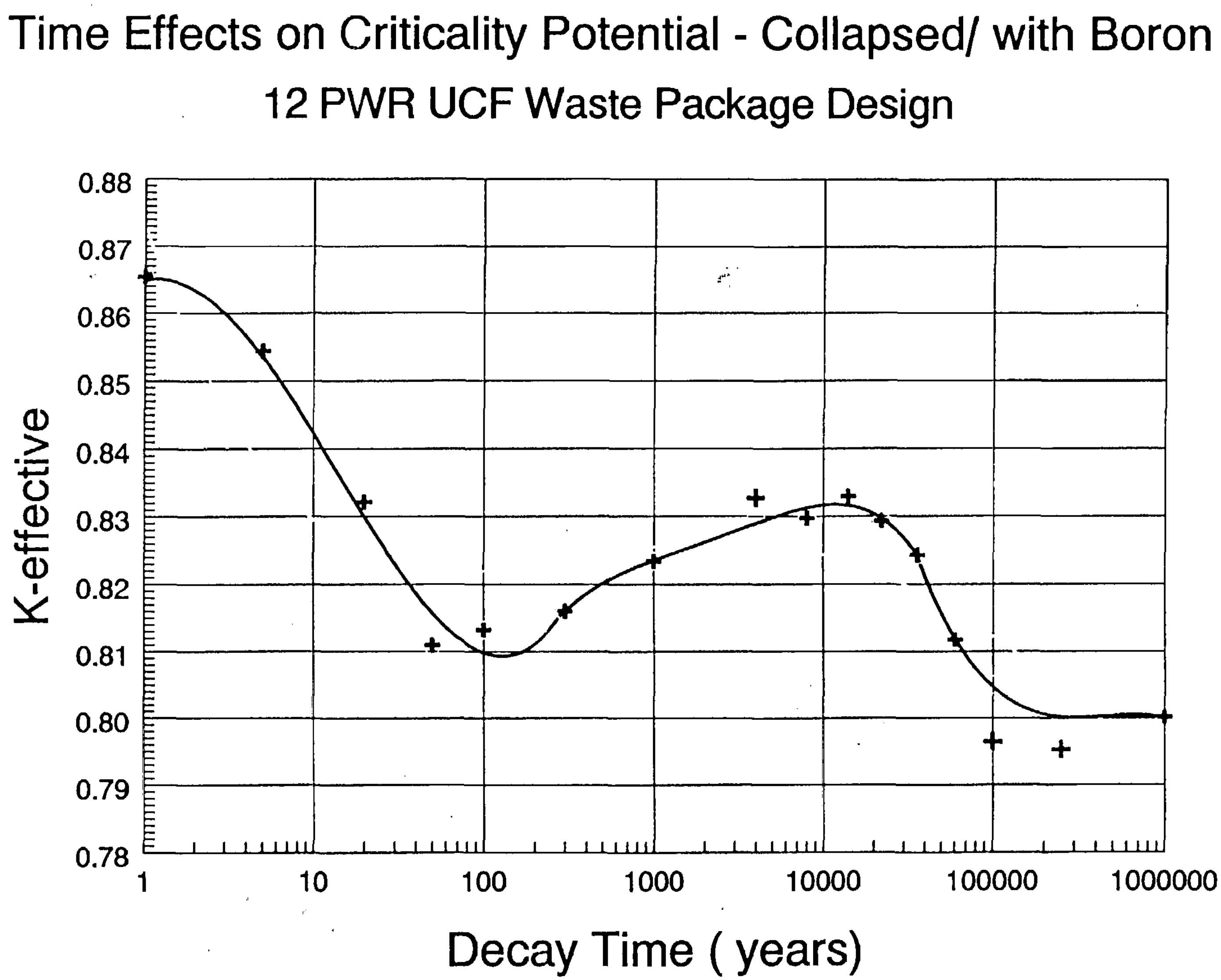

Figure 7.5.1.3-4. Time Effects on Criticality Potential, 12 PWR UCF WP, Collapsed Array, 316B6A Panels.

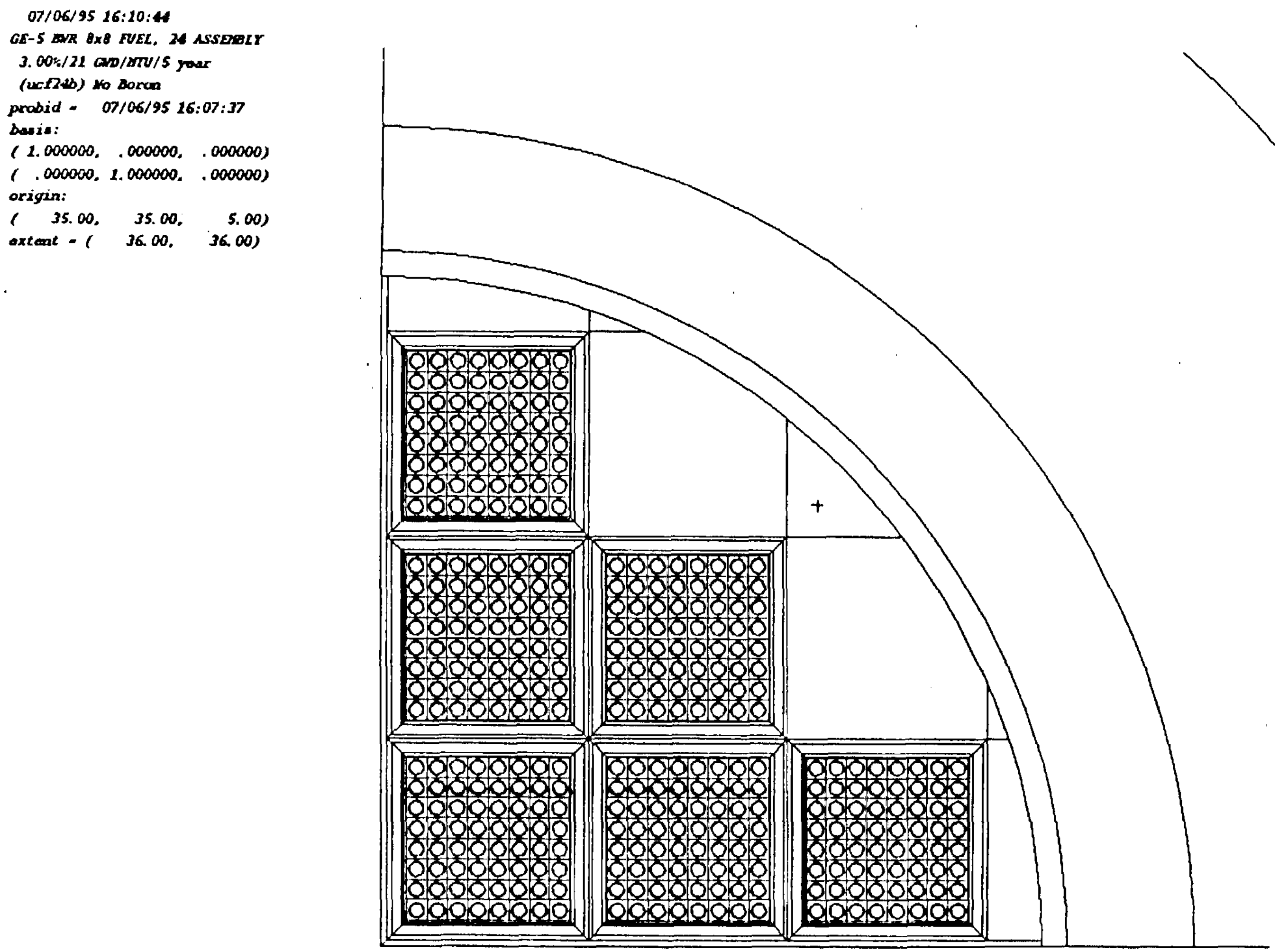

Figure 7.5.2-1. MCNP Cross-Sectional View of the 24 BWR Assembly UCF WP.

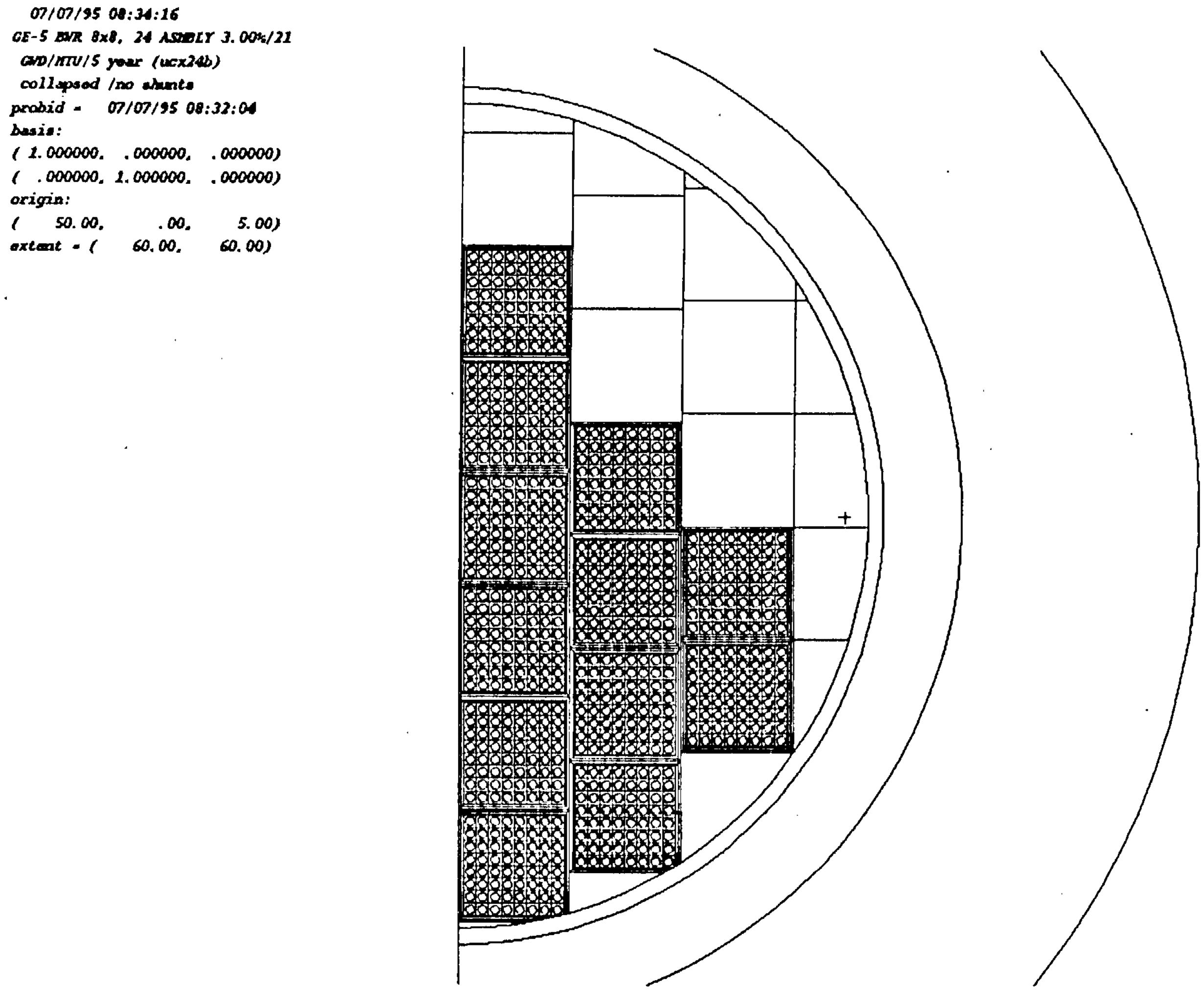

Figure 7.5.2-2. MCNP Cross-Sectional View of the 24 BWR Assembly Collapsed Array UCF WP.

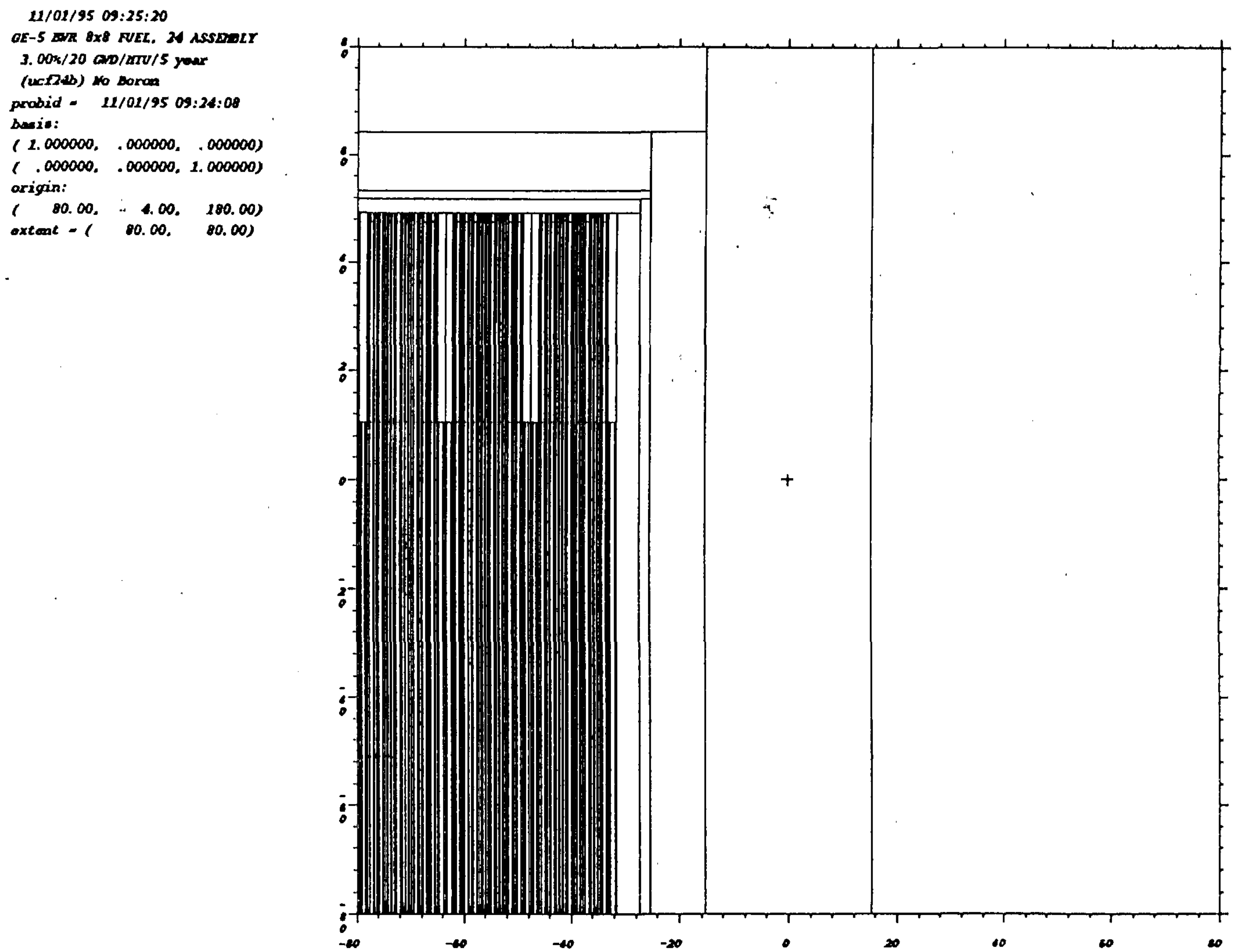

Figure 7.5.2-3. MCNP Axial View of the 24 BWR Assembly UCF WP.

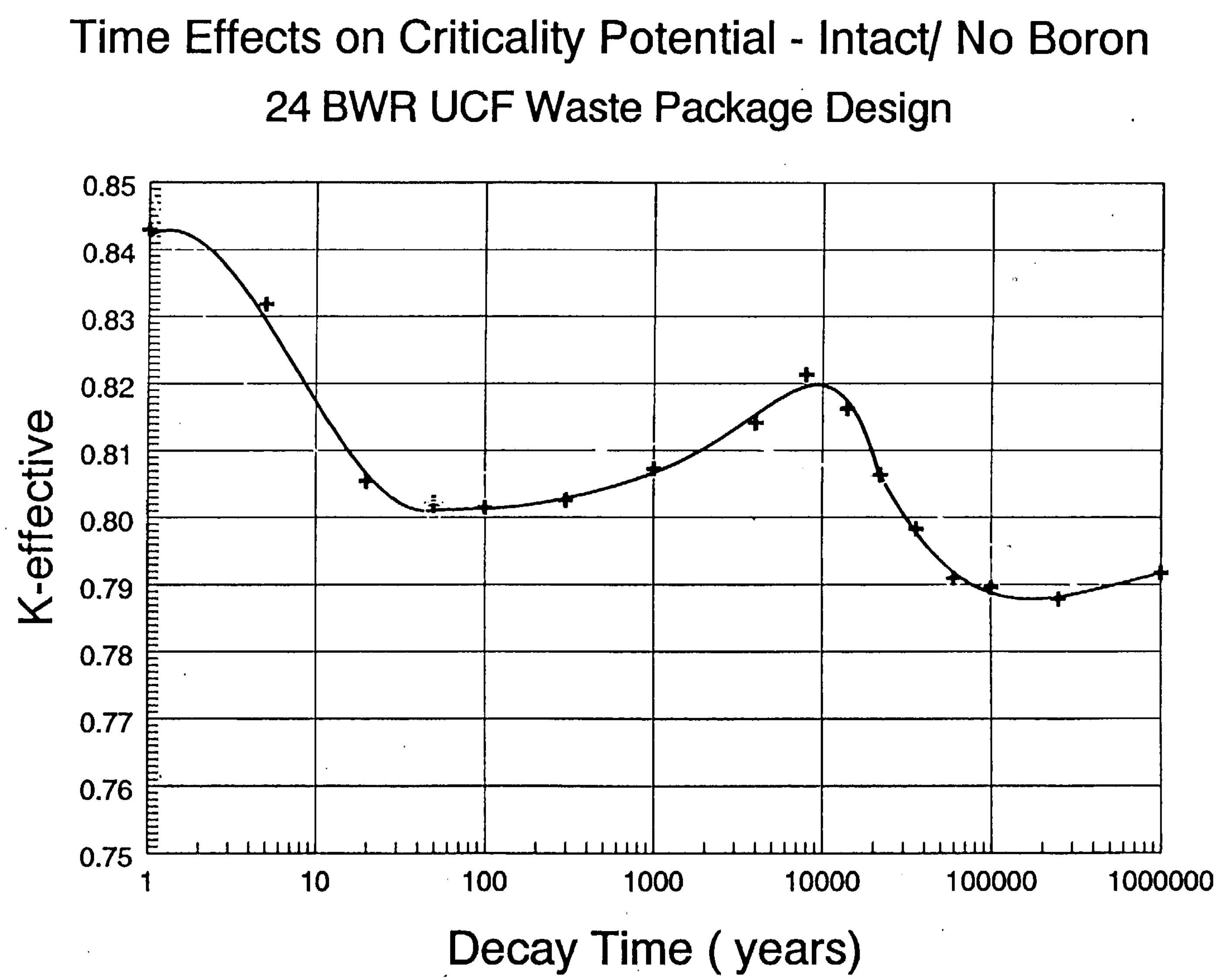

Figure 7.5.2.3-1. Time Effects on Criticality Potential, 24 BWR UCF WP, Intact Array, SS Panels.

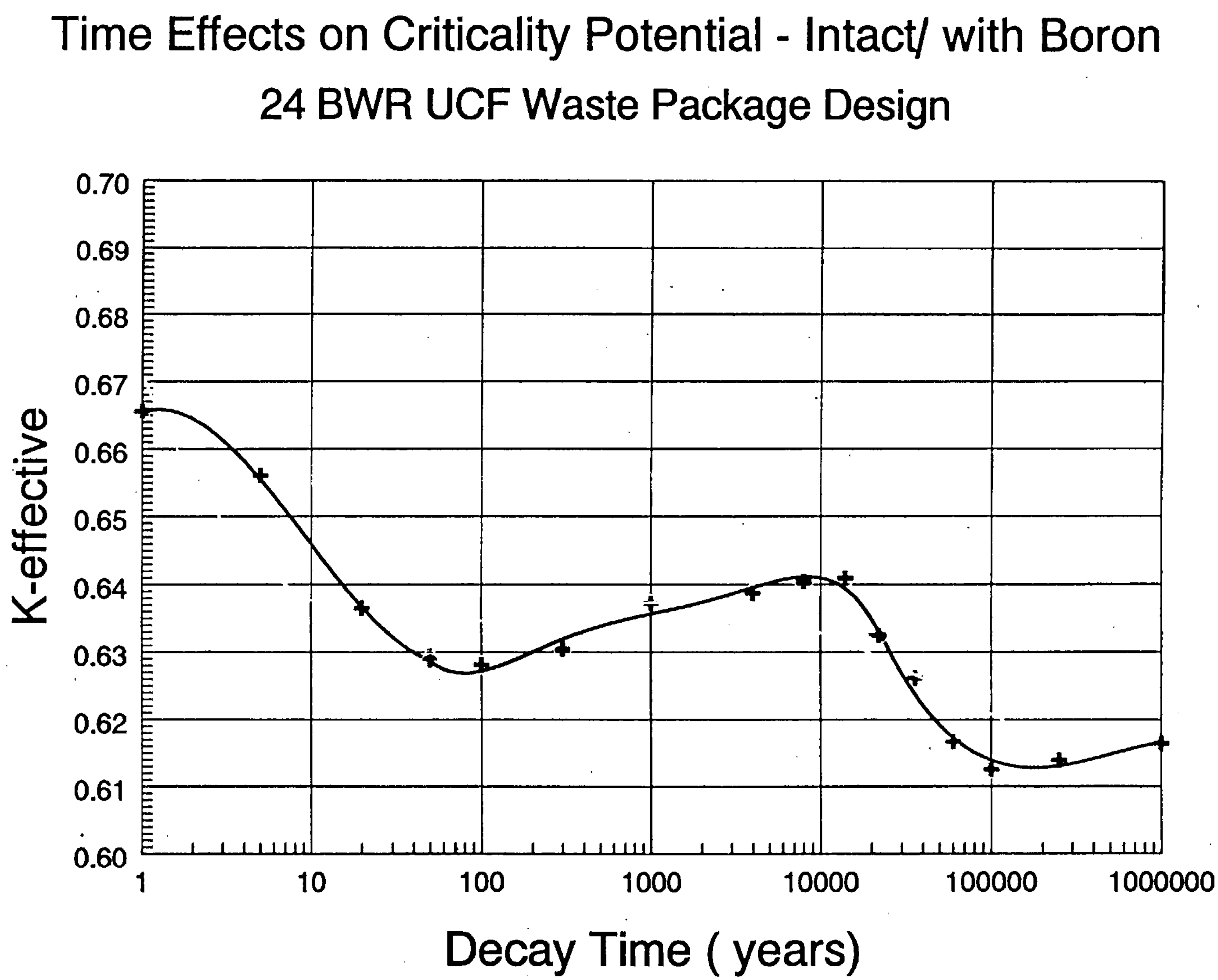

Figure 7.5.2.3-2. Time Effects on Criticality Potential, 24 BWR UCF WP, Intact Array, 316B6A Panels.

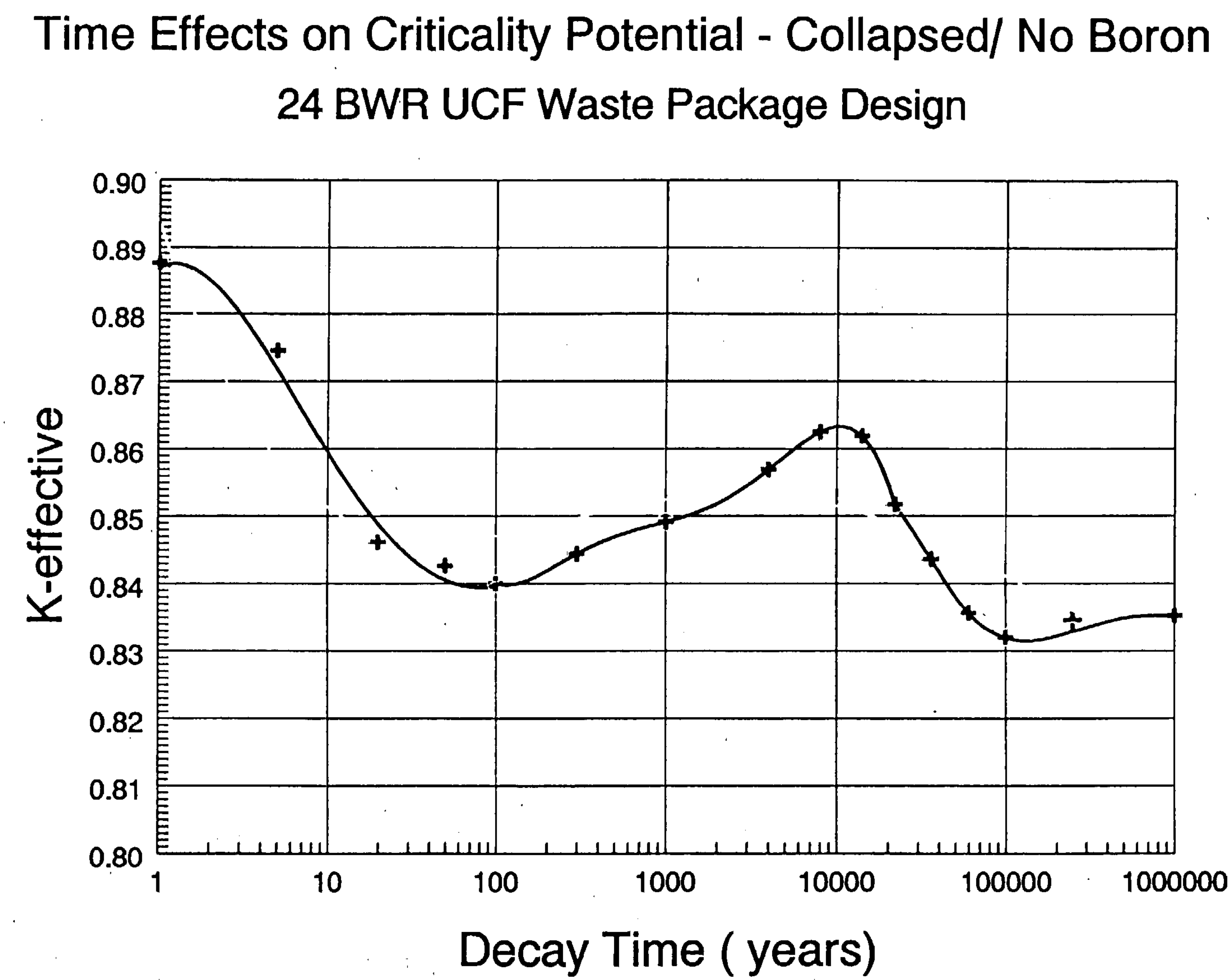

Figure 7.5.2.3-3. Time Effects on Criticality Potential, 24 BWR UCF WP, Collapsed Array, SS Panels.

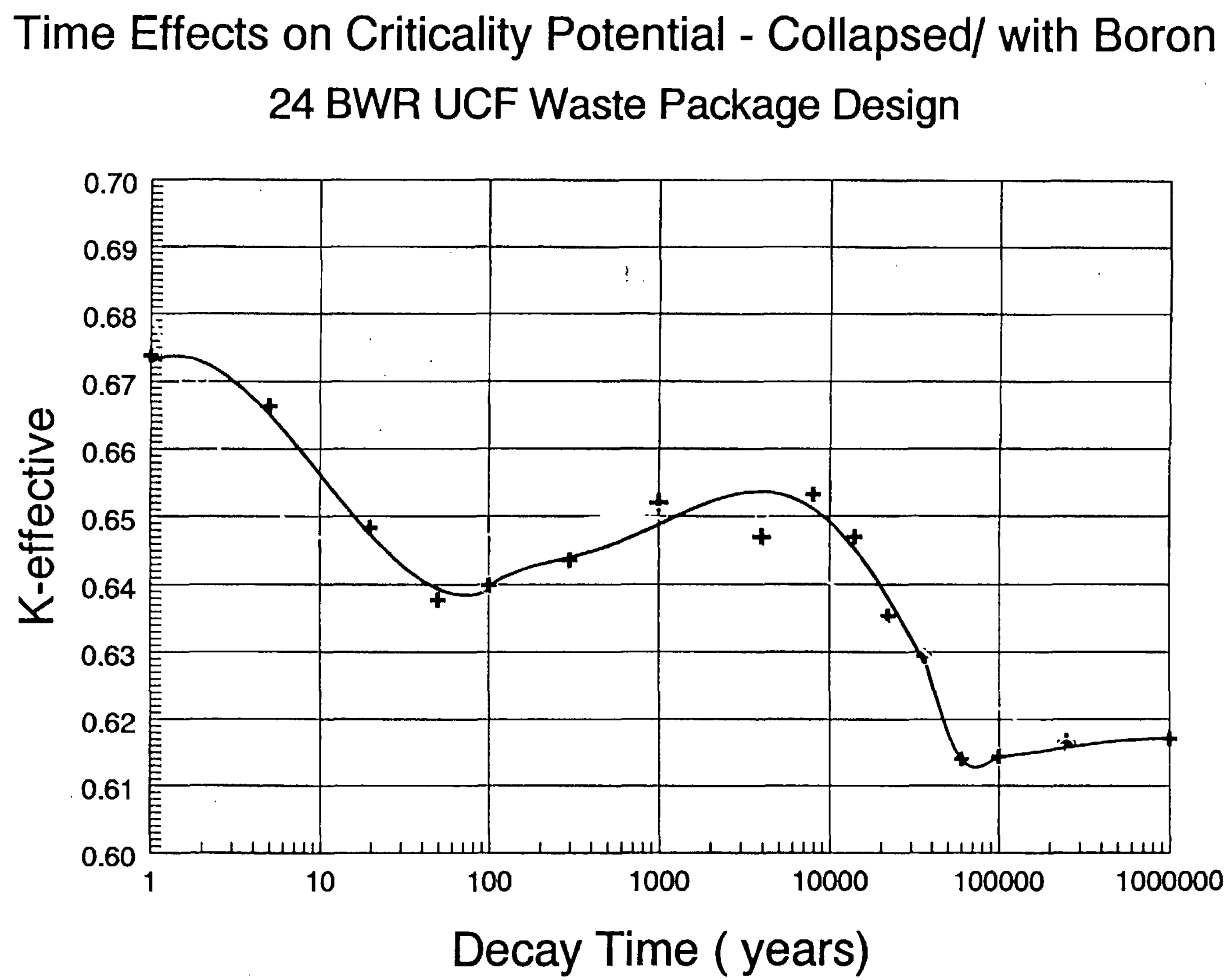

Figure 7.5.2.3-4. Time Effects on Criticality Potential, 24 BWR UCF WP, Collapsed Array, 316B6A Panels.