Global Nuclear Fuel

A Joint Venture of GE, Toshiba, & Hitachi

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December 3, 2004

Mr. E. William Brach, Director
Spent Fuel Project Office, M/S O-13D13
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Subject: GNF-A's Response to the NRC's 5/26/04 RAI for the Model RA-3 Package – TAC No. L23695

Reference(s):
(1) Certificate of Compliance (CoC) 4986, Docket 71-4986
(2) Application Dated 1/21/04
(3) NRC Request for Additional Information (RAI) Dated 5/26/04

File name "GNF-A RA-3 4986 12.3.04 Proprietary" is on the enclosed CD that contains business proprietary Information. GNF-A requests that this file be withheld from public disclosure in accordance with 10CFR2.390. Attachment 5 of this application contains Proprietary information. Upon removal of this attachment, this application is decontrolled.

File name "GNF-A RA-3 4986 12.3.04 Publicly Available" is on the enclosed CD that contains publicly available Information, because the content of Attachment 5 has been removed.

Dear Sir:

Global Nuclear Fuel – Americas, LLC (GNF-A) in Wilmington, NC hereby submits our response to the 5/26/04 Request for Additional Information (RAI) related to Certificate of Compliance number 4986 for the Model RA-3 package. This application replaces our application of 1/21/04 in its entirety.

After our initial review of the RAI and discussions with the staff, we determined that a response would have to be delayed from 6/28/04 until no later than 12/10/04. To answer the RAI, we determined a completely new set of criticality calculations including certain benchmarking calculations and bias evaluations were required.

The following are Attachments to this letter:

Attachment 1 is suggested wording for Condition 5(b)(1)(iii) of NRC CoC 4986.
Attachment 2 is the Affidavit requesting the information identified as proprietary within this application be withheld from the public. The original affidavit is enclosed with the transmittal letter.

Attachment 3 is the summarized response to the NRC's request for additional information.

Attachment 4 is the non-proprietary version of the Criticality Safety Analysis (CSA) and the GEMER Monte Carlo Validation Report. This report is not a proprietary document.
An asterisk has been placed in the right hand margin of the CSA indicating the removal of proprietary information from that page. The sections removed within the text are indicated with a double bracket. This version has been identified as Appendix 7-J(a), because it is associated with the existing 10x10 analysis.

Attachment 5 is GNF-A's Proprietary Information Notice and the proprietary version of the Criticality Safety Analysis and has been marked in accordance with 10CFR2.390(b)(1)(i). The proprietary marking is on the top of the first page of the document and on the top of each page containing proprietary information. The proprietary information has been identified by enclosing it in double brackets with a superscript notation $^{\{3\}}$ of the enclosed Affidavit that provides the basis for the proprietary determination. This version has been identified as Appendix 8-J(a), because it is associated with the existing 10x10 analysis.

Attachment 6 contains replacement / new pages to the existing consolidated application. They are identified on the footer showing the date of the change and the revision number.

This application is being submitted on two CD's accompanied by this original letter and the original affidavit. As stated at the beginning of this letter, one CD contains proprietary information and the other one contains publicly available information.

Please contact me on (910) 675-5656 or at charles.vaughan@gnf.com if you have any questions.

Sincerely,

Global Nuclear Fuel – Americas, L.L.C.

Original Signed by Richard Foleck
Acting for CM Vaughan

Original Signed Letter Enclosed with Transmittal

Charles M. Vaughan, Manager
Facility Licensing
P.O. Box 780, Mail Stop K-84
Wilmington, NC 28402

cc: CMV-04-052

FILE NAME: GNF-A RA-3 4986 12.3.04 Proprietary
FILE SIZE: 2.7 MB

FILE NAME: GNF-A RA-3 4986 12.3.04 Publicly Available
FILE SIZE: 2.3 MB

ATTACHMENT 1

Suggested wording to be used in Condition 5.(b)(1)(iii) of NRC CoC 4986 at the end of the existing paragraph.

"and Section 5.1 and Table 5.1 contained in Appendix 8-J(a) of the application dated 12/03/04."

ATTACHMENT 2

Affidavit

Affidavit

I, Lon E. Paulson, state as follows:

(1) I am Manager, Nuclear Safety, Global Nuclear Fuel – Americas, L.L.C. ("GNF-A") and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in the attachment, "GNF-A's Response to the NRC's 5/26/04 RAI for the Model RA-3 Package – TAC No. L23695," December 3, 2004. GNF-A proprietary information is indicated by enclosing it in double brackets. In each case, the superscript notation $^{\{3\}}$ refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which it is the owner or licensee, GNF-A relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4) and 2.390(a)(4) for "trade secrets and commercial or financial information obtained from a person and privileged or confidential" (Exemption 4). The material for which exemption from disclosure is here sought is all "confidential commercial information," and some portions also qualify under the narrower definition of "trade secret," within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by GNF-A's competitors without license from GNF-A constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals cost or price information, production capacities, budget levels, or commercial strategies of GNF-A, its customers, or its suppliers;

d. Information which reveals aspects of past, present, or future GNF-A customer–funded development plans and programs, of potential commercial value to GNF-A;

e. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a. and (4)b., above.

(5) To address the 10 CFR 2.390 (b) (4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GNF-A, and is in fact so held. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in (6) and (7) following. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GNF-A, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge, or subject to the terms under which it was licensed to GNF-A. Access to such documents within GNF-A is limited on a “need to know” basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his delegate), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GNF-A are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2) is classified as proprietary because it contains details of GNF-A’s fuel design and licensing methodology.

The development of the methods used in these analyses, along with the testing, development and approval of the supporting methodology was achieved at a significant cost, on the order of several million dollars, to GNF-A or its licensor.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GNF-A’s competitive position and foreclose or reduce the availability of profit–making opportunities. The fuel design and licensing methodology is part of GNF-A’s comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC–approved methods.

The research, development, engineering, analytical, and NRC review costs comprise a substantial investment of time and money by GNF-A or its licensor.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GNF-A's competitive advantage will be lost if its competitors are able to use the results of the GNF-A experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GNF-A would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GNF-A of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing and obtaining these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed at Wilmington, North Carolina, this 3rd day of December, 2004.

Original Signed by Lon E. Paulson

Original Signed Affidavit Enclosed with Transmittal

Lon E. Paulson
Global Nuclear Fuel – Americas, LLC

Response To NRC RAI For Model No. RA-3

> ***Reference:*** ***Certificate Of Compliance No. 4986 For The Model No. RA-3 Package – Request For Additional Information, JR Cuadrado (USNRC, Spent Fuel Project Office, Office of NMSS) To CM Vaughan (GNF-A, Manager, Facility Licensing), Docket No. 71-4986, TAC No. L23695, May 26, 2004.***

Introduction

The following discussion serves to answer concerns expressed in the referenced RAI and are organized into eight sections to match the eight sections in the RAI. (There are two distinct parts to the first section.)

The RAI appears to question the adequacy of the analytical bias that has been used in the past. Therefore, a new validation is incorporated into the RA-3 analysis for GNF2 fuel. The new validation results in a lower USL, requiring that the undamaged container array size and damaged container array sizes be adjusted accordingly.

The RAI also appears to disagree with the approach taken of demonstrating similarity between the GNF2 fuel and the generic 10x10 fuel design for one arrangement of enrichment and gadolinium and inferring similarity for the other arrangements. Therefore, a revised submittal is made stand alone with explicit analysis of all arrangements for GNF2 fuel, dropping the reactivity comparison arguments.

NRC RAI 6-1

6-1 Establish the bias of the calculation method used in the current application, analyzing benchmarks that closely resemble the proposed fresh fuel contents and packaging.

The validation of the GEMER code is briefly described in Section 2.4 of the proposed Appendices 7-J(a) and 8-J(a) of the application. The code is said to have been compared against over one hundred critical experiments. However, this validation appears to have been performed with a different version of the code and different hardware than was used to perform the analyses for the proposed contents. Comparison of results between the previous code system and the code system used in the amendment application was done for a particular fuel assembly to validate the new code systems.

ANSI/ANS-8.1 states that validation and the bias of a computational method cannot be established by comparing results with another computational method.[1] *Proper benchmarking is required to establish computational bias and to ensure that the requirements for subcriticality are met. Benchmarking should properly account for the computer code (including version), hardware, and cross-section library used to calculate the k-effective values in the package analysis.*[2]

Analyses of critical experiments that most closely represent the package models analyzed in the application are sufficient for determining bias.

Additionally, for the single undamaged package model, the k-effective results significantly differ between the previous code system and the code system used in the amendment application for low inter-unit water densities (less that 5% of full density water. In comparison, for the array models, results from the two code systems appear to closely agree for the same low inter-unit densities. While this low water density region is not of interest for the single undamaged package model, it is important in the analysis of package arrays. Thus, the question arises as to why the two code systems' results significantly differ for the single undamaged package model when the results for the array models closely agree and the purpose of the applicant's comparison is to demonstrate that the two code systems are equivalent.

This information is needed to determine compliance with 10 CFR 71.55(b), (d), (e), and 71.59.

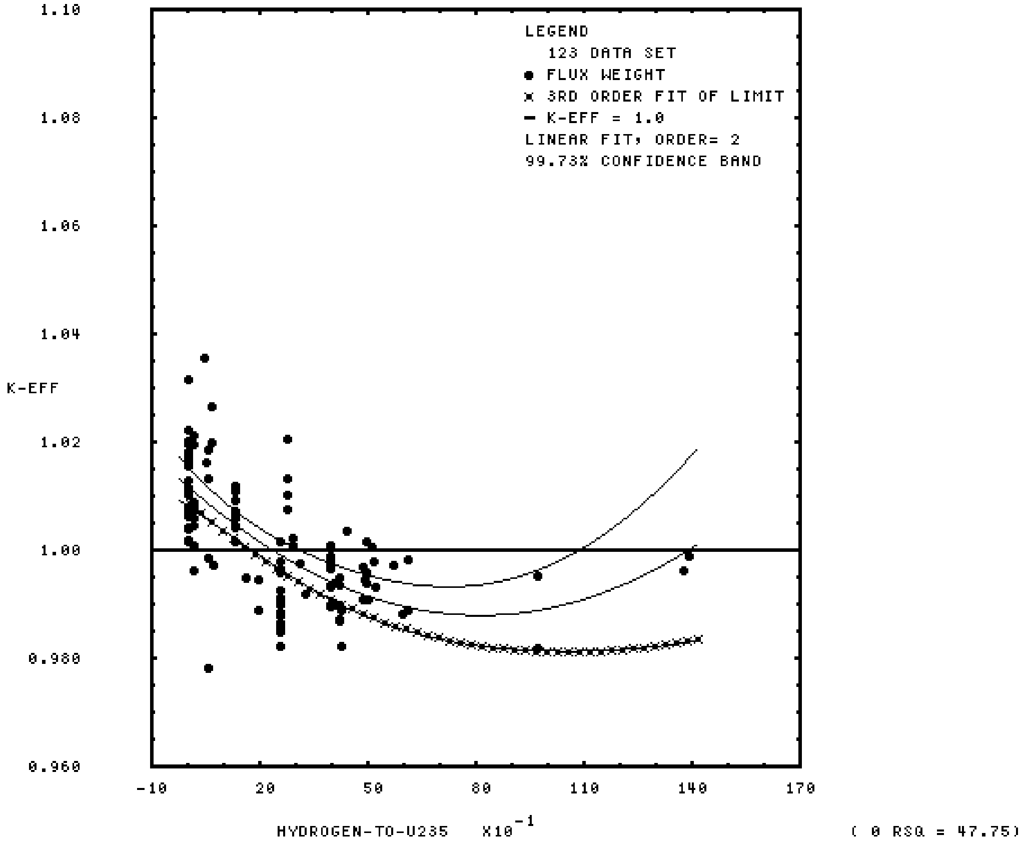
GNF-A Response: 6-1.a – Establish the bias

Validation/bias is always an interesting topic. The description of the bias provided in the criticality safety demonstration was taken from the RA-3D shipping container analysis performed in 1995 for the generic 10X10 fuel assemblies with cluster separators. That analysis was performed using GEMER01V, an implementation of the GEMER.4 program for DEC VAX platforms. The bias for the GEMER10 program (PC platform) is the same as that for the GEMER01V program (VAX platform) based on the discussion below. The bias was not emphasized in the current analysis since the main objective of the current analysis was to show no significant difference between the calculations with the GNF2 fuel design and the generic 10x10 fuel assemblies previously analyzed. Because of the similarity between the two fuel assemblies, the bias is the same for equivalent calculations (i.e.- same shipping container model and moderation condition).

Providing the geometry treatment is "correct", in principle the calculational bias is a function only of the cross-section treatment. In actual application, it is also a function of the calculational uncertainty, degree of convergence, choice of representative critical experiments, errors in description of the critical conditions, and development of a fit and uncertainty of that fit. The forerunner of the GEMER program was the MERIT program, which ran on HONEYWELL 3000 and CDC 7600 platforms, and which used a 190 multigroup structure and explicit resonance treatment to generate cross-sections from the ENDFB-IV cross-section basic data. Since MERIT was used mainly for reactor physics calculations, the validation used mainly reactor experiments having a typical fuel assembly water-to-fuel ratio. The MERIT program validation claimed an expected bias of approximately –0.005 (defined to be kcalc –1.0) with a 3σ uncertainty 0f 0.006.

The GEMER program was developed in 1980 to run on PRIME mini-computers. GEMER uses the same cross-sections and treatment as MERIT. Therefore, the calculational bias is in principle the same as for MERIT. The original GEMER program was validated using 120 critical experiments representing a wide range of conditions (fuel type, enrichment, structure, geometry, moderation, and reflection). This validation produced a calculational bias that was a function of the hydrogen-to-U235 atom ratio and was represented as the lower 3σ confidence limit on a second order linear fit. This fit is provided in the following figure.

FIGURE 3 - GEMER BIAS DETERMINATION, FLUX WEIGHT



A revision to the GEMER program was made in 1988 which produced GEMER.4. The validation for this program produced a similar calculational bias fit. (Differences are attributed to calculational uncertainty and convergence. Naturally, the Central Limit Theorem says that the calculational uncertainty should pretty much disappear from the fit because of the number of calculations.) The GEMER and GEMER.4 fits were compared, and the more conservative fit was selected. This enabled both programs to be used in analysis with the same bias correction.

In 1990 a version of GEMER.4 was created in San Jose to run on a DEC VAX platform. This version was named GEMER01V and was validated in San Jose using the same 120 benchmark set of critical experiments. The requirement for acceptance of this validation was agreement with the GEMER.4 validation results based on review of the results in Wilmington. This agreement was achieved.

In 1994, GEMER.4 was converted to run on an 80X86 compatible PC using Lahey FORTRAN 77. The resulting compilation was named GEMER0.0. The same set of 120 critical experiments was used to validate GEMER0.0 with the same selection of most conservative bias fit as was used before. Two subsequent revisions (GEMER0.1 and GEMER0.2) were developed. In 2003, GEMER0.2 was converted to Lahey FORTRAN 90 and released as GEMER1.0. GEMER1.0 was validated with the same 120 critical experiments. For all of these versions, the validations produced similar fits as would be expected since all of these versions use the same cross-section libraries.

To assure that the validation would apply to PC's and operating systems other than the one the validation was performed on, a set of verification cases were run on any new computer and/or operating system prior to use of that computer/system for criticality safety analysis. The verification cases all included a starting seed for the pseudo-random number generator, thus forcing the calculation to produce identical results each time it is run. Therefore, acceptance of the verification of a new computer/system required identical results for the verification cases to the results on the computer/system where the validation was performed.

In 2004, a new validation was performed for GEMER1.0. This validation used 284 critical experiments to develop a set of bias fits against H/U235 for six subgroups of the experiments as follows:

LEU solution systems (30 benchmarks)
HEU solution systems (46 benchmarks)
Non-solution systems (104 benchmarks)
LEU lattice systems without poisons (71 benchmarks)
LEU lattice systems with cadmium (15 benchmarks)
LEU lattice systems with boron and gadolinium (18 benchmarks)

The bias was developed using today's standard methods which attempt to assign the bias to individual observations rather than the expected value, thus producing a more conservative bias as follows:

SYSTEM	BIAS RANGE

LEU solution systems	0.9845 – 0.9907
HEU solution systems	0.9752 – 0.9812
Non-solution systems	0.9807 – 1.0000
LEU lattice systems without poisons	0.9816 – 0.9866
LEU lattice systems with cadmium	0.9897 – 0.9904
LEU lattice systems with boron and gadolinium	0.9642 – 0.9851

Unfortunately, the group of experiments representing the LEU lattice systems with boron and gadolinium only had five cases with gadolinium and all cases had high boron. Therefore, this fit was not considered appropriate for the RA-3 container analysis.

An independent validation has been performed specifically for the RA-3 container analysis, using the calculations from the 2004 general validation of GEMER Version 1.0.

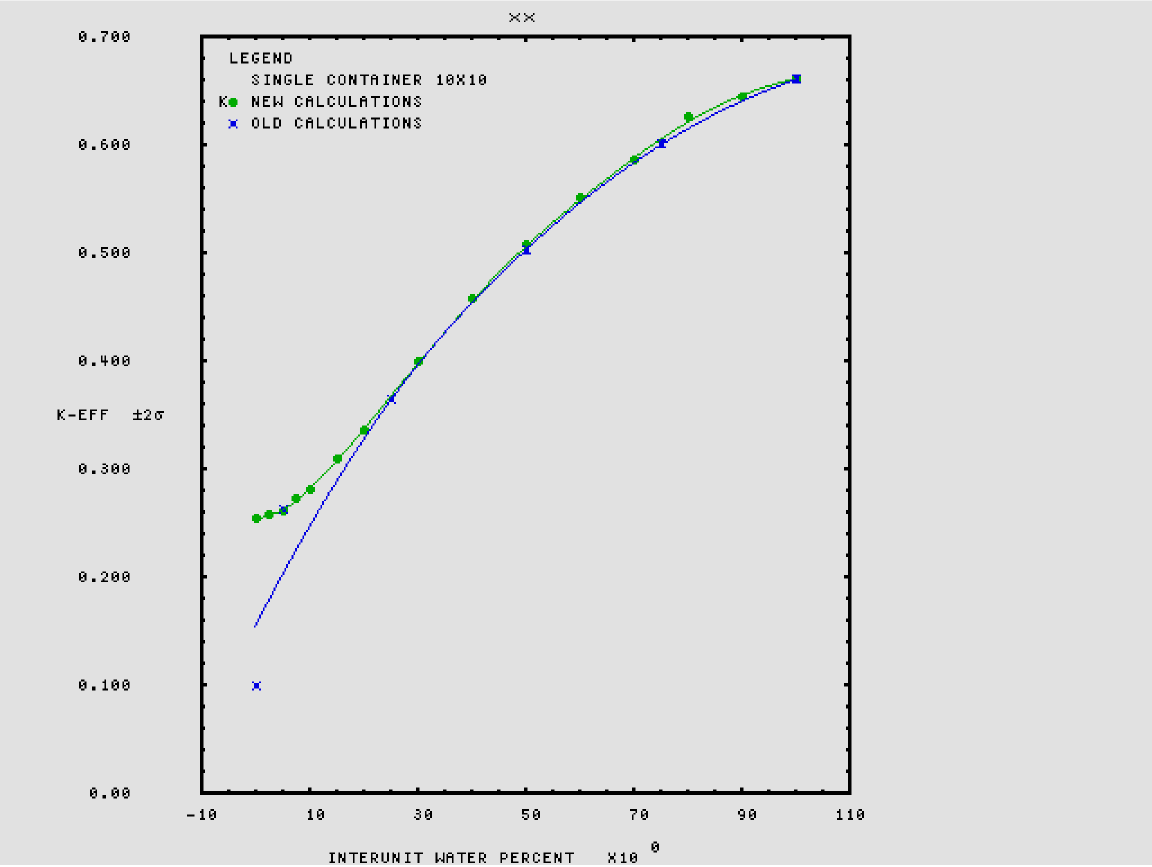
This validation produced an upper safety limit, USL = 0.933, which is more conservative than the previously used USL = 0.945. The determination of the revised analytic bias for this RA-3 analysis with GNF2 fuel is included as a separate attachment to this response.

The RA-3 shipping container analysis with GNF2 fuel has been revised to incorporate this new analytic bias.

<u>GNF-A Response: 6-1.b – Explain difference between previous and new low moderation results</u>

New calculations of the single, undamaged package results for the generic 10x10 fuel design were compared to previous results with the generic 10x10 fuel assembly in Figure 4.1-1. Excellent agreement is observed except for low interunit water. While it appears that this difference occurs over a range of interunit water, there is only one value that actually differs. The previous results were only provided at 0, 5, 25, 50, 75, and 100% of full density interunit water.

The figure shows that the results are the same for the two analyses at 5% interunit water. The previous result is significantly lower than the new result at 0% interunit water. It is obvious from the consistency of the new results and the agreement at 5% interunit water that the problem lies with the previous result at 0% interunit water.



As indicated in the question, the concern is not with the single unit calculations but with the undamaged container array calculations that are most limiting at 0% interunit water. The previous undamaged container array result for the GE8 model is 0.9358 ± .0010. The new result is 0.93568 ± .00057. This is excellent agreement and indicates no problem with the previous undamaged container array calculation.

NRC RAI 6-2

6-2 Provide detailed specifications for all GNF2 fuel assembly parameters in addition to those already provided for the pellet diameter, and the cladding thickness and inner diameter. If there are differences between the contents specifications and the analyzed GNF2 model, justify these differences and the applicability of the model.

The applicant states that the proposed contents, labeled as the GNF2 fuel assembly, are very similar to prior 10x10 designs. Yet, two differences (increased pellet diameter and reduced cladding thickness in the GNF2) are listed. Other assembly parameters, such as whether or not the assembly may have partial fuel rods and the number of these rods, are not discussed at any point in the proposed appendices. Lack of these specifications makes it unclear as to the degree of similarity of the GNF2 and the approved 10x10 assemblies. Further, the specifications are *important for characterizing the contents for which the criticality analyses are performed and the applicability of the analyses to the actual contents.*

This information is needed to determine compliance with 10 CFR 71.7(a), 71.33(b), 71.55(b), (d), (e), and 71.59.

GNF-A Response: 6-2 – Provide detailed specifications for GNF2 fuel assembly parameters

The objective of the submittal was to demonstrate no significant neutronic difference between the GNF2 fuel design and the generic 10x10 fuel design. Therefore, only fuel assembly parameters that differed were specified. In response to this RAI, the remaining specifications have been added to the submittal.

NRC RAI 6-3

6-3 Clarify whether the pellet diameter and cladding specifications of Tables A4 and A5 in the proposed Appendix 8-J(a) supercede the pellet and cladding specifications of Appendix 8-J, Section 6.1 of the application, or if they apply to assemblies with pellet diameters that exceed the specifications given in Section 6.1.

The applicant requested the appending of a statement to paragraph 5.(b)(1)(iii) of the Certificate of Compliance suggesting that the assembly, together with the specifications given in Section 6.1, Appendix 8-J of the application, together with the specifications of pellet diameter and cladding dimensions in Table A4 and A5 of the proposed Appendix 8-J(a) determine the approved contents. However, Section 6.1 has its own pellet and cladding specifications. It is not clear which pellet diameter and cladding specifications are to be followed – whether the proposed specifications supercede the previous specifications or only apply to fuel assemblies with fuel pellets and cladding that do not meet the specifications stated in Section 6.1.

Furthermore, the relationship of the specifications in proposed Tables A4 and A5 is not clear. Will fuel assemblies with pellet diameters larger than the Section 6.1 specification but not exceeding the specification in Table A4 be required to have cladding that meets the specifications of Table A5? Or is cladding that meets the cladding specifications of Section 6.1 acceptable for these fuel assemblies? It would be preferable to consolidate the fuel assembly parameters described in Section 6.1, Appendix 8-J of the application, and proposed Tables A4 and A5 into a single revised table that can be referenced in the Certificate of Compliance.

This information is needed to determine compliance with 10 CFR 71.33(b).

GNF-A Response: 6-3 – Clarify dimension specifications

The pellet diameter and cladding specifications in Tables A4 and A5 of the proposed Appendix 8-J(a) apply specifically to the GNF2 fuel design. For use of GNF2 fuel, the specifications of Table 6.1 (Appendix 8-J) would apply except for those identified in Tables A4 and A5 (Appendix 8-J(a)) which are also in Section 3.2 of Appendix 8-J(a). To avoid any confusion, the implied specifications have been explicitly added to Appendix 8-J(a) as a separate Table 5.1. The specifications in Table 6.1 of Appendix 8-J continue to apply to the generic 10x10 fuel design.

NRC RAI 6-4

6-4 Confirm that the pellet diameter and cladding dimensions in proposed Tables A4 and A5 will apply only to 10x10 assemblies that meet the enrichment and accompanying gadolinium rod requirements described in Appendix 8-J, Section 6.1, of the application for which analyses were performed.

For the proposed pellet and cladding specifications, the applicant only analyzed fuel assemblies that have a maximum peak pellet enrichment of 5 wt% U-235, a maximum lattice average enrichment of 4.7 wt% U-235, and 12 gadolinium rods with a minimum of 3 wt% Gd2O3. These enrichment and gadolinium rod specifications correspond to a single enrichment range, and its accompanying gadolinium rod requirements, list in Appendix 8-J, Section 6.1, of the application. Thus, the analysis only demonstrate that fuel assemblies within that enrichment range can have fuel pellets and cladding that meet the specifications in proposed Tables A4 and A5 and still meet 10CFR Part 7 criticality requirements.

The Certificate of Compliance will need to clearly indicate that the pellet and cladding specifications of proposed Tables A4 and A5 apply only to 10x10 assemblies that meet the fuel enrichment range and gadolinium rod requirements to which the applicant's analysis applies.

This information is need to confirm compliance with 10 CFR 71.33(b), 71.55(b), (d), (e), and 71.59.

GNF-A Response: 6-4 – Clarify that dimensions only apply to 10X10 assemblies

If similarity between the GNF2 fuel design and the generic 10x10 fuel design is demonstrated for one of the enrichment/gadolinium arrangements, it is believed that similarity also exists for the other enrichment/gadolinium arrangements. However, this section of the RAI requests that all desired arrangements be analyzed. Therefore, these calculations are performed and included in the revised analysis.

NRC RAI 6-5

6-5 Justify the material properties differences between models in the analyses.

In the different models, particularly the undamaged single package and package array models, changes are made to the packaging materials' properties in the models. For example, the honeycomb density in the package array model is half its value in the single package model. While the changes are stated, no justification is provided to explain why the changes were appropriate.

Justification for the changes should include analytical support that provides the basis for the justification. For example, while a system may exhibit a general over-moderated condition, it isn't clear that all of the system's subparts are over-moderated. Thus, a reduction in moderator mass may not always result in an increase in k-effective, but may decrease k-effective in some subparts. An analysis of the system could help identify material property changes' effects on different system subparts as well as the dominant effect.

This information is need to determine compliance with 10 CFR 71.55(b), (d), (e), and 71.59.

GNF-A Response: 6-5 – Justify differences in material specifications

Since this analysis was performed as a demonstration of neutronic similarity between the GNF2 fuel design and the generic 10x10 fuel design, the same compositions were used for the RA-3 container. Justification for these compositions has been provided in previous RA-3 analyses. This justification is included in the revised analysis.

NRC RAI 6-6

6-6 Confirm that the atom densities used for oxygen and carbon in the honeycomb in the analyses in the application are correct. Also, show how the atom densities used for the honeycomb were calculated and provide the reference(s) for the data on the honeycomb's composition.

There is a discrepancy between the application and the models (as detailed in the sample GEMER inputs) regarding the correct atom densities of the oxygen and carbon in the honeycomb material. Looking in the applicant-provided code input files, the oxygen atom density is 1.221970E-03 atoms/b-cm and the carbon atom density is 2.092900E-03 atoms/b-cm in full density honeycomb. However, Table A-1, Appendix 5-A of the application reverses these atom densities (i.e., carbon's atom density is 1.221970E03 atoms/b-cm and oxygen's atom density is 2.092900E-03 atoms/b-cm).

The models or the application, as appropriate, will need to be corrected, the calculation for the atom densities of the honeycomb's components needs to be shown, and the reference(s) of the calculation's input data need to be provided.

This information is needed to confirm compliance with 10CFR 71.7(a), 71.55(b), (d), (e), and 71.59.

GNF-A Response: 6-6 – Fix Oxygen vs. Carbon number densities

As stated in the RAI, Table A-1 of Appendix 5-A shows an Oxygen number density of 2.0929E-03 and a Carbon number density of 1.22197E-03. However, the models shown in Appendix 8-A (8X8), 8-D (8X8), 8-E (9X9), 8-F (9X9), and 8-K (8X8, 9X9, 10X10) all show Oxygen as 1.22197E-03 and Carbon as 2.0929E-03. The number densities in the GNF2 submittal are consistent with the previous models. The question is "Which is correct?" Per the original calculation performed for the 1976 submittal (verified by WC Peters), The correct number densities are H = 3.0131E-3, O = 1.22197E-3, C = 2.0929E-3. Therefore, the numbers in Table A-1 of Appendix 5-A will be changed.

NRC RAI 6-7

6-7 Explain how GEMER processes geometries involving intersecting bodies.

There appear to be instances of intersecting volumes in the sample GEMER input files where one object is placed inside another that is smaller in one dimension than the body being placed in it. There also appear to be instances in the input files where portions of multiple bodies are intersected with a large body occupying the same volume and location as the portions of the multiple bodies it intersects. For example, the units labeled 'top water' and 'bottom water' and the array of fuel rods making the fuel assembly are placed in the cluster separator. However, the water that is modeled to extend above and below each fuel rod appears to occupy the same space as the top and bottom water units, respectively, causing multiple intersection of bodies in the same region.

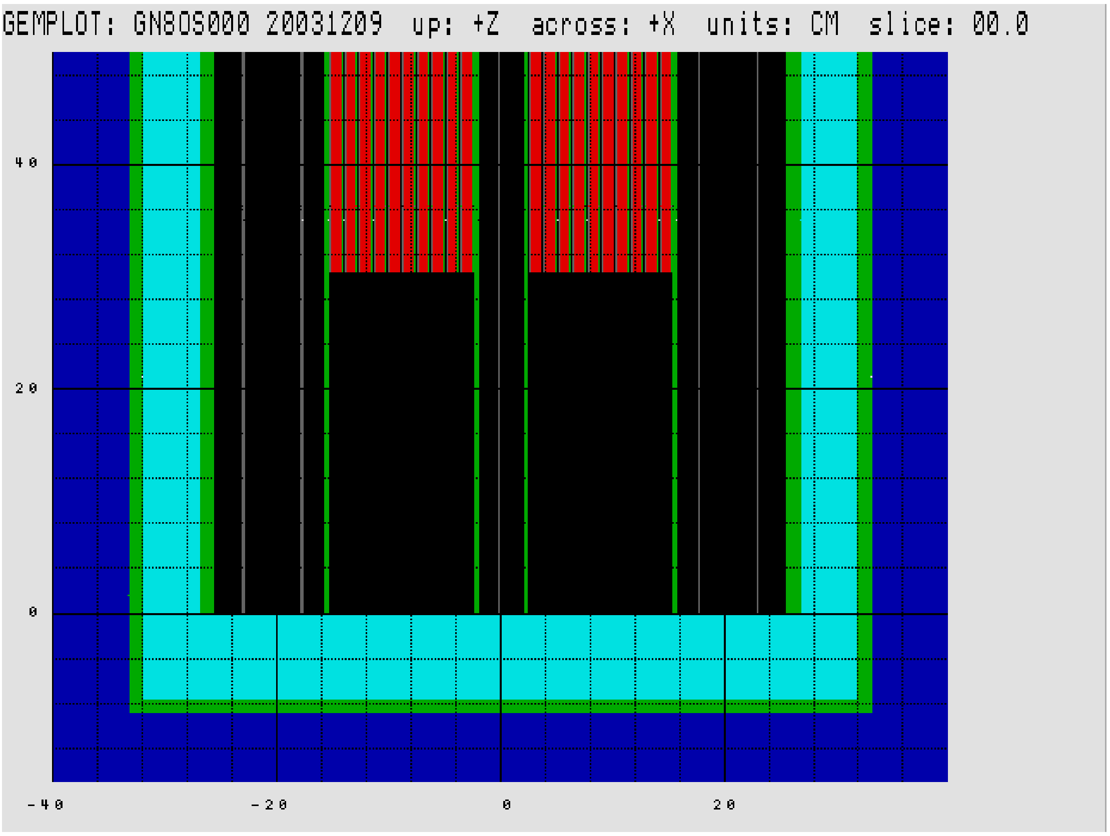
Additionally, the top and bottom water units have the same cross-sectional dimensions as the cluster separator unit into which they are placed, this would apparently mean that the cluster separator is not modeled beyond the modeled fuel rods. Yet, the figures and explanation of the models in the application test indicate the cluster separator extends above and below the fuel rods.

This information is needed to confirm compliance with 10 CFR 71.35(a), 71,55(b), (d), (e), and 71.59.

GNF-A Response: 6-7 – Explain how GEMER handles intersecting bodies

The RA-3 models use the Complex Embedded Option (CEO) to create the geometry. The CEO allows one box type to be embedded anywhere within the first region of another box type, thus creating a complex region. The embedded region can overlap the complex region boundary at the first embedded level but not at higher levels of embedding. If the embedded region overlaps the boundary of the complex region at the first level, the part of the embedded region that is inside of the complex region is kept and any part of the embedded region that is outside of the complex region is deleted. If an embedded region is input such that it overlaps another embedded region, the previous embedded region is deleted and the new embedded region is included in the model. This replacement occurs because the embedded region overlap option is not invoked in the RA-3 models.

The specific question regarding 'top water' and 'bottom water' is a good one. As described in the previous paragraph, box type 25 is embedded into box type 24 and fits exactly at the top of box type 24. Next, box type 26 is embedded into box type 24 and fits exactly at the bottom of box type 24. Next, box type 23 is embedded into box type 24, filling box type 24 except for a small gap at the four sides. However, box type 23 overlaps the embedded regions created by embedding box type 25 and box type 26. Therefore, according to the CEO rules, both box types 25 and 26 are deleted from the model. It's as if they never existed! Therefore, as you note, the cluster separators do extend above and below the fuel in the model as shown below.



This is the way the RA-3 was modeled previously. Since the primary objective of the current analysis was to demonstrate no significant change in k-effective for the GNF2 fuel relative to the generic 10X10 fuel assembly, this treatment was not changed.

To consider the effect of extending the cluster separator backbone beyond the ends of the fuel, the most reactive case of the normal array with cluster separator (GN8N000) and the most reactive case of the damaged package array (GN8A-007) were modified to terminate the backbone at the ends of the fuel. This was accomplished by changing the ±Z cuboid dimensions in BOX TYPEs 1, 8, 9, 10, 11, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, and 24 to 411.48 30.48. Then, instead of embedding BOX TYPEs 25 and 26 into BOX TYPE 24, they are embedded into BOX TYPE 7 along with BOX TYPE 24. The new cases are compared to the old cases in the following table.

OLD MODEL	KEFF	SIGMA	NEW MODEL	KEFF	SIGMA	% CHANGE
GN8N-000	0.85746	0.00075	GN8N-NOC	0.86646	0.00081	1.05%
GN8A-007	0.93928	0.00081	GN8A-NOC	0.93986	0.00081	0.06%

This study shows a one percent increase for the undamaged container array (as expected for overmoderated RA-3 container design). However, this result is still much less than the infinite undamaged container array without cluster separators (GN8NX000) for which keff = 0.93658. For the damaged container array, the change is well within the uncertainty of the calculations. This insignificant change is expected since the damaged container array is only one container long, unlike the undamaged container array which is an infinite number of containers long.

NRC RAI 6-8

6-8 Clarify the description of the material included in the model as having half-density honeycomb and no ethafoam present. However, the test following this list references the accompanying Figure 3.4-1 and states that the figure shows the model with half-density ethafoam and no honeycomb.

This information is needed to confirm compliance with 10 CFR 71.7(a), 71.55(b), (d), (e), and 71.59.

GNF-A Response: 6-8 – Clarify description of materials in model of undamaged array

The text should be changed to say ‘half density honeycomb (mixture 7)’.

ATTACHMENT 4

Non-Proprietary Version of:

"eDRF NO. 0000-0024-2885
Criticality Safety Analysis
RA-3 Shipping Container
For Use With The GNF2 Fuel Design
[Rev. 01]
November, 2004"

An asterisk has been placed in the right hand column indicating the removal of proprietary information from that page. The sections removed within the text are indicated with a double bracket. This version has been identified as Appendix 7-J(a), because it is associated with the existing 10x10 analysis.

and

"GEMER Monte Carlo
Validation Report:
RA-3 Analysis with GNF2 Fuel
November, 2004"

This document does not contain proprietary information

Global Nuclear Fuel

A Joint Venture of GE, Toshiba, & Hitachi

eDRF No. 0000-0024-2885
CRITICALITY SAFETY ANALYSIS RA-3 SHIPPING CONTAINER FOR USE WITH THE GNF2 FUEL DESIGN
[Rev. 01]

November 2004

Analysis By: ***Original Signature on File*** **Date 11/22/04**
John T. Taylor
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Verified By: ***Original Signature on File*** **Date 11/22/04**
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1 SUMMARY

This report summarizes the criticality safety analysis applicable to the RA-3 container when used with the GNF2 fuel design. For these calculations to apply this 10x10 fuel design must have at least a minimum number of gadolinium rods, as a function of the lattice average enrichment, in which there is at least a minimum concentration of Gd_2O_3. Further, the maximum U^{235} enrichment must not exceed 5.00 weight percent, the lattice average U^{235} enrichment must not exceed 4.70 weight percent, and the gadolinium rods must be arranged symmetrically about the major diagonal of the fuel assembly. When these conditions are met the RA-3 fresh nuclear fuel shipping container satisfies Title 10 CFR Part 71 – Packaging and Transportation of Radioactive Material [Ref. 4].

This report has been revised to reflect questions in the USNRC “Request for Additional Information” [Ref. 9].

1.1 Background

Reference 1 presents criticality safety calculations which show that the RA-3 shipping container, with generic 10x10 fuel assemblies with and without cluster separators, meets the requirements of 10 CFR Part 71. The cluster separator is a means by which separators, which are used to prevent unwanted motion and vibration during transport, are connected to one another so that they may be easily extracted from the assembly. This is accomplished by adding a separator holder (backbone) around the periphery of the assembly which is connected to each of the separators (fingers) themselves. This separator holder results in the addition of a moderating material tightly fitted around each assembly.

1.2 Analysis Scope

The GNF2 fuel assembly [Ref. 8] is similar to the generic 10x10 fuel assembly evaluated in Reference 1. Preliminary calculations of the two fuel designs at the same conditions confirmed this similarity. However, this analysis is performed as a separate evaluation.

In recent years, the Nuclear Regulatory Commission has developed a more uniform and rigorous approach to validation of the analytical methods. To comply with this approach, the GEMER Monte Carlo program has been revalidated [Ref. 10] for use in analysis of the RA-3 shipping container.

No changes have been made in the shipping container. All details of construction remain as they were in the earlier work and in References 6 and 7. Previously, infinite arrays of undamaged containers, arrays of 260 (i.e. 13 x 20 x 1) damaged containers, and single containers have been analyzed.

The most limiting array calculations were at or near the previous calculational USL = 0.945. As a result of this analysis, a new USL is determined (discussed in Section 2.4

below) resulting in a revised USL = 0.933, representing an absolute limit reduction of 0.012.

As a result, the undamdaged and damaged package array sizes per 10CFR71.59 have been reduced and corresponding CSI for this evaluation derived as follows:

- The undamaged fissile container array has been revised from the previous 5N = infinite system to a new finite 5N = 16x19x2 = 608 unit array.
- The damaged fissile container array has been revised from the previous 2N = 13x20x1 = 260 unit array to a a new 2N = 10x16x1 = 160 unit array.

In both cases, the aspect ratio of the fully reflected array has, to the extent practical, been conserved to provided a "near cubic" array of RA-3 packages.

1.3 The GNF2 Design

For purposes of criticality safety analysis the GNF2 fuel design is very similar to prior 10x10 designs. The important differences are a small increase in pellet diameter (~.007 cm) and a small decrease in clad thickness (~.0035 cm). The calculations were performed for the most limiting allowable combinations of lattice average enrichment, number of gad rods, and gad rod content.

One other significant difference is the lengths and locations of partial length rods in the GNF2 bundle relative to the generic 10x10 fuel bundle.

2 INTRODUCTION

2.1 Historical Perspective

In previous analyses, the RA container has been shown to meet the requirements for a Type A, Fissile radioactive material shipping containers for BWR fuel assemblies subject to constraints on authorized contents. These include:

1. 7x7 and 8x8 fuel assemblies shipped two assemblies per container in which the maximum lattice U-235 enrichment is 3.2 percent or less and with no Gadolinia absorber required.
2. 8x8 fuel assemblies shipped two assemblies per container in which the maximum lattice U-235 enrichment is no greater than 5.0 percent subject to specific requirements on amounts and locations of Gadolinia. The Gadolinia requirements vary with the U-235 enrichment of the fuel assemblies.
3. 9x9 fuel assemblies shipped one assembly per container in which the maximum lattice U-235 enrichment is no greater than 4.025 percent and with no Gadolinia absorber required.

4. 9x9 fuel assemblies shipped two assemblies per container in which the maximum lattice U-235 enrichment is no greater that 4.6 percent subject to specific requirements on amounts and locations of Gadolinia.

5. 9x9 fuel assemblies shipped two assemblies per container with cluster separators in which the maximum lattice U-235 enrichment is no greater than 4.6 percent subject to specific requirements on amounts and locations of Gadolinia.

6. 10x10 fuel assemblies shipped one assembly per container in which the maximum lattice U-235 enrichment is no greater than 4.94 percent and with no Gadolinia absorber required.

7. 10x10 fuel assemblies shipped two assemblies per container without cluster separators in the RA-3D[1] in which the maximum lattice U-235 enrichment is no greater than 4.70 percent subject to specific requirements on amounts and locations of Gadolinia.

8. 10x10 fuel assemblies shipped two assemblies per container, with or without cluster separators, in which limits are placed on the lattice average enrichment and the amount and location of Gadolinia absorber.

9. 10x10 fuel assemblies shipped two assemblies per container with cluster separators in the RA-3D in which the maximum lattice U-235 enrichment is no greater than 4.70 percent subject to specific requirements on amounts and locations of Gadolinia.

10. 10x10 GNF2 design fuel assemblies shipped two assemblies per container in the RA-3D in which the maximum lattice U-235 enrichment is no greater than 4.70 percent subject to specific requirements on amounts and locations of Gadolinia.

The purpose of the present analysis is to demonstrate that the RA-3 shipping container meets the criticality safety requirements for a Type A, Fissile shipping container for the GNF2 design fuel assembly with and without cluster separators.

2.2 Definitions

Terminology used in this report is the same as that used in the previous analyses.

The following definitions are used throughout this report.

---

[1] The RA-3D container is a modified form of the RA-3. The RA-3D container differs from the RA-3 in that the RA-3D inner container is fabricated out of stainless steel 321 rather than carbon steel.

1. Fuel Assembly – A complete fuel unit consisting of a basic 10x10 fuel rod structure. Eight rods around the center of the assembly are replaced by two larger diameter water rods. Several shorter rods called “partial length” rods, may be included in the assembly.

2. Gadolinia – The compound Gd2O3. The Gadolinium content in Gd rods is usually expressed in weight percent Gadolinia.

3. Gd Rod – A fuel rod containing UO2 and Gadolinia over its full active fuel length.

4. Lattice – An axial zone of a fuel assembly within which the nuclear characteristics of the individual rods are unchanged. Fuel assemblies usually have more than one lattice, in which case reference to the lattice enrichment (etc.) is intended unless otherwise stated to refer to the lattice with maximum enrichment.

5. Major Diagonal – The diagonal of the GNF2 fuel assembly which passes between the water rods.

6. Minor Diagonal – The diagonal of the GNF2 fuel assembly which passes through the centers of the water rods.

7. Subcritical – A neutron multiplication factor (keff) less than 1.0 after taking into account statistical uncertainties and biases. In criticality safety analyses in which Monte Carlo codes are used, subcriticality is usually demonstrated by showing that the maximum $k + 2\sigma$ - bias is sufficiently less than 1.0. Biases are usually determined from benchmark calculations of real critical experiments or well established analytical cases. In the $k + 2\sigma$ - bias formula, biases are considered to be negative if critical benchmarks are underpredicted (ie., result in calculated multiplications less than 1.00).

8. Cluster separater – The polyethylene (hydrogen-bearing) holder for rod separators which are used in packaging the bundle. These holders surround an individual fuel assembly and provide an easy means for packing and unpacking the assembly’s rod separators. This is meant to apply to both the combination of rod separators (fingers) and separator holders (backbone).

9. Interunit water – As used in this document, interunit water refers to any water within the array or single unit. It is generally represented as a percent of full density water.

2.3 Analytical technique

In this analysis the effective neutron multiplication, keff, of a modeled system is calculated using the **GEMER** Monte Carlo Code. GEMER is a GNF-A proprietary Monte Carlo program, which solves the neutron transport equation as an eigenvalue problem in three spacial dimensions. Calculations documented in this report are performed using GEMER version 1.0 [Ref. 5] on verified microcomputer workstations at GNF-A.

GEMER is a Monte Carlo neutron transport code developed by combining geometry and Monte Carlo features from the KENO IV and MERIT Monte Carlo codes and by adding enhanced geometry, 2D and 3D geometry checking and editing features. Hence, GEMER is the evolution of the Geometry Enhanced MERIT code [Ref. 5]. The General Electric MERIT code is premised on the Battelle Northwest Laboratory's BMC code and is characterized by its explicit treatment of resolved resonance in material cross section sets [Ref. 5]. Functionally, the GEMER Monte Carlo code is similar in analytic capability to industry-recognized codes such as KENO Va. or MCNP.

Cross sections in GEMER are processed from the ENDF/B-IV library in multigroup and resonance parameter formats. Cross-sections are prepared in the 190 energy group format and those in the resonance energy range have the form of resonance parameters. This treatment of cross-sections with explicit resonance parameters is especially suited to the analysis of uranium compounds in the form of heterogeneous accumulations or lattices.

Thermal scattering of hydrogen is represented by the Hayward Kernel $S(\alpha,\beta)$ data in the ENDF/B-IV library. The types of reactions considered in the Monte Carlo calculation are fission, elastic, inelastic, and (n,2n) reactions; absorption is implicitly treated by applying the non-absorption probability to neutron weights on each collision. As part of the solutions, GEMER produces eigenvalue, micro- and macro-group fluxes, reaction rates, cross sections, and neutron balance by isotopes.

GEMER calculations were run with 200 edit batches, using 2500 neutrons per batch, skipping 50 batches prior to starting the statistical output processing - for a total of 500,000 active neutron histories. Unless otherwise specified, start type = 0 (flat) distribution over the fuel region is used. The plotted effective neutron multiplications show 2 times the calculated statistical uncertainties.

The following (representative) verified hardware workstation and validated GEMER code executable/cross-section libraries were used under a Microsoft Windows 2000 operating system:

```
organization:        gnfa, crit.safety, wilmington, nc
system:              taylor, pentium-iii, 1-ghz (bj2h011)
hardware:            dell, optiplex, gx150, serial no.
program name:        C:\PROGRAMS\GEMER.EXE
program version:     1.0
program date:        03/24/04
library name:        C:\XSEC.LIB\GEMLIB
library date:        1AB3
library time:        762F
```

2.4 Validation of Calculation Method

In recent years, the Nuclear Regulatory Commission has developed a more uniform and rigorous approach to validation of the analytical methods. To comply with this approach, the GEMER Monte Carlo program has been revalidated for use in analysis of the RA-3 shipping container.

Previously, GEMER calculations supporting the RA-3 shipping container were assigned a calculational bias of –0.005. Shipping analyses require an arbitrary safety margin of 0.05. Therefore, calculations in support of the RA-3 shipping container were required to satisfy the following equation.

$$\mathrm{Keff} + 2\sigma < 1.0 - 0.005 - 0.05 \quad = 0.945$$

A new validation [Ref. 10] has been performed specifically in support of the RA-3 shipping container. This validation establishes a new calculational bias of –0.017 for RA-3 calculations with GEMER based on a 95 % tolerance interval at 99% confidence and establishes an Upper Safety Limit (USL) that includes a 0.05 aribitrary safety margin. This new validation requires that calculations in support of the RA-3 shipping container satisfy the following equation.

$$\mathrm{Keff} + 2\sigma < 1.0 - 0.017 - 0.05 \quad = 0.933$$

It is noted that the new USL is 0.012 less (i.e.- more conservative) than the previous USL. The new USL has resulted in reduced array sizes evaluated in this analysis.

2.5 Analytical Procedure

Both single package containers and package arrays are considered, the latter pursuant to 10CFR71.59, which states:

> **§ 71.59 Standards for arrays of fissile material packages.**
>
> (a) A fissile material package must be controlled by either the shipper or the carrier during transport to assure that an array of such packages remains subcritical. To enable this control, the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close full reflection on all sides of the stack by water:
>
> (1) Five times "N" undamaged packages with nothing between the packages would be subcritical;
>
> (2) Two times "N" damaged packages, if each package were subjected to the tests specified in § 71.73 ("Hypothetical accident conditions") would be subcritical with optimum interspersed hydrogenous moderation; and

> (3) The value of "N" cannot be less than 0.5.
>
> (b) The CSI[2] must be determined by dividing the number 50 by the value of "N" derived using the procedures specified in paragraph (a) of this section. The value of the CSI may be zero provided that an unlimited number of packages are subcritical, such that the value of "N" is effectively equal to infinity under the procedures specified in paragraph (a) of this section. Any CSI greater than zero must be rounded up to the first decimal place.
>
> (c) For a fissile material package which is assigned a CSI value--
>
> (1) Less than or equal to 50, that package may be shipped by a carrier in a nonexclusive use conveyance, provided the sum of the CSIs is limited to less than or equal to 50.
>
> (2) Less than or equal to 50, that package may be shipped by a carrier in an exclusive use conveyance, provided the sum of the CSIs is limited to less than or equal to 100.
>
> (3) Greater than 50, that package must be shipped by a carrier in an exclusive use conveyance, provided the sum of the CSIs is limited to less than or equal to 100.
>
> [69 FR 3795, Jan. 26, 2004]

10CFR71 also requires that a single package be subcritical under both normal conditions of transport and under the hypothetical accident conditions.

To meet the requirements of 10CFR71, the following will be demonstrated:

1. A single undamaged RA-3 container (two GNF2 assemblies per container) will be demonstrated to be subcritical at optimum moderation and full water reflection.

2. A single damaged RA-3 container (two GNF2 assemblies per container) will be demonstrated to be subcritical at optimum moderation and full water reflection.

3. An array of undamaged RA-3 containers (two GNF2 assemblies per container) will be demonstrated to be subcritical at optimum interunit water and full water reflection. The undamaged array will be demonstrated to be overmoderated. The remaining enrichment bands will be demonstrated subcritical based on a single calculation at zero interunit water. The effect of cluster separators will be examined over the full range of interunit water.

4. An array of damaged RA-3 containers (two GNF2 assemblies per container) will be demonstrated to be subcritical at optimum interunit water and full water

---

[2] *Criticality Safety Index (CSI)* means the dimensionless number (rounded up to the next tenth) assigned to and placed on the label of a fissile material package, to designate the degree of control of accumulation of packages containing fissile material during transportation. Determination of the criticality safety index is described in §§ 71.22, 71.23, and 71.59.

reflection. This demonstration will be performed for each enrichment band. In addition, the effect of partial rods and bundle orientation will be examined.

5. The allowable number of containers per shipment will be determined from the minimum of one fifth of the number of containers in the undamaged array and one half of the number of containers in the damaged array.

3 MODELING

3.1 General Description

In general, the RA-3 package consists of a wooden overpack and a steel inner container cushioned with ethafoam and honeycomb. The RA-3 inner and outer container is shown in drawings 769E231 [Ref. 6] and 769E229 [Ref. 7]. The modeled RA-3 inner/outer container and associated dimensions remain unchanged from the detailed descriptions provided in Reference 1 criticality safety analysis.

3.2 The fuel rods and assemblies

The fuel rods and pellets have been modeled conservatively using data from Reference 8. The pellet and clad data are as follows:

Dimension (cm)	Nominal	As Modeled	
Pellet OD	[[ ]]	0.891	*
Clad ID	[[ ]]	0.901	*
Clad Thickness	[[ ]]	0.052	*

Other values used were a theoretical density of UO_2 of 10.96 gm/cc, a fraction of theoretical density of 0.98, a smear factor of 0.978, and a factor of 0.965 combining the effect of density uncertainties and possible process variations on the specified density of Gd_2O_3. An example of the calculation and a tabulation of the values used are given in Appendix 1 with other modeling details.

Figure 3.2-1 shows a cross-sectional view of a single fuel bundle. In Figure 3.2-1, red represents fuel rods, purple represents fuel rods which also contain gadolinium, grey represents zirconium, and green represents poly. Figure 3.2-2 shows a blow-up view of several fuel rods.

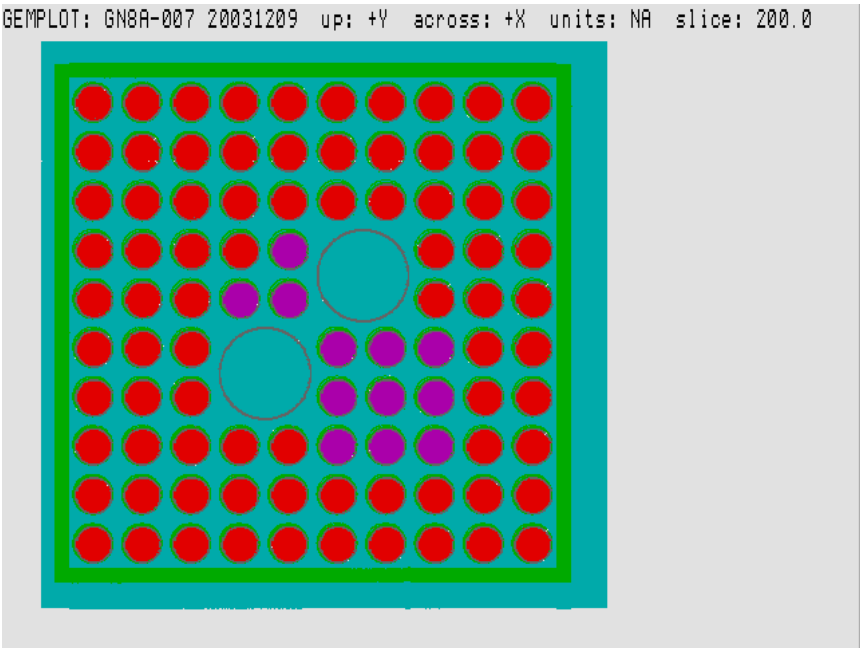


Figure 3.2-1 A GNF2 10x10 Fuel assembly

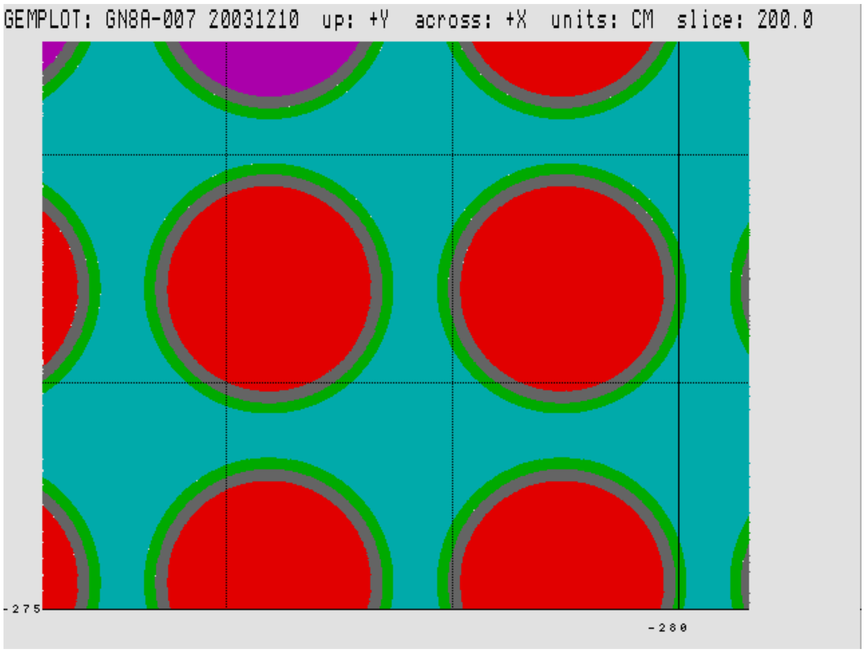
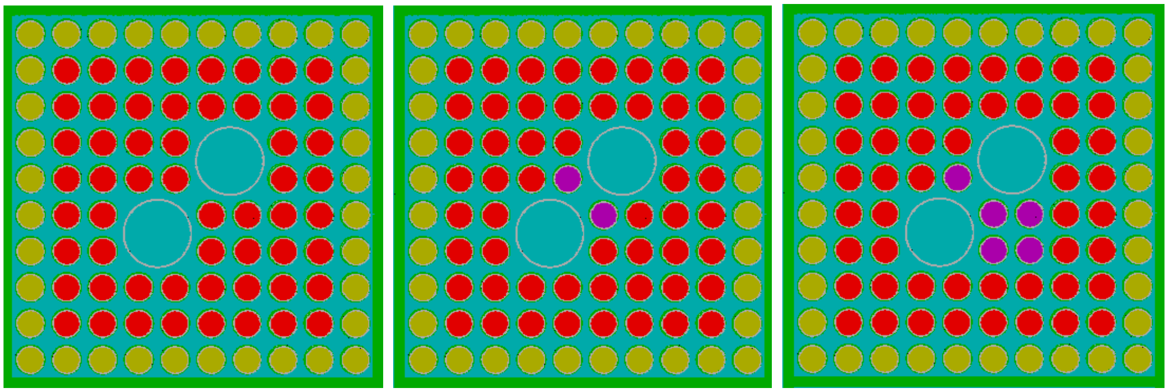


Figure 3.2-2 Details of GNF2 Fuel Rods

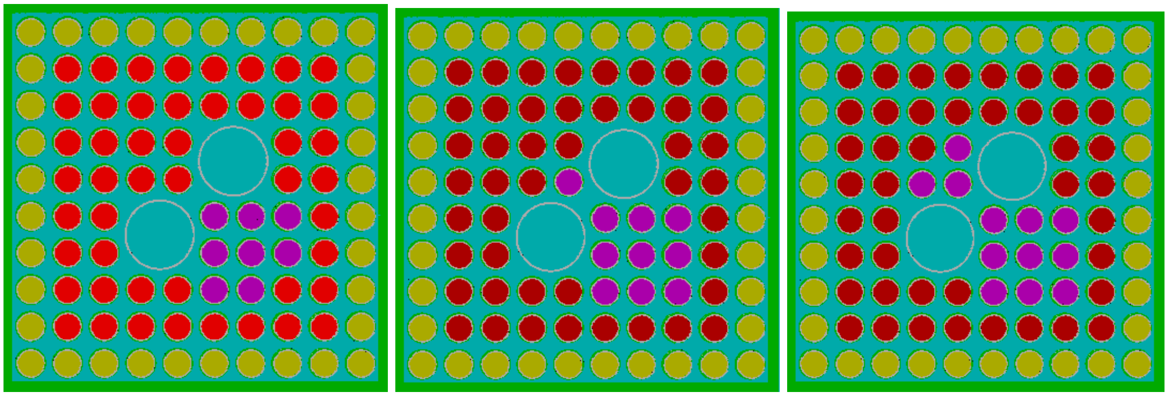
The GNF2 fuel design is similar to the generic 10x10 fuel design previously analyzed. The same requirements apply to the number of fuel rods that must contain gadolinium and the percentage of gadolinium contained in these rods as a function of lattice average enrichment. Based on previous analysis [1], bundle models were created having the highest allowed enrichment (i.e.- 5.00%) in the peripheral rods, reduced enrichment rods elsewhere to achieve the lattice average enrichment, and gad containing rods clustered near the center of the bundle. The six evaluated lattice configurations are shown in Figure 3.2-3. In this figure, enrichment plotting has been turned on to show the locations of the 5.00% enriched rods (yellow), the lower enriched rods (red), and the gad containing rods (purple).



Model G00A
Max Enr 5.00%
Min Enr 1.39%
Avg Enr 2.80%
Gad Rods 0
Gad % 0

Model GA1A
Max Enr 5.00%
Min Enr 2.04%
Avg Enr 3.20%
Gad Rods 2
Gad % 2

Model GF1A
Max Enr 5.00%
Min Enr 2.70%
Avg Enr 3.60%
Gad Rods 5
Gad % 2



Model GBTA
Max Enr 5.00%
Min Enr 3.36%
Avg Enr 4.00%
Gad Rods 8
Gad % 2

Model GD8A
Max Enr 5.00%
Min Enr 4.01%
Avg Enr 4.40%
Gad Rods 10
Gad % 3

Model GN8A
Max Enr 5.00%
Min Enr 4.51%
Avg Enr 4.70%
Gad Rods 12
Gad % 3

Figure 3.2-3 RA-3 with GNF2 fuel as a function of enrichment and gadolinium

3.3 Other Materials

There are no changes to the RA-3 shipping container as a result of this analysis. The geometry and compositions used in this analysis are the same as in previous analyses. These compositions are provided here for completeness and because one (i.e.- Honeycomb) was previously tabulated incorrectly.

Honeycomb - ρ = 4.92 lb/ft^3 (range 4.9 – 5.1 lb/ft$^{3)}$

Assuming 33% (C_6H_5OH-CH_2O)
63.65% $(C_6H_{10}O_5)_x$
2.68% lignins $(C_{10}H_{15}O_3)_x$

N(hydrogen) = 0.0030131 atoms/bn·cm
N(oxygen) = 0.00122197 atoms/bn·cm
N(carbon) = 0.0020929 atoms/bn·cm

Ethafoam (expanded polyethylene)

Assuming 2.2 lb/ft^3 = 0.0352 g/cc

N(hydrogen) = 0.003030 atoms/bn·cm
N(carbon) = 0.001515 atoms/bn·cm

Wood - ρ = 0.5 g/cc (soft wood)

Assuming 7% water (H_2O)
65% cellulose $(C_6H_{10}O_5)_x$
28% lignins $(C_{10}H_{15}O_3)_x$

N(hydrogen) = 0.021334 atoms/bn·cm
N(carbon) = 0.011858 atoms/bn·cm
N(oxygen) = 0.0085933 atoms/bn·cm

High density polyethylene - ρ = 0.9658 g/cc * 0.8275 = 0.799 g/cc

Assuming poly covers 82.75% of active length

N(hydrogen) = 0.06863830 atoms/bn·cm
N(carbon) = 0.03431917 atoms/bn·cm

Carbon Steel - ρ = 7.82 g/cc

N(carbon) = 0.003921 atoms/bn·cm
N(iron) = 0.083491 atoms/bn·cm

As in previous analyses, the undamaged package array calculations conservatively use half of full density honeycomb and no ethafoam in the outer container and half of full density ethafoam in the inner container because the array is overmoderated. The overmoderation is demonstrated by the undamaged array calculations producing a maximum Keff at zero interunit water, even with the reduced honeycomb and ethafoam. (For the damaged package array calculations, all materials outside of the inner container are assumed to have been burned away by a fire, and ethafoam within the inner container is replaced by optimum interunit water.)

As in previous analyses, the carbon steel basket uses 85% of full density carbon steel to allow for perforations in the basket.

As in previous analyses, the plastic separators are conservatively represented as uniform annuli surrounding each fuel rod.

Regions within the array that do not contain other material are assumed to contain optimum interunit water. The hydrogen and oxygen number densities for mixtures 2 and 8 are assigned the appropriate values from Table 3.5-1.

CASE*	Interunit Water	$N_{hydrogen}$ (Atoms/bn·cm)	N_{oxygen} (Atoms/bn·cm)
000	0.0 %	1.000000E-10	1.000000E-10
002	2.5 %	1.672780E-03	8.363900E-04
005	5.0 %	3.345560E-03	1.672780E-03
007	7.5 %	5.018333E-03	2.509167E-03
010	10.0 %	6.691110E-03	3.345560E-03
015	15.0 %	1.003670E-02	5.018340E-03
020	20.0 %	1.338220E-02	6.691120E-03
030	30.0 %	2.007330E-02	1.003670E-02
040	40.0 %	2.676440E-02	1.338220E-02
050	50.0 %	3.345560E-02	1.672780E-02
060	60.0 %	4.014670E-02	2.007340E-02
070	70.0 %	4.683780E-02	2.341890E-02
080	80.0 %	5.352890E-02	2.676450E-02
090	90.0 %	6.022000E-02	3.011000E-02
100	100.0 %	6.691110E-02	3.345560E-02

* CASE is the last three characters of the filename (e.g.- GBTA-**000**, no interunit water)

3.4 Single RA-3 Unit: Undamaged and Damaged

Two single container models are used in this demonstration; one undamaged, the other damaged. These models are similar to those used in Reference 1, except for the use of the GNF2 fuel and the termination of cluster separators at the end of the fuel.

A cross section through the Z axis of the undamaged single unit model is shown in Figure 3.4-1, and a cross section through the Y axis is shown at one end in Figure 3.4-2. In this figure blue represents water, gray represents carbon steel or zircaloy, teal represents full density honeycomb, black represents interunit water,and dark green represents cluster separators, half density ethafoam, or wood. It is noted that the end plates of the inner container are conservatively omitted.

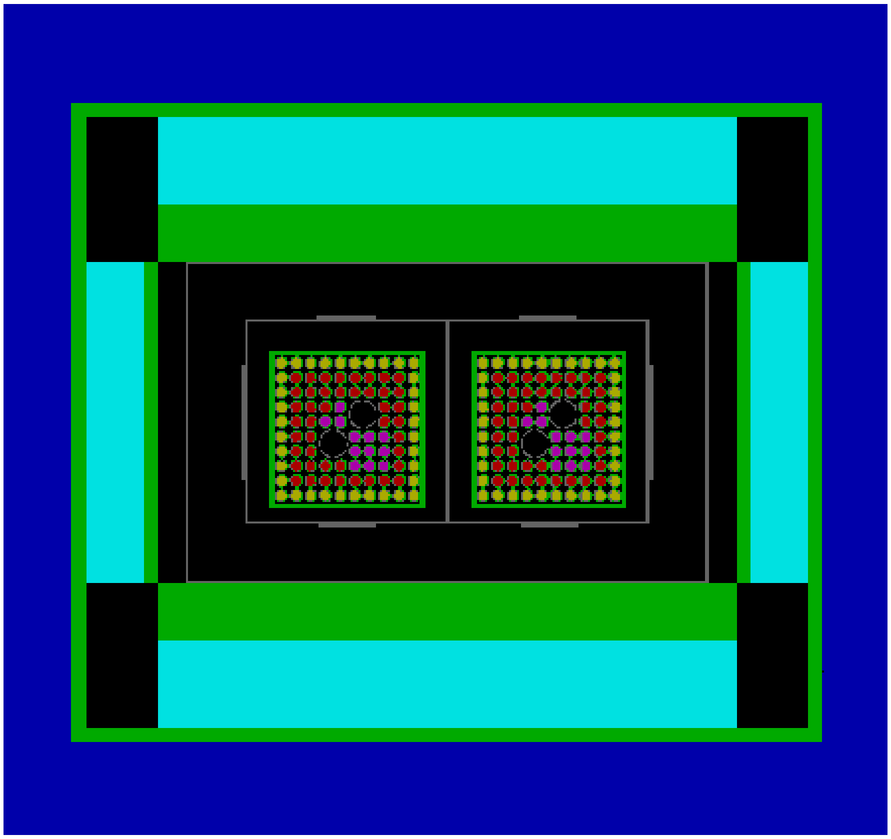


Figure 3.4-1 - X-Y Plot of Single Undamaged RA-3 Unit

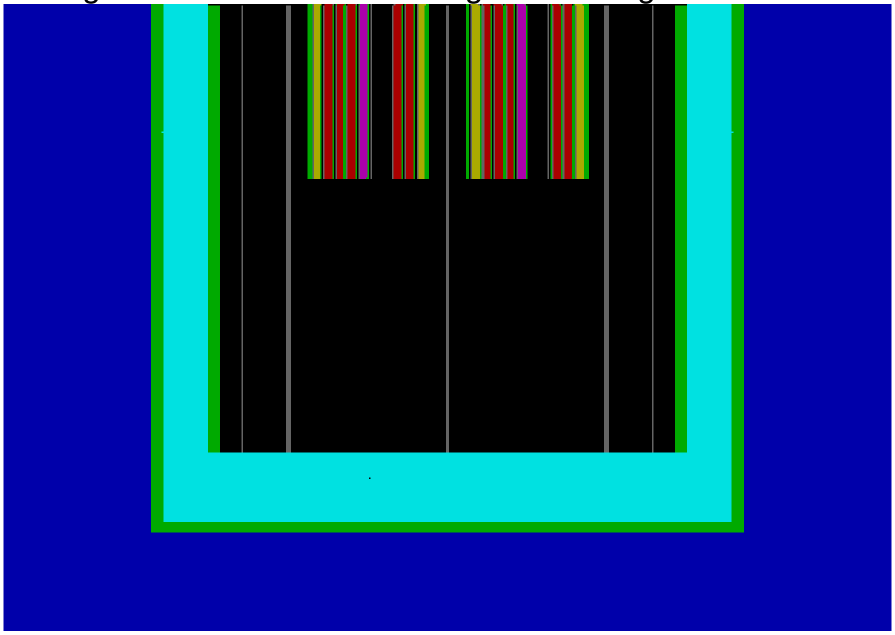


Figure 3.4-2 - X-Z Plot of Single Undamaged RA-3 Unit

A sample undamaged single container input file (GN8OS100) is provided in Appendix 2.

A cross section through the Z axis of the damaged single unit model is shown in Figure 3.4-3, and a cross section through the Y axis is shown at one end in Figure 3.4-4. In this figure blue represents water moderation, gray represents carbon steel or zircaloy, and dark green represents cluster separators. It is noted that the end plates of the inner container are included.

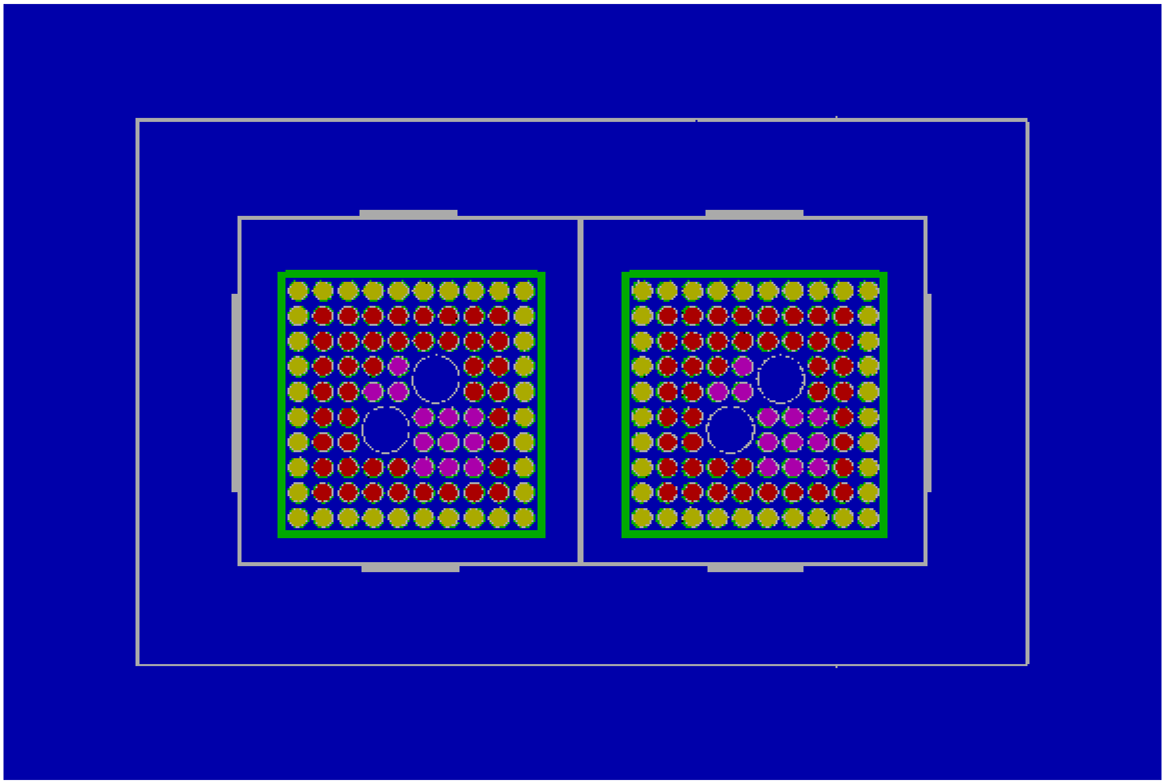


Figure 3.4-3
X-Y Plot of Single Damaged RA-3 Unit

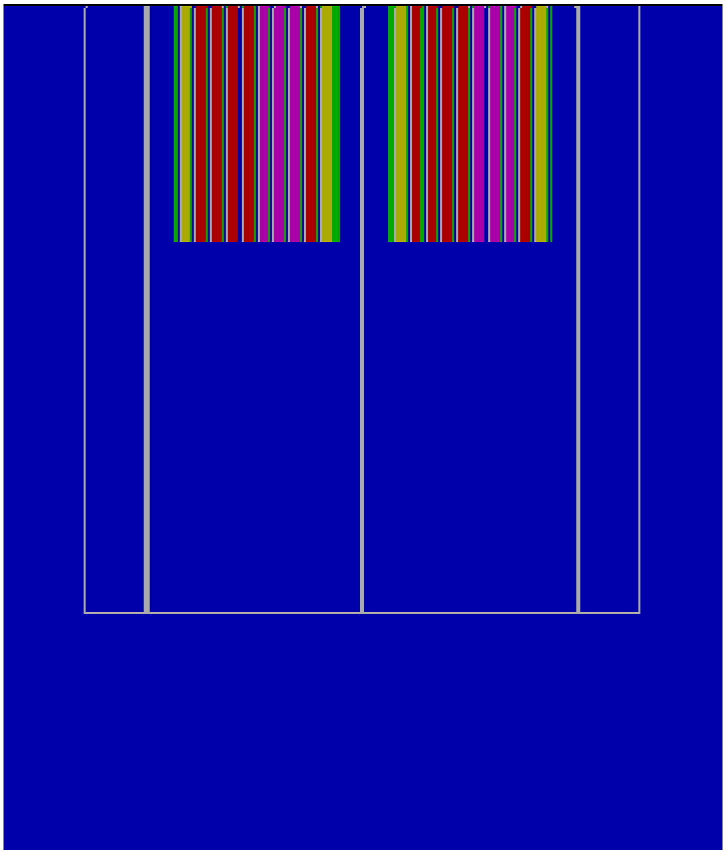


Figure 3.4-2
X-Z Plot of Single Damaged RA-3 Unit

A sample damaged single container input file (GN8IS100) is provided in Appendix 2.

3.5 Undamaged RA-3 package array

Two undamaged package array models are used, GN8N-nnn and GN8NXnnn, where nnn represents the percent interunit water. The models are identical except that GN8N-nnn contains the cluster separators and GN8NXnnn does not. An array consisting of 608 containers is modeled as a 16 wide by 19 high by 2 deep array having dimensions of 1061.76 cm (wide) by 1067.76 cm (high) by 919.48 cm (deep). This array has full water reflection on all six faces. Differences from the single container model are:

- Full density honeycomb (mixture 7) is replaced by 50% density honeycomb.
- Half density ethafoam (mixture 12) is replaced by void.
- The interunit water region (mixture 2) in Box Types 3, 4, 5, and 6 is replaced by void.
- The poly (mixture 3) backbone of the cluster separator (Box Type 24) is replaced by interunit water (mixture 2).

A cross section through the Z axis of an undamaged array model is shown in Figure 3.4-1. A cross section through the Y axis of an undamaged array model is shown in Figure 3.4-2.In these figures, blue represents the full water reflector and teal represents the half density honeycomb (mixture 7).

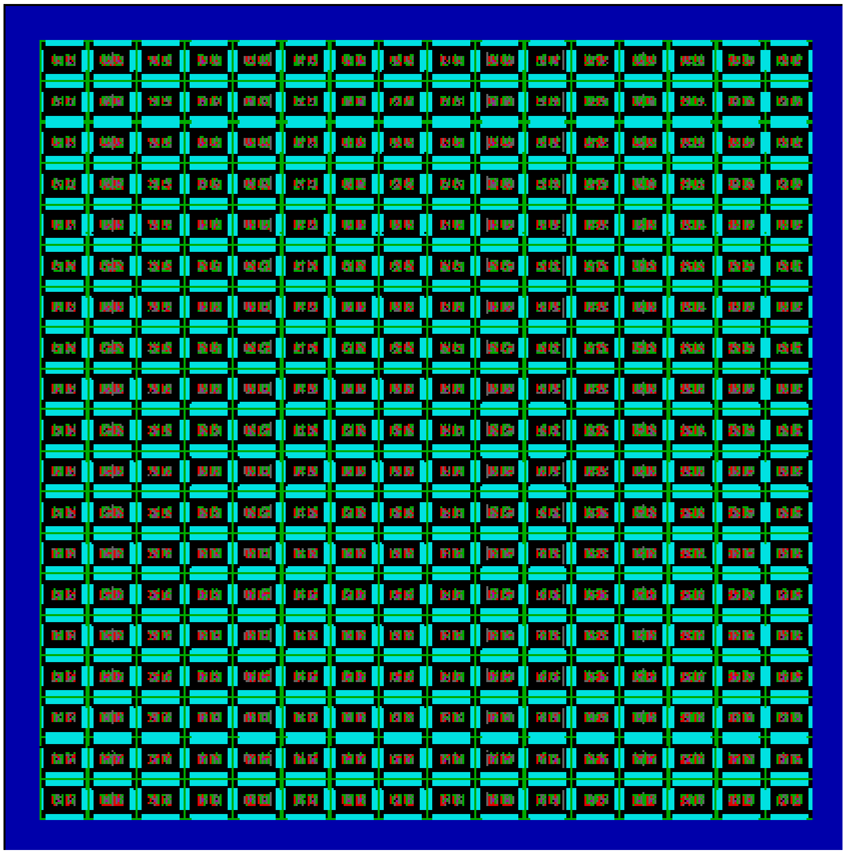


Figure 3.4-1
X-Y Plot of Undamaged RA-3 Array

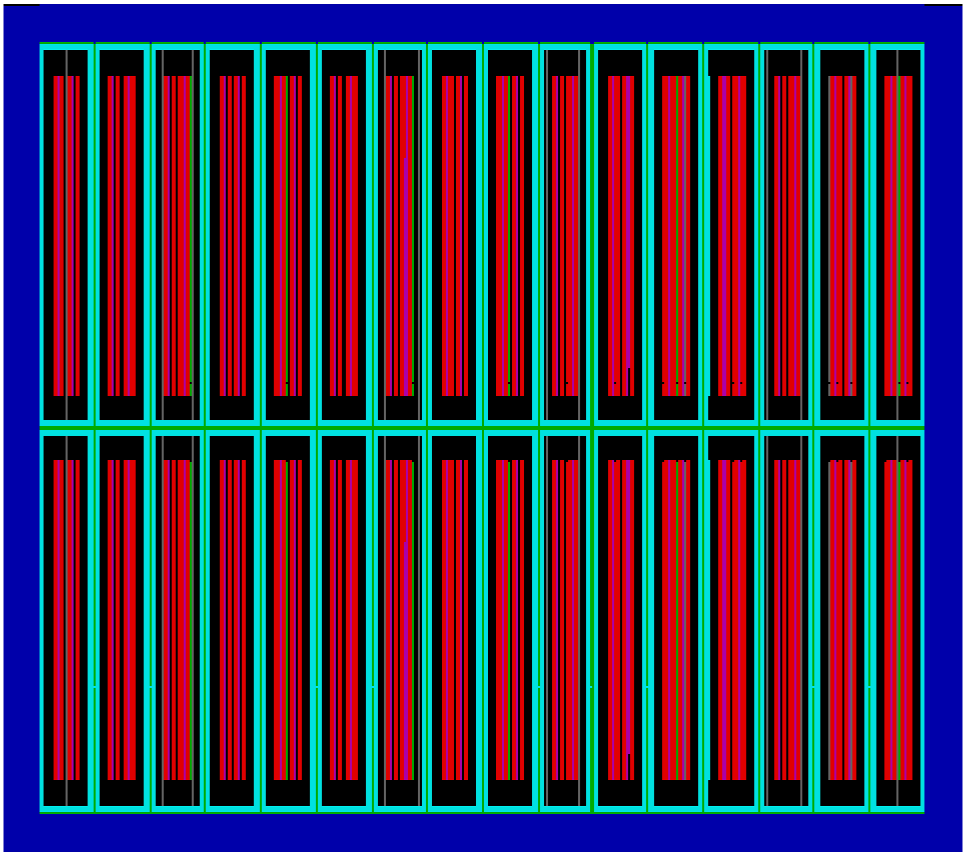


Figure 3.4-2
X-Z Plot of Undamaged RA-3 Array

A cross section through the Z axis of a single container in an undamaged array model is shown in Figure 3.4-3. In this figure, teal represents the half density ethafoam (mixture 7), black represents void or interunit water,gray represents carbon steel (or zirconium water rods), and dark green represents wood and cluster separator. The boundaries of the single container are halfway through the thickness of the outer green regions. Beyond these boundaries are the adjacent containers.

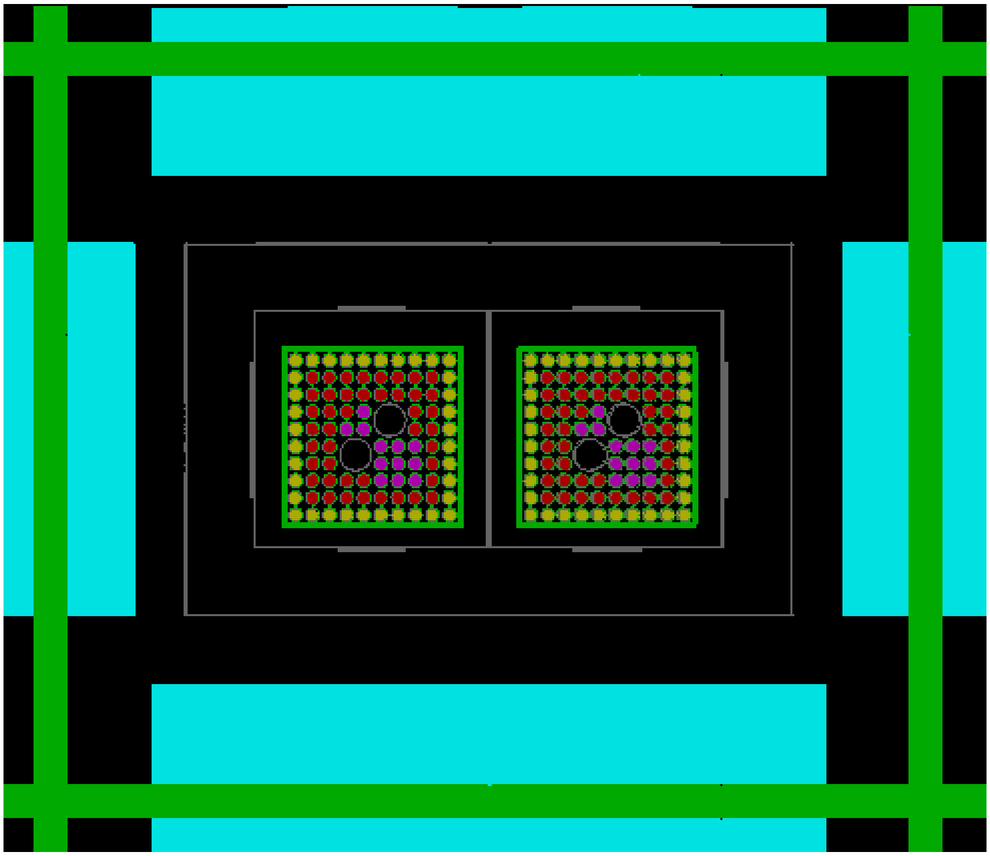


Figure 3.4-4
X-Y Plot of Single Container in Undamaged RA-3 Array

A cross section through the Y axis of the adjoining ends of two single containers in an undamaged array model is shown in Figure 3.4-4. In this figure, teal represents the half density ethafoam (mixture 7), black represents void or interunit water,gray represents carbon steel, and dark green represents wood and cluster separator. The boundaries of the single container are halfway through the thickness of the outer green regions and the center horizontal green region. Beyond these boundaries are the adjacent containers.

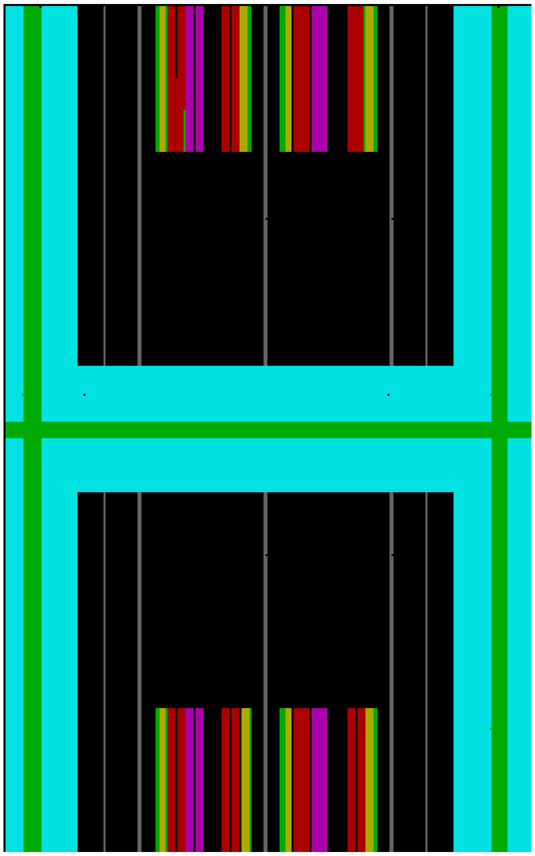


Figure 3.4-4
X-Z Plot of Ends of Two Containers in Undamaged RA-3 Array

A sample undamaged package array model without separators (GN8NX000) is provided in Appendix 2. The undamaged package array model with cluster separators (GN8N-000) is identical to this model except that mixture 2 is changed to mixture 3 in the following regions:

Box Type 1	Region 3
Box Type 8	Region 3
Box Type 14	Region 3
Box Type 24	Region 1

The undamaged container array models do not represent structure at the ends of the inner container. (This is a conservative approximation.)

3.6 Damaged RA-3 package array

The model (GN8A-nnn) used (including atomic densities) to demonstrate safety for the damaged package array is similar to the one used in Reference 1. However, the array size has been reduced from 260 inner containers as a 13 wide by 20 high by 1 deep array to 160 containers as a 10 wide by 16 high by 1 deep array to satisfy the new validation limits. This array is very near cubic, having dimensions of 460.4 cm x 452.1 cm x 442.3 cm. The model includes full water reflection on all six faces. As in previous analyses, it is assumed that the outer container has burned away and the insulating materials within the inner container have been replaced by optimum interunit water. A model was created for each combination of U-235 enrichment and gad, similar to Reference 1. These models are named as follows:

Model Name	Enrichment Range**	Minimum Number Of Gad Rods	Minimum Gad Concentration
G00A-nnn*	**E ≤ 2.80%**	**None**	**N/A**
GA1A-nnn*	**2.80% ≤ E ≤ 3.20%**	**2**	**2%**
GF1A-nnn*	**3.20% ≤ E ≤ 3.60%**	**5**	**2%**
GBTA-nnn*	**3.60% ≤ E ≤ 4.00%**	**8**	**2%**
GD8A-nnn*	**4.00% ≤ E ≤ 4.40%**	**10**	**3%**
GN8A-nnn*	**4.40% ≤ E ≤ 4.70%**	**12**	**3%**

* Interunit water as a percent of full density

** Lattice Average Enrichment. Represented in the model as the maximum value.

A cross section of one container in the model is shown in Figure 3.5-1. In this figure blue represents interunit water (mixture 2 or 8), gray represents carbon steel or zircaloy, and green represents poly. This figure shows only one of the 160 containers. The regions beyond the cross-overs of the grey regions in the corners are adjacent regions of other containers. A cross section of all 160 containers in the damaged package array is provided in Figure 3.5-2.

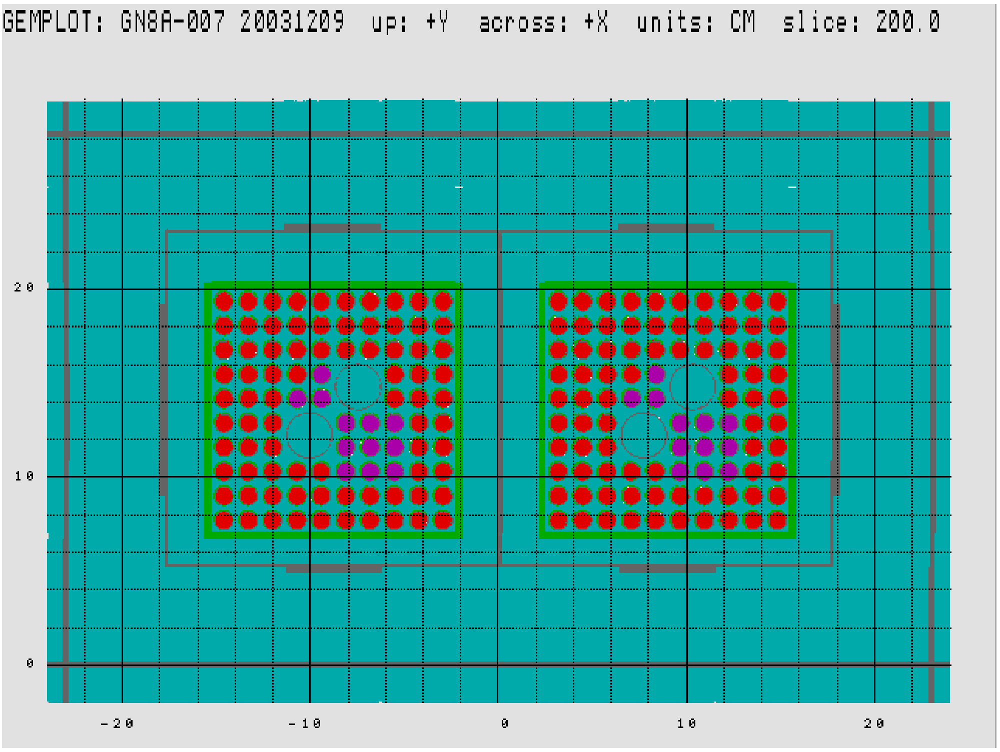


Figure 3.5-1 - A Damaged RA-3 Inner Container

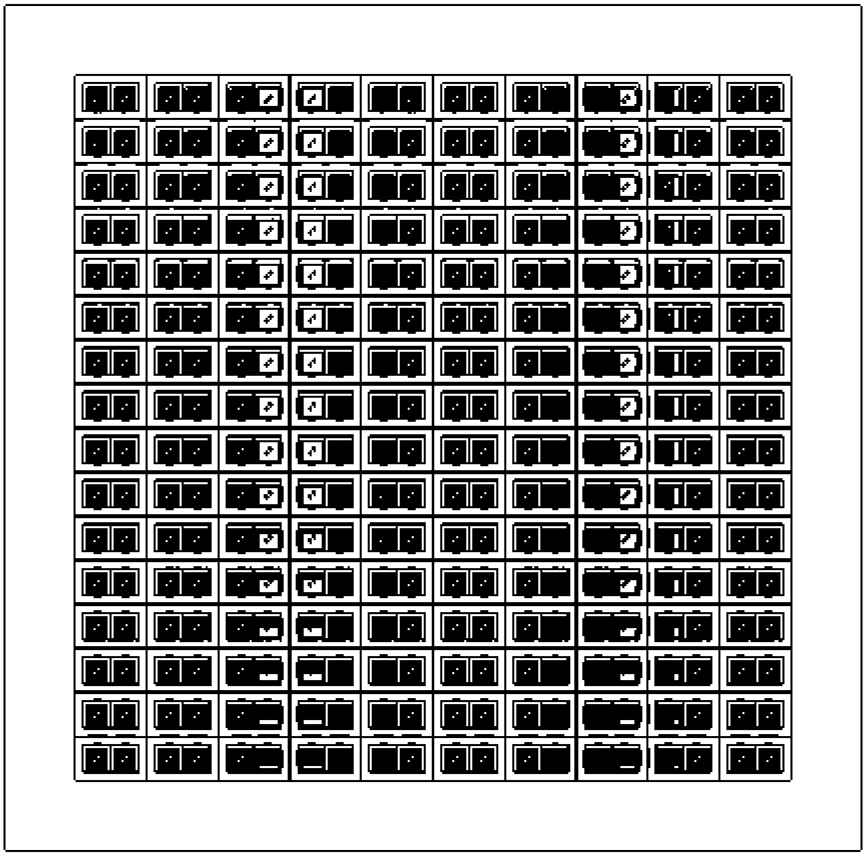


Figure 3.5.2 - Damaged package array of 160 units

A sample damaged container array model (GN8A-007) is provided in Appendix 2.

4 RESULTS OF THE CALCULATIONS

4.1 Single RA-3 Unit: Undamaged and Damaged

Calculations were run for the single fully reflected RA–3 container (both the undamaged and damaged package models) over the full range of interunit moderation. The results of these calculations are provided in Figure 4.1-1 and Table 4-1.1.

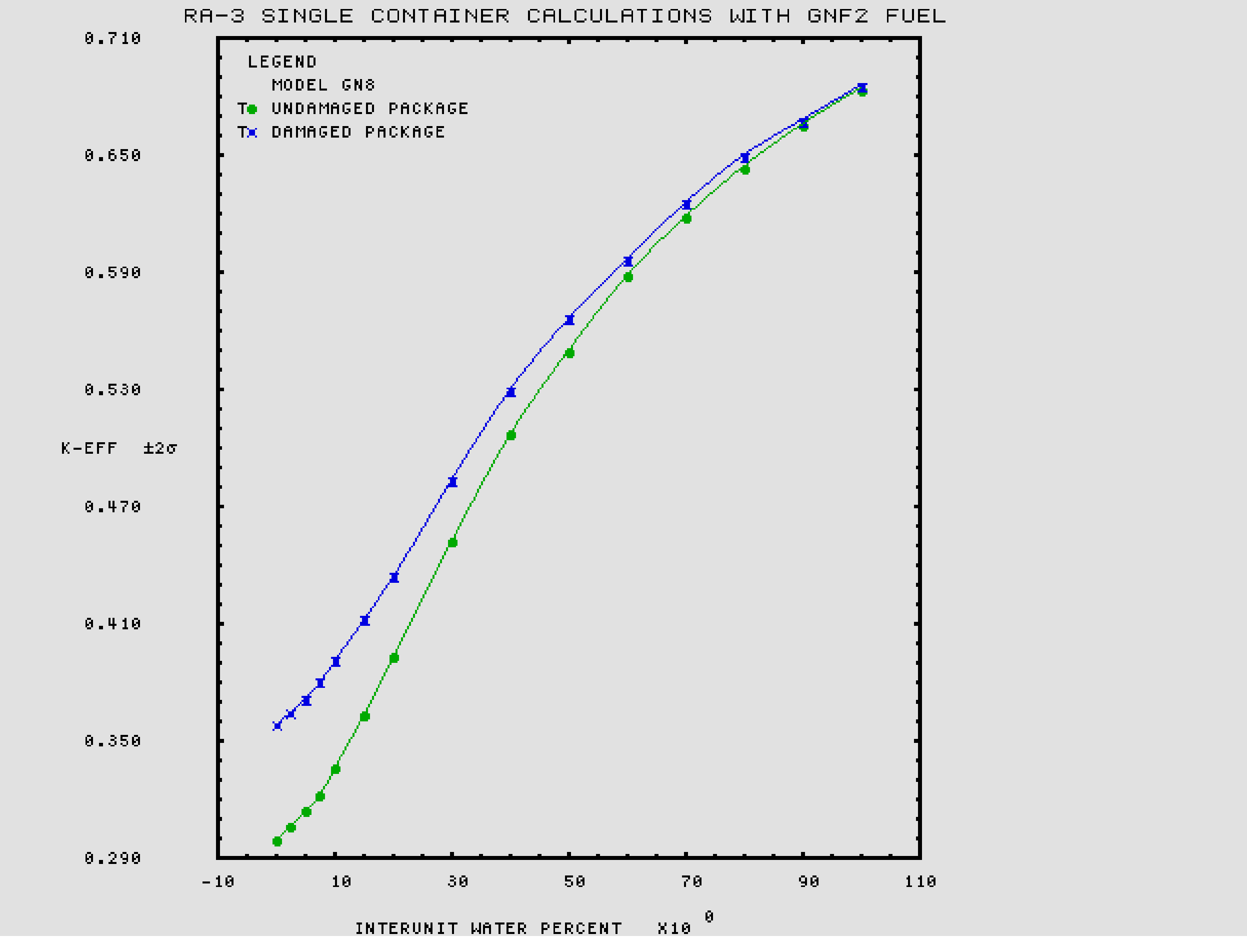


Figure 4.1-1
Single RA-3 Package, Undamaged and Damaged

TABLE 4.1-1 SINGLE PACKAGE CALCULATIONAL RESULTS

FILENAME	K-EFF	SIGMA	K	BIAS	KB	# HIST	LOST	DATE
				Limit = 0.9500				
Single undamaged package								
GN8OS000	0.2816	0.0007	0.2829	-.0170	0.2999	500000	554	11/16/04
GN8OS002	0.2886	0.0007	0.2899	-.0170	0.3069	500000	541	11/16/04
GN8OS005	0.2963	0.0007	0.2977	-.0170	0.3147	500000	477	11/16/04
GN8OS007	0.3049	0.0007	0.3064	-.0170	0.3234	500000	482	11/16/04
GN8OS010	0.3187	0.0007	0.3201	-.0170	0.3371	500000	483	11/16/04
GN8OS015	0.3456	0.0008	0.3471	-.0170	0.3641	500000	493	11/17/04
GN8OS020	0.3751	0.0009	0.3769	-.0170	0.3938	500000	460	11/17/04
GN8OS030	0.4346	0.0009	0.4364	-.0170	0.4534	500000	484	11/17/04
GN8OS040	0.4893	0.0009	0.4912	-.0170	0.5082	500000	436	11/17/04
GN8OS050	0.5318	0.0010	0.5338	-.0170	0.5508	500000	374	11/17/04
GN8OS060	0.5700	0.0011	0.5722	-.0170	0.5892	500000	474	11/17/04
GN8OS070	0.6001	0.0011	0.6023	-.0170	0.6193	500000	378	11/17/04
GN8OS080	0.6259	0.0011	0.6281	-.0170	0.6451	500000	359	11/17/04
GN8OS090	0.6475	0.0011	0.6497	-.0170	0.6667	500000	395	11/17/04
GN8OS100	**0.6658**	**0.0011**	**0.6680**	**-.0170**	**0.6850**	**500000**	**213**	**11/17/04**
Single damaged package								
GN8IS000	0.3404	0.0007	0.3418	-.0170	0.3588	500000	71	11/16/04
GN8IS002	0.3468	0.0007	0.3482	-.0170	0.3652	500000	53	11/16/04
GN8IS005	0.3539	0.0008	0.3554	-.0170	0.3724	500000	33	11/16/04
GN8IS007	0.3623	0.0008	0.3638	-.0170	0.3808	500000	37	11/16/04
GN8IS010	0.3731	0.0008	0.3747	-.0170	0.3916	500000	25	11/16/04
GN8IS015	0.3941	0.0008	0.3957	-.0170	0.4127	500000	15	11/16/04
GN8IS020	0.4163	0.0009	0.4181	-.0170	0.4351	500000	16	11/16/04
GN8IS030	0.4658	0.0010	0.4677	-.0170	0.4847	500000	16	11/16/04
GN8IS040	0.5117	0.0011	0.5138	-.0170	0.5308	500000	16	11/16/04
GN8IS050	0.5482	0.0009	0.5500	-.0170	0.5670	500000	12	11/16/04
GN8IS060	0.5787	0.0009	0.5805	-.0170	0.5975	500000	8	11/16/04
GN8IS070	0.6072	0.0011	0.6094	-.0170	0.6264	500000	5	11/16/04
GN8IS080	0.6318	0.0011	0.6339	-.0170	0.6509	500000	7	11/16/04
GN8IS090	0.6499	0.0010	0.6519	-.0170	0.6689	500000	10	11/16/04
GN8IS100	**0.6677**	**0.0010**	**0.6698**	**-.0170**	**0.6868**	**500000**	**11**	**11/16/04**
Cosine starting source								
GN8IC100	0.6670	0.0011	0.6693	-.0170	0.6863	500000	10	11/17/04

As the interunit water increases, the results of the two models converge to near equality at full interunit water. To assure adequate convergence for the most reactive case, the single damaged package was rerun at full density interunit water with a cosine starting source distribution (GN8IC100). All calculations are far from limiting as would be expected with only two bundles. The higher results for the damaged package result from replacing the outer container contents with a full density water reflector. It is further noted that replacing all structural and insulating materials with full density water and assuming full density water both within and outside of the bundles results in Keff of 0.7102 ± 0.0012, still far below the USL.

The convergence plots for the most reactive single unit case (GN8IS100 and GN8IC100) are provided in Figure 4.1-2 to show that the calculation is adequately converged. In this plot, data to the left of the vertical line show the average k-eff as generations are added. Data to the right of the vertical line show the average k-eff as initial generations are removed. (50 initial batches were skipped prior to collection of data.)

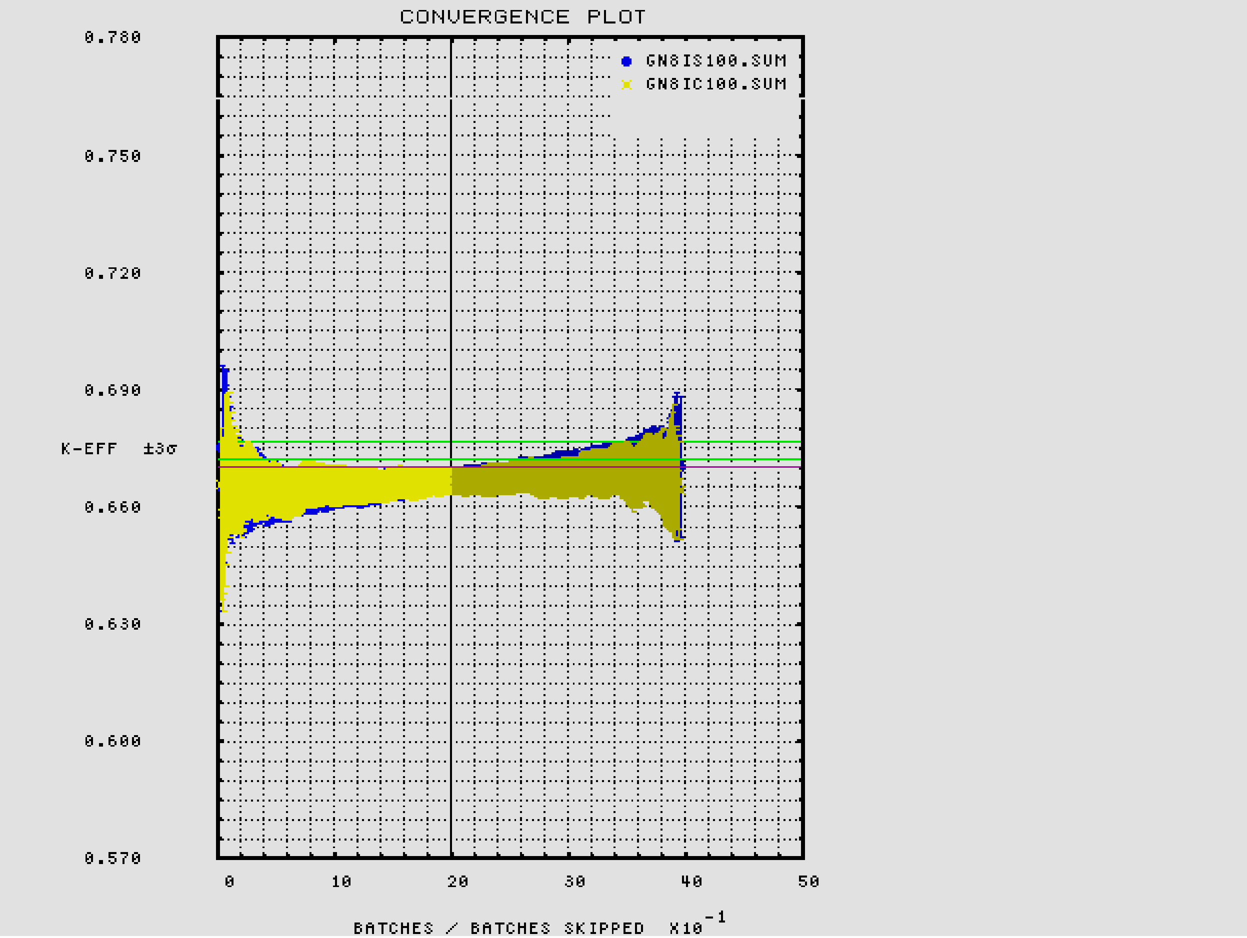


Figure 4.1-2
Convergence Plot for GN8IS100

These results show that the RA-3 container meets the single unit multiplication limit for transporting the GNF2 fuel assemblies. The required limit is that calculated multiplication factors plus two times the statistical uncertainty minus bias must not exceed 0.95.

4.2 Undamaged RA-3 Package Array

Calculations were run for a undamaged package array consisting of 608 undamaged RA–3 containers, both with and without the cluster separators. These calculations were based on the model constructs described in Section 3.5. The GN8N model was run over the full range of interunit water to establish the optimum value. The results of these calculations are provided in Figure 4.2-1 and Table 4.2-1. This figure demonstrates that the GN8A model results are well below the USL over the full range of interunit moderation and that the peak occurs at no interunit water. Keff for the model without cluster separators is significantly higher at no interunit water than for the model with cluster separators. Both models show an increasing trend with decreasing moderation, thus demonstrating that the use of less than nominal moderation in the model is conservative. The models for the other enrichment bands were run at zero interunit water and are also shown in Table 4.2-1. These calculations are also well below the USL.

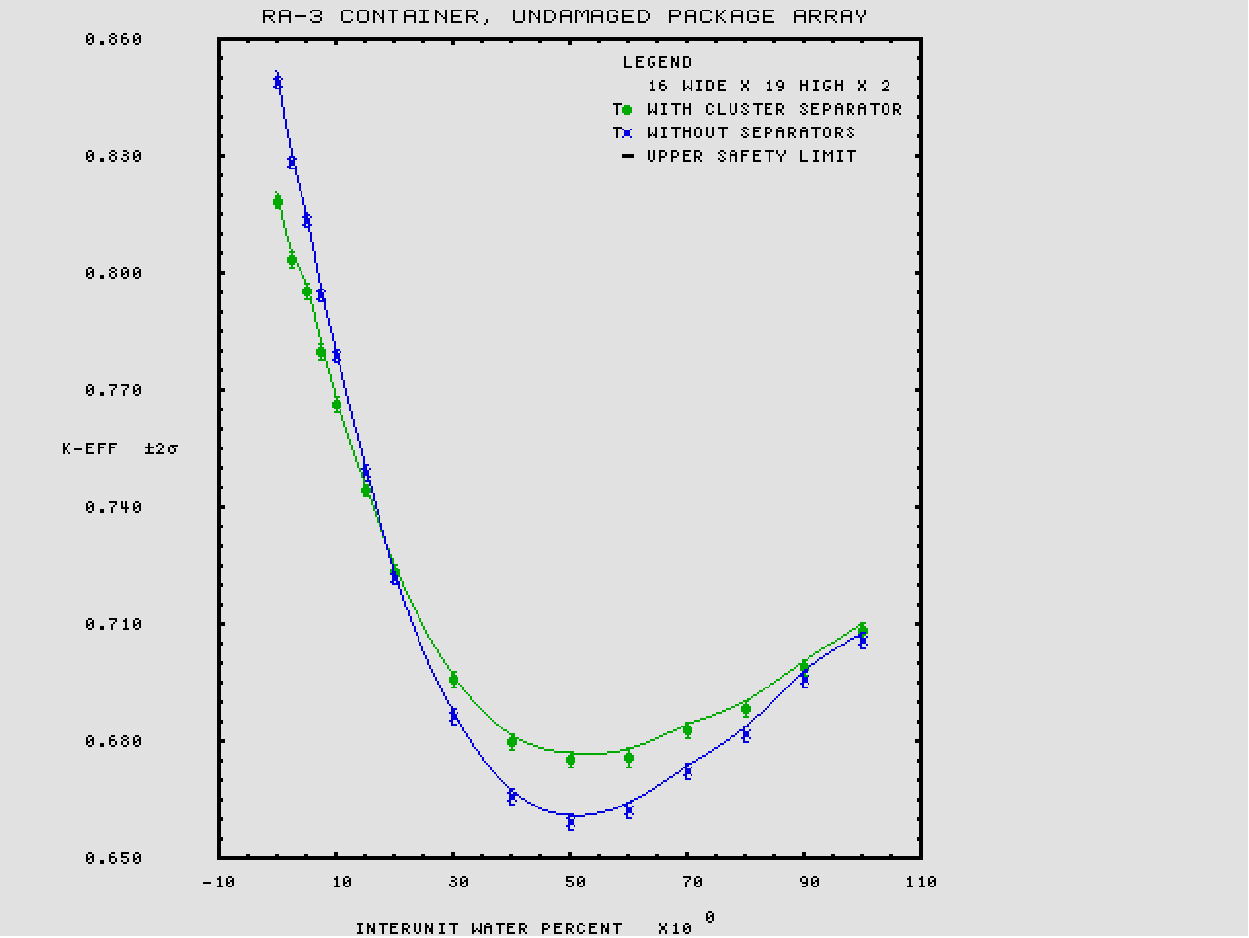


Figure 4.2-1
Undamaged Package Array, with and without Cluster Separators

TABLE 4.2-1 – UNDAMAGED PACKAGE ARRAY CALCULATIONAL RESULTS

FILENAME	K-EFF	SIGMA	K	BIAS	KB	# HIST	LOST	DATE
Limit = 0.9500								
Includes Cluster Separators								
GN8N-000	**0.8012**	**0.0008**	**0.8027**	**-.0170**	**0.8197**	**500000**	**224**	**11/12/04**
GN8N-002	0.7863	0.0009	0.7880	-.0170	0.8051	500000	122	11/09/04
GN8N-005	0.7784	0.0009	0.7802	-.0170	0.7972	500000	77	11/09/04
GN8N-007	0.7629	0.0009	0.7646	-.0170	0.7816	500000	59	11/09/04
GN8N-010	0.7494	0.0009	0.7513	-.0170	0.7683	500000	62	11/09/04
GN8N-015	0.7273	0.0008	0.7290	-.0170	0.7460	500000	39	11/12/04
GN8N-020	0.7064	0.0010	0.7083	-.0170	0.7253	500000	28	11/09/04
GN8N-030	0.6786	0.0009	0.6804	-.0170	0.6974	500000	13	11/09/04
GN8N-040	0.6629	0.0010	0.6649	-.0170	0.6819	500000	23	11/09/04
GN8N-050	0.6581	0.0011	0.6602	-.0170	0.6772	500000	11	11/09/04
GN8N-060	0.6588	0.0012	0.6611	-.0170	0.6781	500000	15	11/17/04
GN8N-070	0.6655	0.0010	0.6676	-.0170	0.6846	500000	14	11/17/04
GN8N-080	0.6714	0.0010	0.6735	-.0170	0.6905	500000	14	11/17/04
GN8N-090	0.6815	0.0011	0.6837	-.0170	0.7007	500000	8	11/17/04
GN8N-100	0.6913	0.0010	0.6932	-.0170	0.7102	500000	13	11/17/04
Without separators								
GN8NX000	**0.8319**	**0.0007**	**0.8334**	**-.0170**	**0.8504**	**500000**	**410**	**11/12/04**
GN8NX002	0.8113	0.0008	0.8128	-.0170	0.8298	500000	208	11/12/04
GN8NX005	0.7961	0.0008	0.7977	-.0170	0.8147	500000	131	11/12/04
GN8NX007	0.7770	0.0008	0.7785	-.0170	0.7955	500000	81	11/12/04
GN8NX010	0.7616	0.0008	0.7633	-.0170	0.7803	500000	67	11/12/04
GN8NX015	0.7318	0.0009	0.7335	-.0170	0.7505	500000	36	11/12/04
GN8NX020	0.7048	0.0008	0.7065	-.0170	0.7235	500000	30	11/12/04
GN8NX030	0.6690	0.0010	0.6710	-.0170	0.6880	500000	29	11/12/04
GN8NX040	0.6489	0.0009	0.6508	-.0170	0.6678	500000	20	11/12/04
GN8NX050	0.6424	0.0009	0.6441	-.0170	0.6611	500000	14	11/12/04
GN8NX060	0.6452	0.0011	0.6474	-.0170	0.6644	500000	13	11/17/04
GN8NX070	0.6550	0.0009	0.6569	-.0170	0.6739	500000	13	11/17/04
GN8NX080	0.6645	0.0011	0.6667	-.0170	0.6837	500000	17	11/17/04
GN8NX090	0.6789	0.0011	0.6810	-.0170	0.6980	500000	16	11/17/04
GN8NX100	0.6888	0.0010	0.6909	-.0170	0.7079	500000	16	11/17/04
Other enrichment bands								
G00NX000	0.8168	0.0008	0.8184	-.0170	0.8354	500000	495	11/15/04
GA1NX000	0.8202	0.0009	0.8219	-.0170	0.8389	500000	536	11/15/04
GBTNX000	0.8283	0.0007	0.8297	-.0170	0.8467	500000	458	11/15/04
GD8NX000	0.8300	0.0008	0.8315	-.0170	0.8485	500000	432	11/15/04
GF1NX000	0.8224	0.0008	0.8239	-.0170	0.8409	500000	529	11/15/04

The model without poly is more reactive at low interunit water density. At intermediate interunit water densities the model with poly becomes more reactive. At full density interunit water, the results of the two models are approximately equal, as would be expected.

The convergence plot for the most reactive case (GN8NX000) is provided in Figure 4.2-2 to show that the calculation is adequately converged. In this plot, data to the left of the vertical line show the average k-eff as generations are added. Data to the right of the vertical line show the average k-eff as initial generations are removed. (50 initial batches were skipped prior to collection of data.)

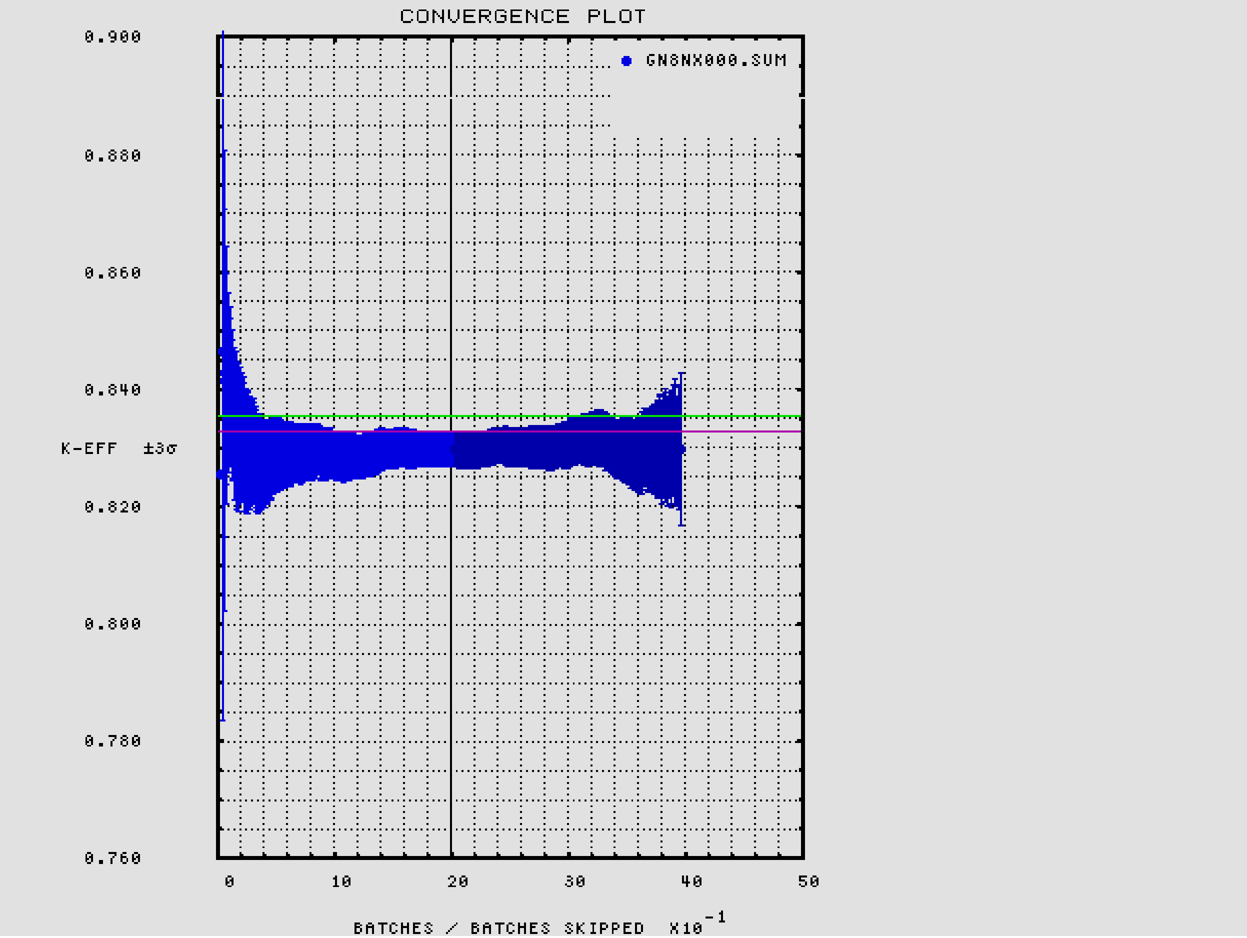


Figure 4.2-2
Convergence Plot for GN8NX000

These undamaged package array results show that the RA-3 container meets the undamaged array multiplication limit for transporting the GNF2 fuel assemblies. The requirement is that calculated multiplication factors plus two times the statistical uncertainty must not exceed 0.95 plus bias.

$$\text{Keff} + 2\sigma \leq 0.95 + \beta$$

$$0.8319 + 0.0014 \leq 0.95 + (-0.017)$$

$$0.8333 \leq 0.933$$

Since five times the allowable number of containers must be demonstrated to be safe as an undamaged package array, this demonstration supports an allowable number of 120. (NOTE: The damaged package array is most limiting and determines the value of N to be used for this demonstration.)

4.3 Damaged RA-3 Package Array

Calculations were run for a damaged package array consisting of 160 damaged RA–3 containers. These calculations were based on the model constructs described in Section 3.6. The GN8A model was run over the full range of interunit water to establish the optimum value. The results of these calculations are provided in Figure 4.3-1. This figure demonstrates that the GN8A model results are below the USL over the full range of interunit moderation and that the peak occurs in the vicinity of 7.5% interunit water.

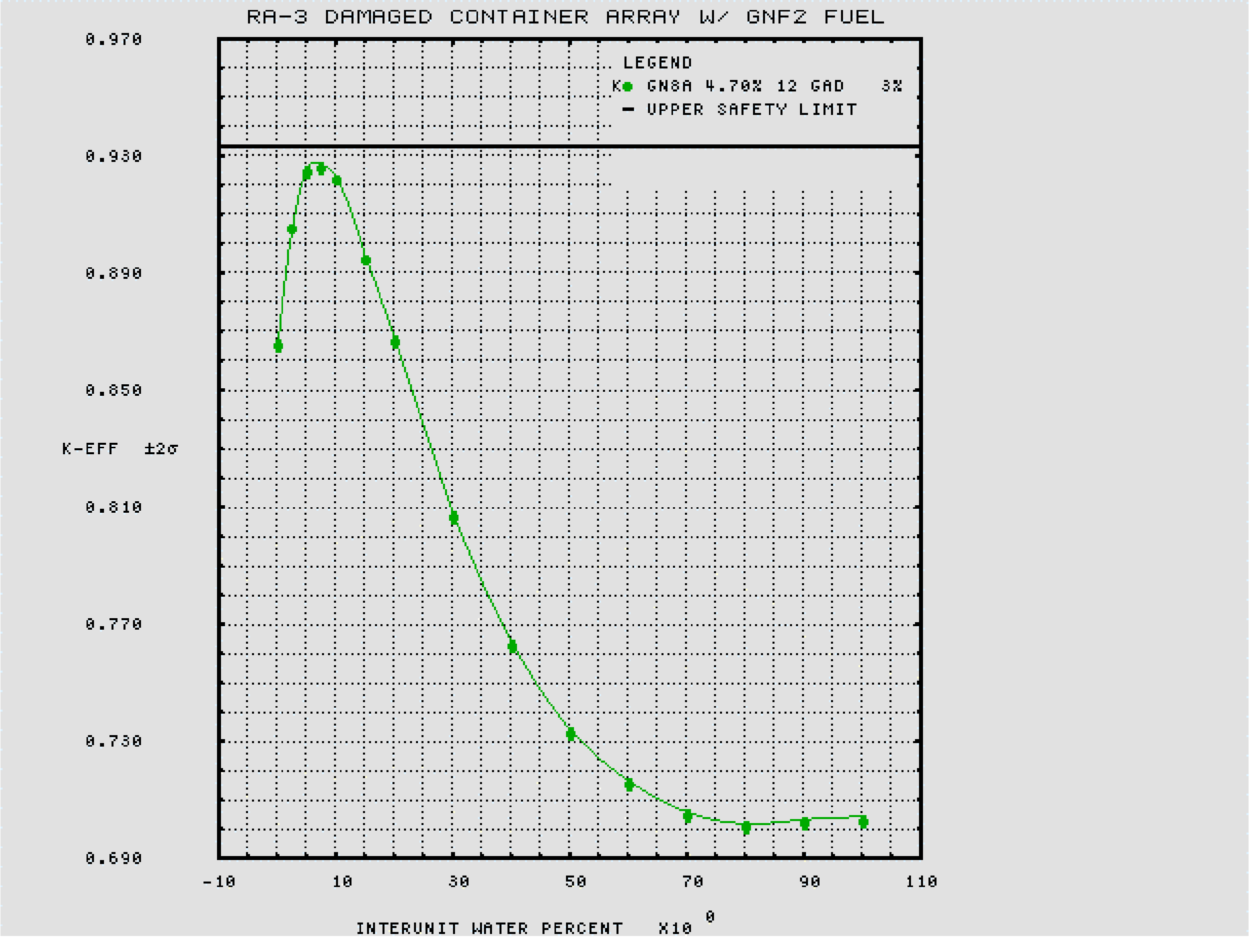


Figure 4.3-1
Damaged Container Array, Model GN8A

The other five fuel models were run over the interunit moderation range of zero to 20% for comparison. The results of the calculations for models GD8A, GBTA, and GF1A are compared to GN8A in Figure 4.3-2. This figure demonstrates that these results are also below the USL and peak at about the same amount of interunit water. (The other two models (GA1A and G00A) are not shown but produce results slightly less limiting.) The most limiting condition appears to be model GBTA at 7.5% interunit water for which $k+2\sigma = 0.931 < 0.933$.

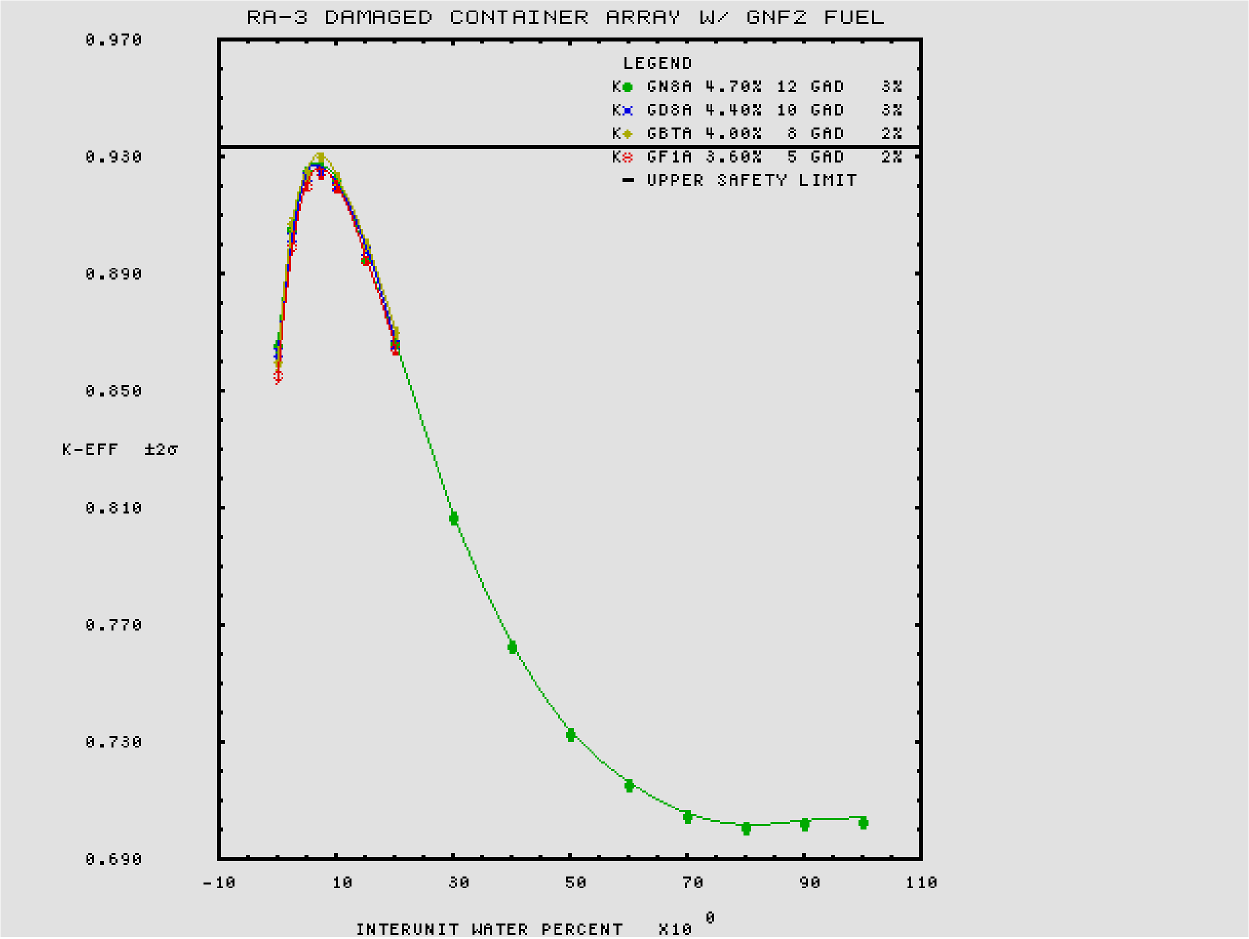


Figure 4.3-2
GNF2 Damaged Container Array, Models GF1A, GBTA, GD8A GN8A

The convergence plot for the most reactive case (GBTA-007) is provided in Figure 4.3-3 to show that the calculation is adequately converged. In this plot, data to the left of the vertical line show the average k-eff as generations are added. Data to the right of the vertical line show the average k-eff as initial generations are removed. (50 initial batches were skipped prior to collection of data.) This plot is inconclusive.

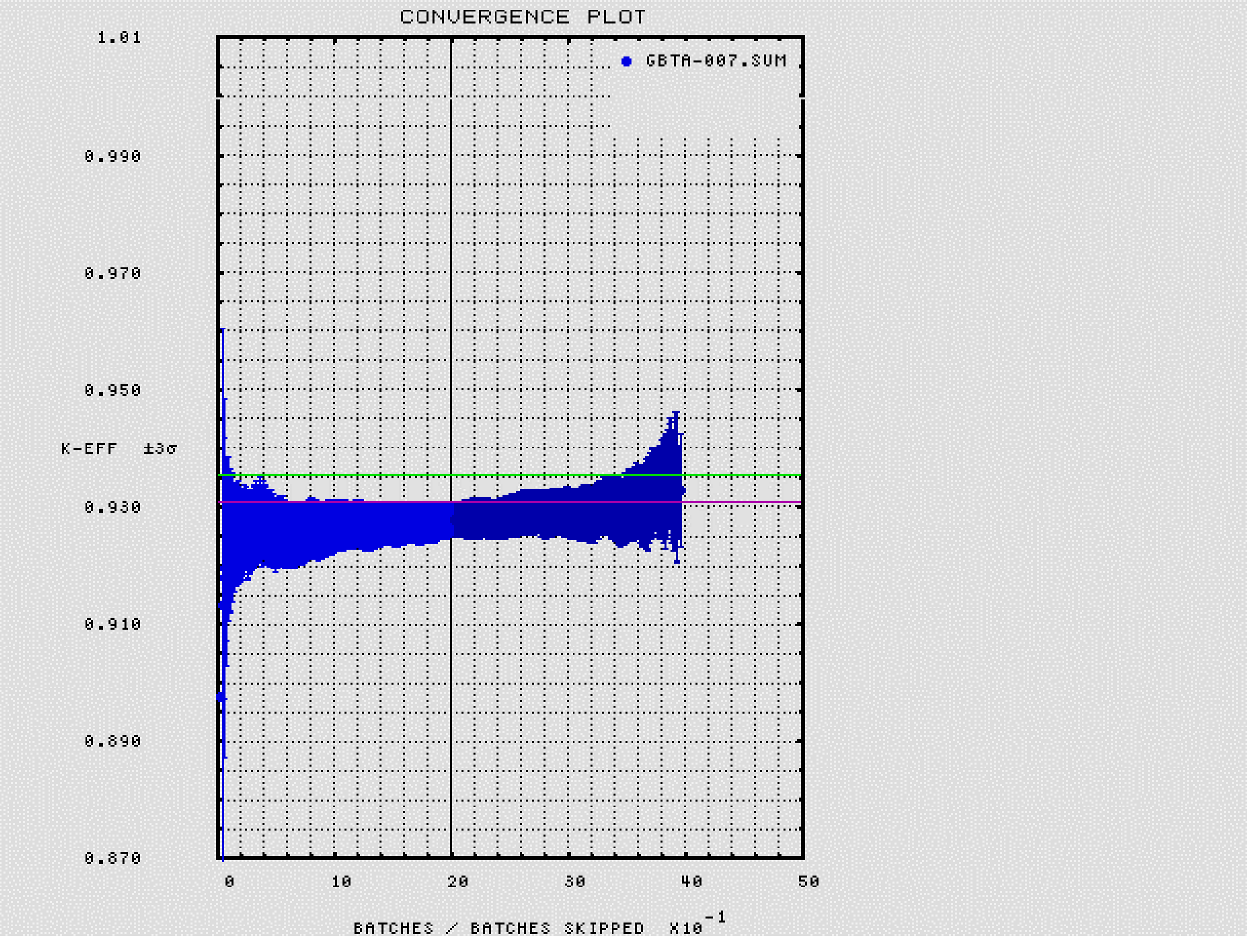


Figure 4.3-3
Convergence Plot for GBTA-007

Because this case is so close to the USL, it was repeated (GBTAC007) with a cosine starting source distribution to assure convergence. For this repeat case, k+2σ = 0.930 which is the same result as that of GBTA-007. For this case, the convergence plot is shown in Figure 4.3-4.

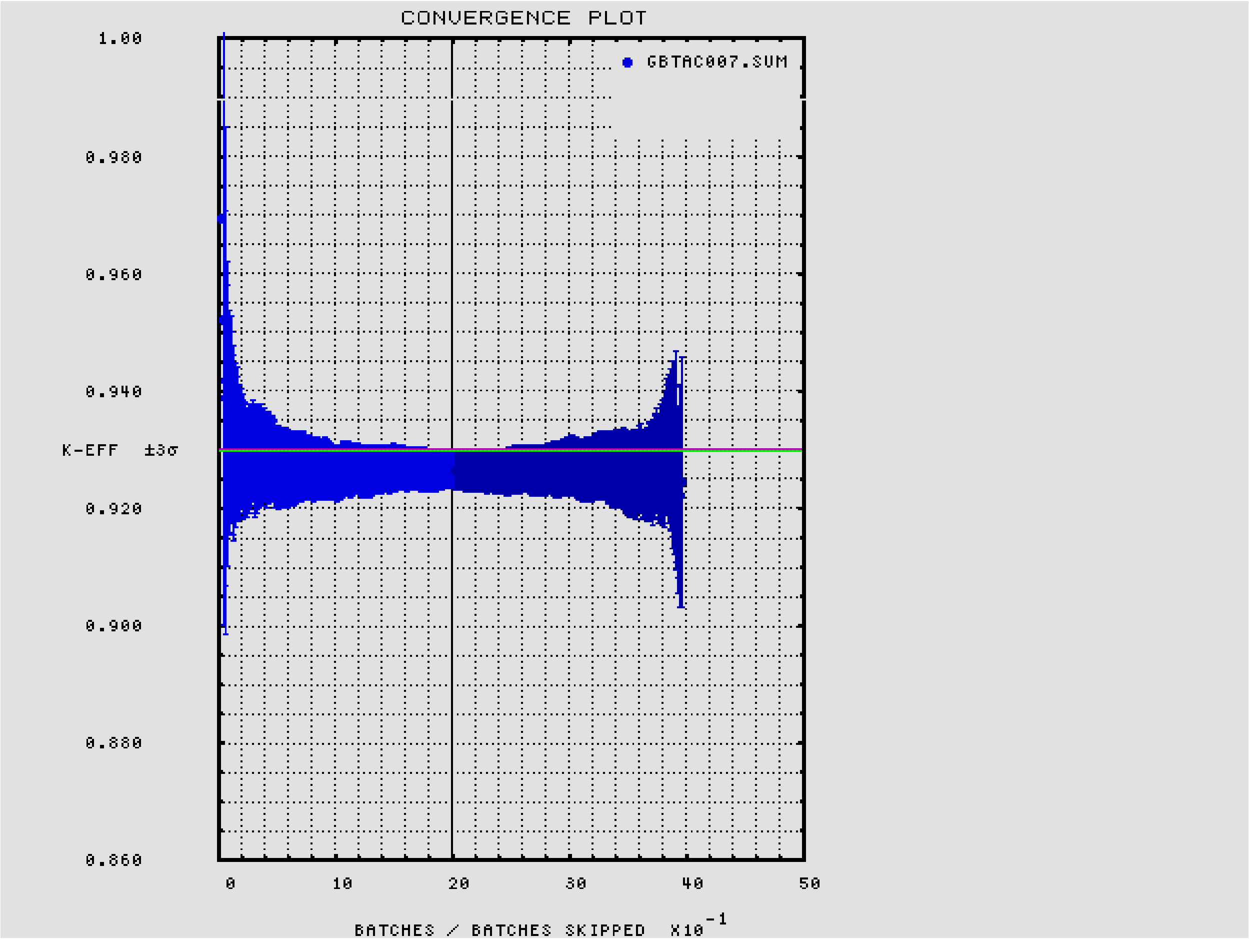


Figure 4.3-4
Convergence Plot for GBTAC007

The GNF2 design results for the damaged package array are provided in Table 4.3-1.

TABLE 4.3-1 – DAMAGED PACKAGE CALCULATIONAL RESULTS

FILENAME	K-EFF	SIGMA	K	BIAS	KB	# HIST	LOST	DATE
Limit = 0.9500								
MODEL G00A								
G00A-000	0.8468	0.0008	0.8484	-.0170	0.8654	500000	335	11/04/04
G00A-002	0.8939	0.0010	0.8958	-.0170	0.9128	500000	134	11/04/04
G00A-005	0.9143	0.0009	0.9160	-.0170	0.9330	500000	86	11/04/04
G00A-007	**0.9216**	**0.0008**	**0.9232**	**-.0170**	**0.9402**	**500000**	**89**	**11/04/04**
G00A-010	0.9186	0.0008	0.9201	-.0170	0.9372	500000	59	11/04/04
G00A-015	0.8963	0.0009	0.8980	-.0170	0.9150	500000	58	11/04/04
G00A-020	0.8654	0.0009	0.8672	-.0170	0.8842	500000	32	11/04/04
MODEL GA1A								

GA1A-000	0.8512	0.0008	0.8527	-.0170	0.8697	500000	319	11/04/04
GA1A-002	0.8972	0.0008	0.8988	-.0170	0.9158	500000	147	11/04/04
GA1A-005	0.9182	0.0008	0.9199	-.0170	0.9369	500000	93	11/04/04
GA1A-007	**0.9229**	**0.0008**	**0.9246**	**-.0170**	**0.9416**	**500000**	**81**	**11/04/04**
GA1A-010	0.9181	0.0008	0.9197	-.0170	0.9367	500000	74	11/04/04
GA1A-015	0.8948	0.0008	0.8964	-.0170	0.9134	500000	43	11/04/04
GA1A-020	0.8657	0.0009	0.8674	-.0170	0.8845	500000	54	11/04/04

MODEL GF1A

GF1A-000	0.8550	0.0008	0.8566	-.0170	0.8736	500000	327	11/04/04
GF1A-002	0.8987	0.0008	0.9004	-.0170	0.9174	500000	119	11/04/04
GF1A-005	0.9198	0.0008	0.9214	-.0170	0.9384	500000	125	11/05/04
GF1A-007	**0.9242**	**0.0009**	**0.9260**	**-.0170**	**0.9430**	**500000**	**85**	**11/05/04**
GF1A-010	0.9195	0.0009	0.9212	-.0170	0.9382	500000	68	11/05/04
GF1A-015	0.8944	0.0008	0.8960	-.0170	0.9130	500000	60	11/05/04
GF1A-020	0.8644	0.0009	0.8662	-.0170	0.8832	500000	41	11/05/04

MODEL GBTA

GBTA-000	0.8597	0.0008	0.8612	-.0170	0.8783	500000	321	11/05/04
GBTA-002	0.9068	0.0009	0.9085	-.0170	0.9255	500000	147	11/05/04
GBTA-005	0.9238	0.0009	0.9256	-.0170	0.9426	500000	105	11/05/04
GBTA-007	**0.9297**	**0.0008**	**0.9313**	**-.0170**	**0.9483**	**500000**	**95**	**11/05/04**
GBTA-010	0.9221	0.0009	0.9238	-.0170	0.9408	500000	76	11/05/04
GBTA-015	0.8999	0.0009	0.9017	-.0170	0.9187	500000	57	11/05/04
GBTA-020	0.8696	0.0009	0.8713	-.0170	0.8883	500000	43	11/05/04

MODEL GD8A

GD8A-000	0.8629	0.0008	0.8644	-.0170	0.8814	500000	303	11/05/04
GD8A-002	0.9023	0.0008	0.9039	-.0170	0.9209	500000	131	11/05/04
GD8A-005	0.9231	0.0010	0.9250	-.0170	0.9420	500000	115	11/05/04
GD8A-007	**0.9252**	**0.0008**	**0.9268**	**-.0170**	**0.9438**	**500000**	**71**	**11/05/04**
GD8A-010	0.9199	0.0008	0.9215	-.0170	0.9385	500000	74	11/05/04
GD8A-015	0.8980	0.0009	0.8997	-.0170	0.9167	500000	49	11/05/04
GD8A-020	0.8659	0.0008	0.8676	-.0170	0.8846	500000	35	11/05/04

MODEL GN8A

GN8A-000	0.8648	0.0009	0.8665	-.0170	0.8835	500000	280	11/05/04
GN8A-002	0.9048	0.0008	0.9063	-.0170	0.9233	500000	134	11/05/04
GN8A-005	0.9241	0.0009	0.9258	-.0170	0.9428	500000	100	11/05/04
GN8A-007	**0.9258**	**0.0009**	**0.9276**	**-.0170**	**0.9446**	**500000**	**72**	**11/06/04**
GN8A-010	0.9214	0.0008	0.9231	-.0170	0.9401	500000	68	11/06/04
GN8A-015	0.8944	0.0008	0.8961	-.0170	0.9131	500000	40	11/06/04
GN8A-020	0.8661	0.0009	0.8679	-.0170	0.8849	500000	52	11/06/04
GN8A-030	0.8063	0.0009	0.8082	-.0170	0.8252	500000	27	11/06/04
GN8A-040	0.7621	0.0010	0.7642	-.0170	0.7811	500000	37	11/06/04
GN8A-050	0.7323	0.0010	0.7343	-.0170	0.7513	500000	26	11/06/04
GN8A-060	0.7149	0.0010	0.7169	-.0170	0.7339	500000	38	11/06/04
GN8A-070	0.7041	0.0010	0.7061	-.0170	0.7231	500000	20	11/06/04
GN8A-080	0.7000	0.0010	0.7021	-.0170	0.7191	500000	23	11/06/04
GN8A-090	0.7015	0.0010	0.7035	-.0170	0.7205	500000	20	11/06/04
GN8A-100	0.7025	0.0010	0.7045	-.0170	0.7215	500000	15	11/06/04

These results show that the RA-3 container meets the damaged container array multiplication limit for transporting the GNF2 fuel assemblies for all analyzed enrichment ranges. The required limit is that calculated multiplication factors plus two times the statistical uncertainty must not exceed 0.95 plus bias.

$$\text{Keff} + 2\sigma \leq 0.95 + \beta$$

$$0.9297 + 0.0016 \leq 0.95 + (-.017)$$

$$0.9313 \leq 0.933$$

Since two times the allowable number of containers must be demonstrated to be safe as a damaged package array, this demonstration supports an allowable number of 80.

4.4 Partial Length Rods

The effect of partial length rods was previously considered in the generic 10x10 analysis (Reference 1) and found to decrease reactivity. Partial length rods are now examined for the GNF2 fuel design. Like the generic 10x10 bundle, the GNF2 bundle may have up to 14 partial length rods. However, the locations have changed significantly. In the generic 10x10 bundle, up to 12 partial rods may be in the next to the outermost ring of rod positions and up to two between the water rods. In the GNF2 bundle, eight partial rods are located in the outermost ring of rod positions (two in the middle of each side) and six are the centermost fuel rods. In the generic 10x10 bundle, all partial rods are the same length. However, in the GNF2 bundle, the innermost partial rods are much shorter than the outermost partial rods. A partial length rod results in a lattice section that is effectively missing that rod. Therefore, the effect of partial length rods can be examined by ommiting rods from the appropriate locations over the entire bundle length. Two partial length rod arrangements are considered as shown in Figure 4.4-1.

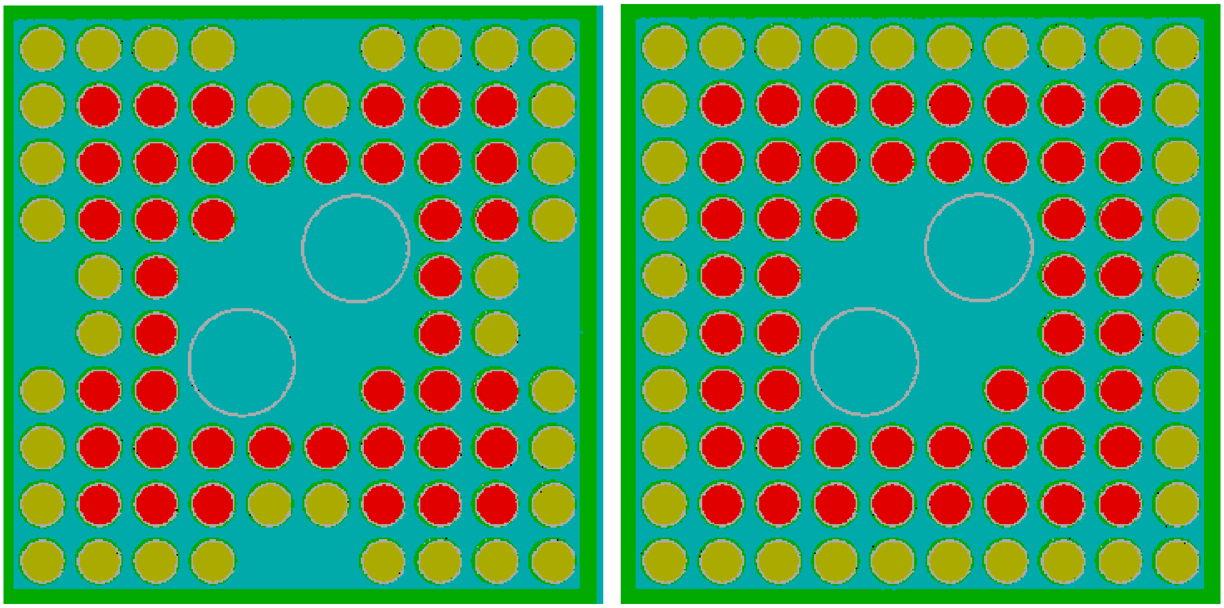


Figure 4.4-1

Model G00AP with 12 partial rods Model G00AQ with 6 partial rods

The model with no gad rods (G00A) was selected since there is no competition for location between the gad rods and partial rods. To assure conservatism in the model with 12 partial rods, the total number of 5.00% enriched rods was conserved. Since the removal of rods changes the lattice water-to-fuel ratio, a range of interunit moderation was considered. The results of these calculations are provided in Table 4.4-1 along with the result from G00A-007 for comparison.

TABLE 4.4-1 -CALCULATIONAL RESULTS

FILENAME	K-EFF	SIGMA	K	BIAS	KB	# HIST	LOST	DATE
				Limit = 0.9500				
G00A-007	**0.9216**	**0.0008**	**0.9232**	**-.0170**	**0.9402**	**500000**	**89**	**11/04/04**
DAMAGED CONTAINER ARRAY CALCULATIONS, 12 PARTIAL RODS								
G00AP002	0.8905	0.0009	0.8922	-.0170	0.9092	500000	361	11/09/04
G00AP005	0.9131	0.0008	0.9148	-.0170	0.9318	500000	243	11/09/04
G00AP007	**0.9181**	**0.0008**	**0.9197**	**-.0170**	**0.9367**	**500000**	**166**	**11/10/04**
G00AP010	0.9143	0.0009	0.9161	-.0170	0.9331	500000	129	11/10/04
DAMAGED CONTAINER ARRAY CALCULATIONS, 6 PARTIAL RODS								
G00AQ002	0.8943	0.0009	0.8960	-.0170	0.9130	500000	171	11/10/04
G00AQ005	0.9162	0.0009	0.9180	-.0170	0.9350	500000	118	11/10/04
G00AQ007	**0.9217**	**0.0009**	**0.9235**	**-.0170**	**0.9405**	**500000**	**112**	**11/10/04**
G00AQ010	0.9186	0.0008	0.9202	-.0170	0.9372	500000	85	11/10/04

Keff is slightly reduced for the case of 12 partial rods. However, there is no change for the case of six partial rods.

Because the GBTA model produced a Keff close to the USL, the six partial rod zone was examined for GBTA. To make room for the partial rods, the gad rods had to be moved away from the center (GBTAG). The interior six rods were then removed (GBTAQ) to examine the effect. Because the peak Keff did not shift for the G00A model, only the 7.5% interunit water condition was considered. The two new configurations are shown in Figure 4.4-2.

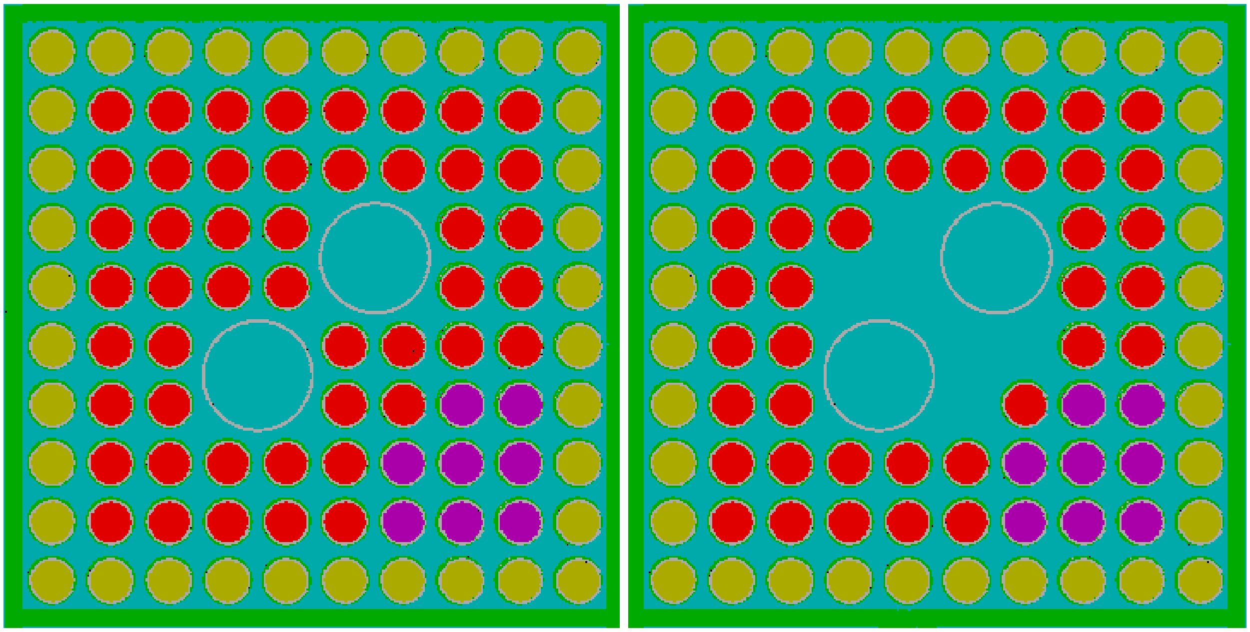


Figure 4.4-2

Model GBTAG with relocated gad rods Model GBTAQ with 6 partial rods

The results of these calculations are provided in Table 4.4-2 along with the result from GBTA-007 for comparison.

TABLE 4.4-2 -CALCULATIONAL RESULTS

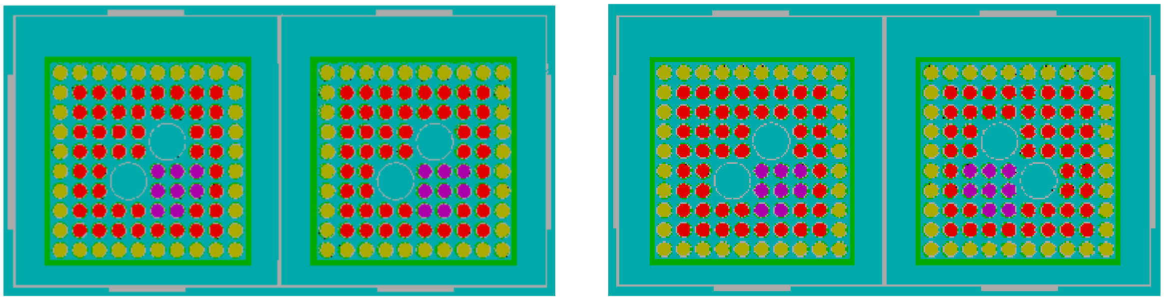
FILENAME	K-EFF	SIGMA	K	BIAS	KB	# HIST	LOST	DATE
Limit = 0.9500								
GBTA-007	**0.9297**	**0.0008**	**0.9313**	**-.0170**	**0.9483**	**500000**	**95**	**11/05/04**
DAMAGED CONTAINER ARRAY CALCULATIONS, 6 PARTIAL RODS								
GBTAG007	0.9193	0.0008	0.9209	-.0170	0.9379	500000	78	11/10/04
GBTAQ007	0.9113	0.0009	0.9132	-.0170	0.9302	500000	104	11/10/04

Moving the gad rods toward the periphery reduced Keff significantly as would be expected. Removing the six innermost rods further reduced Keff.

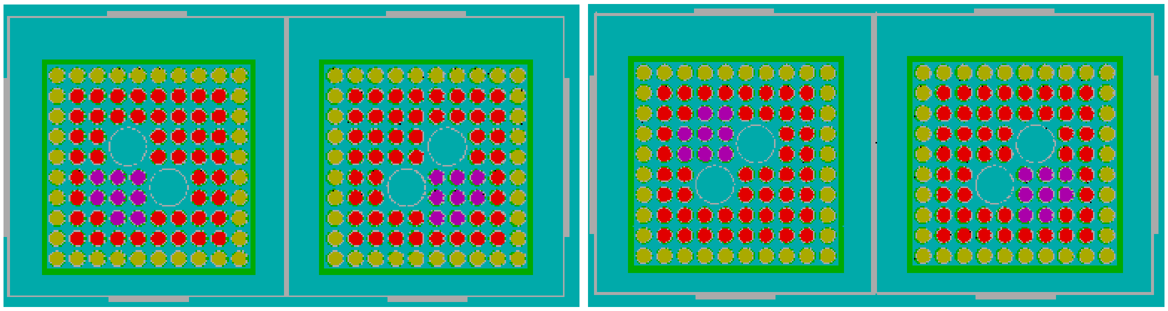
Based on these calculations, there is no significant increase in Keff due to the partial rods.

4.5 Bundle Orientation

In the previous calculations in this evaluation, both bundles in an RA-3 container had the same orientation. Because of the asymmetry introduced by the water rods and the gad rods, the most reactive orientation was reevaluated for other orientations as shown in Figure 4.5-1.



MODEL GBTA - Normal Orientation MODEL GBTAR – Alternate Orientation



MODEL GBTAS – Alternate Orientation MODEL GBTAT – Alternate Orientation

Figure 4.5-1 - Alternate Bundle Orientation Models

The results of these calculations are provided in Table 4.5-1 along with the result from GBTA-007 for comparison.

TABLE 4.5-1 - CALCULATIONAL RESULTS

FILENAME	K-EFF	SIGMA	K	BIAS	KB	# HIST	LOST	DATE
				Limit = 0.9500				
GBTA-007	**0.9297**	**0.0008**	**0.9313**	**-.0170**	**0.9483**	**500000**	**95**	**11/05/04**
DAMAGED CONTAINER ARRAY, ROTATED BUNDLE								
GBTAR007	0.9270	0.0009	0.9288	-.0170	0.9458	500000	94	11/10/04
GBTAS007	0.9276	0.0008	0.9293	-.0170	0.9463	500000	86	11/10/04
GBTAT007	0.9276	0.0009	0.9294	-.0170	0.9464	500000	86	11/10/04

Based on these calculations, the use of the standard orientation appears to be conservative and appropriate.

5 CONCLUSIONS

The calculated neutron multiplication factors show that the shipping requirements are met for the single undamaged package, the single damaged package, the undamaged package array (608 containers) and the damaged package array (160 containers). The damaged package array represents the most limiting condition.

The number of packages that remain below the upper safety limit determines the Criticality Safety Index (CSI) for criticality control. For normal conditions of transport, the contents of 5N=608 RA-3 undamaged packages are demonstrated to remain subcritical. Therefore, N is 120. Since this value is less limiting than N for the damaged package array, the CSI is determined by the 2N damaged package array.

Under hypothetical accident conditions, the contents of 2N=160 RA-3 damaged packages is demonstrated to remain subcritical. Therefore, the CSI for criticality control purposes is:

$$\text{CSI} = 50 / N = 0.625 \approx 0.7 \text{ (rounding up to nearest tenth)}$$

Therefore, the maximum number of RA-3 packages containing GNF2 design fuel bundles that can be transported in a single shipment (using the rounded CSI value) is N = 50 / 0.7 = 71.

5.1 FUEL ASSEMBLY REQUIREMENTS

The criticality safety analysis for the RA-3 shipping container presented in this report is applicable to fuel assemblies meeting the following specifications:

10 x 10 Assemblies

Fuel Assembly Type:	GNF2
Number of Water Rods:	2
Number of Fuel Rods:	92
Maximum No. of Partial Rods:	14 (Eight fuel rods in the outermost ring of rod positions (two centered on each face of the bundle) and six shorter fuel rods in the centermost rod positions)
Nominal Partial Rod Length (fuel):	110” (280.34 cm) above bottom of active fuel (long partial rod) 59” (149.86 cm) above bottom of active fuel (short partial rod) (Partial rods are not a restriction).
Fuel Rod OD:	0.404 inches (1.0262 cm)
Max. Fuel Pellet Diameter:	0.3508 inches (0.891 cm)
Cladding Type:	Zirconium
Cladding Thickness:	[[ ]]*
Maximum Active Fuel Length:	150 inches (381 cm)
Nominal Fuel Rod Pitch:	0.510 inches (1.295 cm)
Maximum U-235 Pellet Enrichment:	5.0%

Cluster Separators

Maximum Effective Backbone Thickness[1]:	0.151” (0.3835 cm)
Maximum Effective Separator Thickness[1]:	0.044” (0.1118 cm)
Max. Backbone H_2O hydrogen equivalent[2]:	0.13 g/cc
Max. Separator H_2O hydrogen equivalent[2]:	0.10 g/cc

[1] The effective thickness is a linear average of the maximum and minimum thickness.

[2] H_2O hydrogen equivalent per cubic centimeter averaged over the assembly.

In addition, the fuel assemblies must meet the U-235 enrichment and Gad rod requirements specified for GNF2 lattices. These requirements are the same as for the generic 10x10 latices. These are summarized in Table 5.1.

TABLE 5.1
Enrichment and Gad Rod Requirements for GNF2 Fuel Assemblies

Enrichment Range*	Peak U-235 Enrichment	Minimum Number Of Gad Rods**	Minimum Gad Concentration
E ≤ 2.80%	**5.00%**	**None**	**N/A**
2.80% ≤ E ≤ 3.20%	**5.00%**	**2**	**2%**
3.20% ≤ E ≤ 3.60%	**5.00%**	**5**	**2%**
3.60% ≤ E ≤ 4.00%	**5.00%**	**8**	**2%**
4.00% ≤ E ≤ 4.40%	**5.00%**	**10**	**3%**
4.40% ≤ E ≤ 4.70%	**5.00%**	**12**	**3%**

* Lattice Average Enrichment

** Required Gad Rods Must Be Distributed Symetrically About the Major Diagonal.

6 REFERENCES

1. “Criticality Safety Analysis for the RA-3 Shipping Container with Generic 10x10 fuel Assemblies with Cluster Separators”, S G Walters, May 22, 1995.

2. “Competent Authority Certification for A Fissile Radioactive Materials Package Design”, U. S. Dept. of Transportation, Certificate USA/0460/AF-85, Rev. 2.

3. License Certificate D/4306/AF85 (Rev. 2), Federal Office for Radiation Protection (BfS).

4. Title 10, Code of Federal Regulations, Part 71, United States of America.

5. GEMER Monte Carlo Code:
    - MERIT - A Monte Carlo Neutron Transport Program, CM Kang, AS Crowder, GK Craig, EC Hansen, August 1, 1976.
    - GEMER Monte Carlo - Users Manual, WC Peters, September 15, 1981.
    - GEMER.4 - Users Manual, JT Taylor, November 1989.
    - GEMER - Microcomputer Version Users Guide, JT Taylor, June 21, 1994.
    - GEMER01 – Supplemental Users Guide, JT Taylor, August 21, 2001.
    - GEMER02 – Supplemental Users Guide, JT Taylor, June 25, 2002.
    - GEMER Version 1.0 – Users Guide, JT Taylor, March 31, 2004.

6. Drawing Number 769E231, Rev 5, RA-3 Inner Container.

7. Drawing Number 769E229, Rev 7, RA-3 Outer Container.

8. GNF-A drawings:

    - #234C5372, GNF2 Drawing, "Pellet UO_2," rev. 00, 3/10/03
    - #234C5375, GNF2 Drawing, "Tube," rev. 00, 2/10/2003

9. Certificate Of Compliance No. 4986 For The Model No. RA-3 Package – Request For Additional Information, JR Cuadrado (USNRC, Spent Fuel Project Office, Office of NMSS) To CM Vaughan (GNF-A, Manager, Facility Licensing), Docket No. 71-4986, TAC No. L23695, May 26, 2004. .

10. GEMER Monte Carlo Validation Report: RA-3 Analysis with GNF2 Fuel, JT Taylor, November 2004.

7 APPENDIX 1

7.1 MODELING CONSIDERATIONS

7.1.1 Fuel atomic densities.

The density of UO_2 = Theoretical density of UO_2 * fraction of theoretical density * smear factor. Where the theoretical density of UO_2 is 10.96 gm/cc, the fraction of theoretical density is .98, and the smear density (the fraction of volume within the clad occupied by the pellet) is .978. This conservatively ignores the stacking density of the pellet. The density of UO_2 is therefore10.5045024gm/cc. The density of uranium is density of UO_2*.88144 = 9.259088595 gm /cc. The density of a uranium isotope (Nui) is then given, in atoms per barn centimeter, by:

Nui = U_den * Avag_Num * EF *(area/barn)/gm-mol

Avag_Num = .6023 x 10^{24}

EF = enrichment for U^{235} and (1.0 - enrichment for U^{238})

The area per barn is 1.0 x 10^{-24} cm^2. The grams per gram molecular weight are 235.0439 for U^{235} and 238.0508 for U^{238}. The number of oxygen atoms is twice the total number of uranium atoms. The atomic densities resulting are shown in Tables A1 and A2.

Table A1 - Atomic Densities For 4.51 Percent Enriched UO_2

U^{235}	1.07006131 * 10^{-03}
U^{238}	2.23701734 * 10^{-02}
O	4.68804694 * 10^{-02}

Table A2 - Atomic Densities For 5.0 Percent Enriched Uranium

U^{235}	1.18632074 * 10^{-03}
U^{238}	2.22553825 * 10^{-02}
O	4.68834064 * 10^{-02}

7.1.2 Gadolinium Atomic Densities

Gadolinium is added to the fuel in the form of GD_2O_3. The conservative assumption is made that the fuel is not diluted by the presence of the GD_2O_3. The specified density of GD_2O_3 is .0278 times the UO_2 density. A factor of .965 is included to account for manufacturing tolerances and variations in density. The smear factor (.978) is also included. The fraction of gadolinium in GD_2O_3 is .8675905. All of these factors result in a gadolinium density of .2494802 gm/cm3. The grams per gram molecular weight for gadolinium is 157.25. The resulting atomic densities are given in Table A3.

Table A3 - Atomic Densities for a 4.51 % Enriched Fuel Rod (Containing Gadolinium)

U^{235}	$1.07006131 * 10^{-03}$
U^{238}	$2.23701734 * 10^{-02}$
Gd	$9.55560038 * 10^{-04}$
O	$4.83138095 * 10^{-02}$

7.1.3 Fuel rods

Data for the pellet and the clad from Reference 8 are shown in Tables A4 and A5 below. The system was modeled conservatively using this information.

Table A4 - Pellet Data

Attribute	Nominal Diameter (cm)	Maximum Diameter (cm)	As Modeled Diameter (cm)
Pellet	[[0.888 ± 0.003]]	0.891	0.891

Table A5 - Clad Data

Attribute	Nominal Diameter (cm)	Minimum Dimension (cm)	As Modeled Dimension (cm)
Clad Inner Diameter (cm)	[[0.906 ± 0.003]]	0.901	0.901
Clad Thickness (cm)	[[0.060 ± 0.008]]	0.052	0.052

In order to maximize the amount of uranium present the pellet was modeled at the maximum diameter specified. In order to minimize the amount of zirconium present the clad was modeled at the specified minimum inside diameter and at the specified minimum thickness. An annular region of high density polyethylene was included to simulate the cluster separator. Full length rods were modeled as 381 cm (150 inches) in length.

8 APPENDIX 2

8.1 SAMPLE GEMER INPUT

8.1.1 Sample Undamaged Single Container Model (GN8OS100)

```
RA-OUT,      ,350 , 5.000,WTOF0.000,G,000,100,W,CE
   200  /* # BATCHES
  2500  /* # NEUTRONS PER BATCH
    50  /* # BATCHES TO SKIP
     0  /* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
   0   293     0    14
      3  293 0 0 U(4.51)O2 RHO = 10.96 X .980 X .9780
  2351   1.07006131E-03
  2381   2.23701734E-02
    16   4.68804695E-02
      2  293 0 0 MOD IN BUNDLE (100%)
     1   6.691110E-02
    16   3.345560E-02
      2  293 0 0 HIGH DENSITY POLYETHYLENE
     1   6.863830E-02
    12   3.431917E-02
      4  293 0 0 U(4.51)O2+GD2O3(2.78,*0.965*0.9780)RHOUO2=10.96*0.980*0.9780
  2351   1.07006131E-03
  2381   2.23701734E-02
   641   9.55560038E-04
    16   4.83138095E-02
      2  293 0 0 CARBON STEEL
    12   3.921000E-03
    26   8.349100E-02
      2  293 0 0 FULL DENSITY ETHAFOAM
     1   3.030000E-03
    12   1.515000E-03
      3  293 0 0 FULL DENSITY HONEYCOMB
     1   3.013100E-03
    12   2.092900E-03
    16   1.221970E-03
      2  293 0 0 0.00 (100%) INT H2O OS BUN/IN IC
     1   6.691110E-02
    16   3.345560E-02
      2  293 0 0 FULL DENSITY WATER
     1   6.691110E-02
    16   3.345560E-02
      3  293 0 0 FULL DENSITY WOOD
     1   2.133400E-02
    12   1.185800E-02
    16   8.593300E-03
      2  293 0 0 85% CARBON STEEL
    12   3.332900E-03
    26   7.096750E-02
      2  293 0 0 HALF DENSITY ETHAFOAM
     1   1.515000E-03
    12   7.575000E-04
      1  293 0 0 ZIRC (MIX 14)
   401   4.070910E-02
      3  293 0 0 U(5.00)O2 RHO=10.96*0.980*0.9780
  2351   1.18632074E-3
  2381   2.22553825E-2
    16   4.68834064E-2
KENO GEOM
     0  /* "KREFM"
     0  /* "NBOX"
     7  /* "NBXMAX"
```

```
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE     1 /* FUEL ROD W/ LOWER ENRICHMENT
CYLINDER     1   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     3   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477 -.6477    0.6477  -0.6477 411.48 30.48  16*0.5
BOX TYPE     2 /* 85% CARBON STEEL BASKET, VERTICAL BETWEEN BUNDLES
CUBOID      11   0.159  -0.159    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8   0.159  -0.159   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5   0.159  -0.159   14.652  -13.606  441.96  0.00  16*0.5
CUBOID      12   0.159  -0.159   19.732  -18.686  441.96  0.00  16*0.5
CUBOID       7   0.159  -0.159   27.352  -26.306  449.58 -7.62  16*0.5
CUBOID      10   0.159  -0.159   28.622  -27.576  450.85 -8.89  16*0.5
BOX TYPE     3 /* LEFT SIDE VERTICAL BASKET, LEFT SIDE INNER CONTAINER
CUBOID       5  -2.063  -2.380    5.603   -4.557  441.96  0.00  16*0.5
CUBOID       8  -2.063  -2.380    9.572   -8.367  441.96  0.00  16*0.5
CUBOID      11  -1.905  -2.380    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8  -1.905  -7.143   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5  -1.905  -7.302   14.652  -13.606  441.96  0.00  16*0.5
CUBOID       2  -1.905  -9.842   14.652  -13.606  441.96  0.00  16*0.5
CUBOID      12  -1.905  -9.842   19.732  -18.686  441.96  0.00  16*0.5
CUBOID       7  -1.905  -9.842   27.352  -26.306  449.58 -7.62  16*0.5
CUBOID      10  -1.905  -9.842   28.622  -27.576  450.85 -8.89  16*0.5
BOX TYPE     4 /* RIGHT SIDE VERTICAL BASKET, RIGHT SIDE INNER CONTAINER
CUBOID       5   2.380   2.063    5.603   -4.557  441.96  0.00  16*0.5
CUBOID       8   2.380   2.063    9.572   -8.367  441.96  0.00  16*0.5
CUBOID      11   2.380   1.905    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8   7.143   1.905   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5   7.302   1.905   14.652  -13.606  441.96  0.00  16*0.5
CUBOID       2   9.842   1.905   14.652  -13.606  441.96  0.00  16*0.5
CUBOID      12   9.842   1.905   19.732  -18.686  441.96  0.00  16*0.5
CUBOID       7   9.842   1.905   27.352  -26.306  449.58 -7.62  16*0.5
CUBOID      10   9.842   1.905   28.622  -27.576  450.85 -8.89  16*0.5
BOX TYPE     5 /* LEFT SIDE OF OUTER
CUBOID      12   0.0    -1.27    14.652  -13.606  441.96  0.00  16*0.5
CUBOID       7   0.0    -6.35    14.652  -13.606  449.58 -7.62  16*0.5
CUBOID       2   0.0    -6.35    27.352  -26.306  449.58 -7.62  16*0.5
CUBOID      10   0.0    -7.62    28.622  -27.576  450.85 -8.89  16*0.5
BOX TYPE     6 /* RIGHT SIDE OF OUTER
CUBOID      12   1.27    0.0     14.652  -13.606  441.96  0.00  16*0.5
CUBOID       7   6.35    0.0     14.652  -13.606  449.58 -7.62  16*0.5
CUBOID       2   6.35    0.0     27.352  -26.306  449.58 -7.62  16*0.5
CUBOID      10   7.62    0.0     28.622  -27.576  450.85 -8.89  16*0.5
BOX TYPE     7 /* HALF RA INNER WITH TOP AND BOTTOM STEEL
CUBOID       8  14.4824 -2.9816   4.1386 -14.4344 441.96  0.0   16*0.5
CUBOID       8  14.4824 -2.9816   8.7426 -19.1974 441.96  0.0   16*0.5
CUBOID       5  14.4824 -2.9816   8.9016 -19.3564 441.96  0.0   16*0.5
CUBOID      12  14.4824 -2.9816  13.9816 -24.4364 441.96  0.0   16*0.5
CUBOID       7  14.4824 -2.9816  21.6016 -32.0564 449.58 -7.62  16*0.5
CUBOID      10  14.4824 -2.9816  22.8716 -33.3264 450.85 -8.89  16*0.5
BOX TYPE     8 /* PEAK ENRICHMENT FUEL ROD
CYLINDER    14   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     3   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477 -0.6477   0.6477  -0.6477 411.48 30.48  16*0.5
BOX TYPE     9 /* WATER ROD
CYLINDER     2   1.1684 411.48   30.48 16*0.5
CYLINDER    13   1.2446 411.48   30.48 16*0.5
CUBOID       2   1.2446 -1.2954   1.2954  -1.2954 411.48 30.48  16*0.5
BOX TYPE    10 /* NW CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    11 /* CENTRAL SECTOR
CUBOID       2   4.5339 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    12 /* STEEL REINFORCEMENT BAND
CUBOID       5   5.082   0.0       .3170   0.0    411.48 30.48  16*0.5
BOX TYPE    13 /* STEEL REINFORCEMENT BAND
```

```
CUBOID      11  14.8424 -2.9816   0.159    0.0    411.48 30.48  16*0.5
BOX TYPE    14 /* GAD ROD
CYLINDER     4   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     3   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477  -0.6477  0.6477  -0.6477 411.48 30.48  16*0.5
BOX TYPE    15 /* SW CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    16 /* S SIDE SECTOR
CUBOID       2   4.5339 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    17 /* SE CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    18 /* E SIDE SECTOR
CUBOID       2   3.2385 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    19 /* NE CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    20 /* N SIDE SECTOR
CUBOID       2   4.5339 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    21 /* W SIDE SECTOR
CUBOID       2   3.2385 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    22 /* RA INNER CONTAINER ENDPLATE
CUBOID       5  23.020 -23.020   14.129  -14.129    0.159 0.0   16*0.5
BOX TYPE    23 /* LATTICE-BUILDING BOX
CUBOID       2  12.3063 -0.6477   0.6477 -12.3063 411.48 30.48  16*0.5
BOX TYPE    24 /* CLUSTER SEPARATOR
CUBOID       3  12.6898 -1.0312   1.0312 -12.6898 411.48 30.48  16*0.5
BOX TYPE    25 /* TOP WATER
CUBOID       2  12.6898 -1.0312   1.0312 -12.6898 441.96 411.48 16*0.5
BOX TYPE    26 /* BOTTOM WATER
CUBOID       2  12.6898 -1.0312   1.0312 -12.6898  30.48  0.0   16*0.5
CORE BDY     0  33.180 -33.180  22.8716  -33.3264 450.85 -8.89  16*0.5
CUBOID       9  78.900 -78.900 68.5916 -79.0464 496.839 -54.61  16*0.5
7  3 5 2  1 1 1  1 1 1  0
2  4 4 1  1 1 1  1 1 1  0
3  2 2 1  1 1 1  1 1 1  0
4  6 6 1  1 1 1  1 1 1  0
5  1 1 1  1 1 1  1 1 1  0
6  7 7 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* RODS IN NW CORNER SECTOR
COMPLEX  10  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  10  1    1.2954   0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 10    0.0     -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN CENTRAL SECTOR
COMPLEX  11  1    0.0      0.0     0.0   4 4 1  1.2954 1.2954 0.0
COMPLEX  11 14    2.5908   0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  11 14    0.0      2.5908  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  11  1    0.0      3.8862  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  11  9    0.6477   0.6477  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  11  9    3.2385   3.2385  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  23 11    3.8862  -7.7724  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN SW CORNER SECTOR
COMPLEX  15  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  15  1    1.2954   1.2954  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 15    0.0    -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN S SIDE SECTOR
COMPLEX  16  1    0.0      1.2954  0.0   4 2 1  1.2954 1.2954 0.0
COMPLEX  16  8    0.0      0.0     0.0   4 1 1  1.2954 0.0    0.0
COMPLEX  16 14    2.5908   2.5908  0.0   2 1 1  1.2954 0.0    0.0
COMPLEX  23 16    3.8862 -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN SE CORNER SECTOR
COMPLEX  17  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  17  1    0.0      1.2954  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  17 14    0.0      2.5908  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  23 17    9.0678 -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN E SIDE SECTOR
COMPLEX  18  1    0.0      0.0     0.0   2 4 1  1.2954 1.2954 0.0
COMPLEX  18  8    2.5908   0.0     0.0   1 4 1  0.0    1.2954 0.0
COMPLEX  18 14    0.0      0.0     0.0   1 2 1  0.0    1.2954 0.0
COMPLEX  23 18    9.0678  -7.7724  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN NE CORNER SECTOR
```

```
COMPLEX  19  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  19  1    0.0      0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 19    9.0678  -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN N SIDE SECTOR
COMPLEX  20  1    0.0      0.0     0.0   4 2 1  1.2954 1.2954 0.0
COMPLEX  20  8    0.0      2.5908  0.0   4 1 1  1.2954 0.0    0.0
COMPLEX  23 20    3.8862  -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN W SIDE SECTOR
COMPLEX  21  1    1.2954   0.0     0.0   2 4 1  1.2954 1.2954 0.0
COMPLEX  21  8    0.0      0.0     0.0   1 4 1  0.0    1.2954 0.0
COMPLEX  23 21    0.0     -7.7724  0.0   1 1 1  0.0    0.0    0.0
/*TOP H2O IN CLUS
COMPLEX   7 25    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*BOT H2O IN CLUS
COMPLEX   7 26    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*BUNDLE IN CLUST
COMPLEX  24 23    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*INTO HALFCELL
COMPLEX   7 24    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 12    3.2094   3.8216  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 12    3.2904 -14.4344  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 13    0.0    -14.1174  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 13    0.0      3.6626  0.0   1 1 1  0.0    0.0    0.0
END GEOM
*END GEMER*
```

8.1.2 Sample Damaged Single Container Model (GN8IS100)

```
RA-INN,      ,350 , 5.000,WTOF0.000,G,000,007,W,CE
   200  /* # BATCHES
  2500  /* # NEUTRONS PER BATCH
    50  /* # BATCHES TO SKIP
     0  /* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
   0   293     0    14
      3  293 0 0 U(4.51)O2 RHO = 10.96 X .980 X .9780
  2351   1.07006131E-03
  2381   2.23701734E-02
    16   4.68804695E-02
      2  293 0 0 MOD IN BUNDLE (100%)
     1   6.691110E-02
    16   3.345560E-02
      2  293 0 0 HIGH DENSITY POLYETHYLENE
     1   6.863830E-02
    12   3.431917E-02
      4  293 0 0 U(4.51)O2+GD2O3(2.78,*0.965*0.9780)RHOUO2=10.96*0.980*0.9780
  2351   1.07006131E-03
  2381   2.23701734E-02
   641   9.55560038E-04
    16   4.83138095E-02
      2  293 0 0 CARBON STEEL
    12   3.921000E-03
    26   8.349100E-02
      2  293 0 0 FULL DENSITY ETHAFOAM
     1   3.030000E-03
    12   1.515000E-03
      3  293 0 0 FULL DENSITY HONEYCOMB
     1   3.013100E-03
    12   2.092900E-03
    16   1.221970E-03
      2  293 0 0 0.00 (100%) INT H2O OS BUN/IN IC
     1   6.691110E-02
    16   3.345560E-02
      2  293 0 0 FULL DENSITY WATER
     1   6.691110E-02
    16   3.345560E-02
      3  293 0 0 FULL DENSITY WOOD
```

```
     1   2.133400E-02
    12   1.185800E-02
    16   8.593300E-03
      2  293 0 0 85% CARBON STEEL
    12   3.332900E-03
    26   7.096750E-02
      2  293 0 0 HALF DENSITY ETHAFOAM
     1   1.515000E-03
    12   7.575000E-04
      1  293 0 0 ZIRC (MIX 14)
   401   4.070910E-02
      3  293 0 0 U(5.00)O2 RHO=10.96*0.980*0.9780
  2351   1.18632074E-3
  2381   2.22553825E-2
    16   4.68834064E-2
KENO GEOM
     0  /* "KREFM"
     0  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE     1 /* FUEL ROD W/ LOWER ENRICHMENT
CYLINDER     1   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     3   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477 -.6477    0.6477  -0.6477 411.48 30.48  16*0.5
BOX TYPE     2 /* 85% CARBON STEEL BASKET, VERTICAL BETWEEN BUNDLES
CUBOID      11   0.159  -0.159    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8   0.159  -0.159   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5   0.159  -0.159   14.652  -13.606  441.96  0.00  16*0.5
BOX TYPE     3 /* LEFT SIDE VERTICAL BASKET, LEFT SIDE INNER CONTAINER
CUBOID       5  -2.063  -2.380    5.603   -4.557  441.96  0.00  16*0.5
CUBOID       8  -2.063  -2.380    9.572   -8.367  441.96  0.00  16*0.5
CUBOID      11  -1.905  -2.380    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8  -1.905  -7.143   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5  -1.905  -7.302   14.652  -13.606  441.96  0.00  16*0.5
BOX TYPE     4 /* RIGHT SIDE VERTICAL BASKET, RIGHT SIDE INNER CONTAINER
CUBOID       5   2.380   2.063    5.603   -4.557  441.96  0.00  16*0.5
CUBOID       8   2.380   2.063    9.572   -8.367  441.96  0.00  16*0.5
CUBOID      11   2.380   1.905    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8   7.143   1.905   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5   7.302   1.905   14.652  -13.606  441.96  0.00  16*0.5
BOX TYPE     5 /* INDIVIDUAL RA-3 UNIT
CUBOID       0  23.020 -23.020   14.129  -14.129  442.119 -.159 16*0.5
BOX TYPE     6 /* BOX FOR 260 UNIT ARRAY
CUBOID       2 299.26 -299.26   282.58  -282.58   442.119 -.159 16*0.5
BOX TYPE     7 /* HALF RA INNER WITH TOP AND BOTTOM STEEL
CUBOID       8  14.4824 -2.9816   4.1386 -14.4344 441.96  0.0   16*0.5
CUBOID       8  14.4824 -2.9816   8.7426 -19.1974 441.96  0.0   16*0.5
CUBOID       5  14.4824 -2.9816   8.9016 -19.3564 441.96  0.0   16*0.5
BOX TYPE     8 /* PEAK ENRICHMENT FUEL ROD
CYLINDER    14   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     3   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477 -0.6477   0.6477  -0.6477 411.48 30.48  16*0.5
BOX TYPE     9 /* WATER ROD
CYLINDER     2   1.1684 411.48   30.48 16*0.5
CYLINDER    13   1.2446 411.48   30.48 16*0.5
CUBOID       2   1.2446 -1.2954   1.2954  -1.2954 411.48 30.48  16*0.5
BOX TYPE    10 /* NW CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    11 /* CENTRAL SECTOR
CUBOID       2   4.5339 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    12 /* STEEL REINFORCEMENT BAND
CUBOID       5   5.082   0.0       .3170   0.0    411.48 30.48  16*0.5
BOX TYPE    13 /* STEEL REINFORCEMENT BAND
CUBOID      11  14.8424 -2.9816   0.159    0.0    411.48 30.48  16*0.5
```

```
BOX TYPE    14 /* GAD ROD
CYLINDER     4   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     3   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477  -0.6477  0.6477  -0.6477 411.48 30.48  16*0.5
BOX TYPE    15 /* SW CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    16 /* S SIDE SECTOR
CUBOID       2   4.5339 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    17 /* SE CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    18 /* E SIDE SECTOR
CUBOID       2   3.2385 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    19 /* NE CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    20 /* N SIDE SECTOR
CUBOID       2   4.5339 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    21 /* W SIDE SECTOR
CUBOID       2   3.2385 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    22 /* RA INNER CONTAINER ENDPLATE
CUBOID       5  23.020 -23.020   14.129  -14.129    0.159 0.0   16*0.5
BOX TYPE    23 /* LATTICE-BUILDING BOX
CUBOID       2  12.3063 -0.6477   0.6477 -12.3063 411.48 30.48  16*0.5
BOX TYPE    24 /* CLUSTER SEPARATOR
CUBOID       3  12.6898 -1.0312   1.0312 -12.6898 411.48 30.48  16*0.5
BOX TYPE    25 /* TOP WATER
CUBOID       2  12.6898 -1.0312   1.0312 -12.6898 441.96 411.48 16*0.5
BOX TYPE    26 /* BOTTOM WATER
CUBOID       2  12.6898 -1.0312   1.0312 -12.6898  30.48  0.0   16*0.5
CORE BDY     0  23.020 -23.020   14.129  -14.129  442.119 -.159 16*0.5
CUBOID       9  68.740 -68.740   59.849 -59.849 487.839 -45.879 16*0.5
5  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* RODS IN NW CORNER SECTOR
COMPLEX  10  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  10  1    1.2954   0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 10    0.0     -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN CENTRAL SECTOR
COMPLEX  11  1    0.0      0.0     0.0   4 4 1  1.2954 1.2954 0.0
COMPLEX  11 14    2.5908   0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  11 14    0.0      2.5908  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  11  1    0.0      3.8862  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  11  9    0.6477   0.6477  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  11  9    3.2385   3.2385  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  23 11    3.8862  -7.7724  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN SW CORNER SECTOR
COMPLEX  15  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  15  1    1.2954   1.2954  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 15    0.0    -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN S SIDE SECTOR
COMPLEX  16  1    0.0      1.2954  0.0   4 2 1  1.2954 1.2954 0.0
COMPLEX  16  8    0.0      0.0     0.0   4 1 1  1.2954 0.0    0.0
COMPLEX  16 14    2.5908   2.5908  0.0   2 1 1  1.2954 0.0    0.0
COMPLEX  23 16    3.8862 -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN SE CORNER SECTOR
COMPLEX  17  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  17  1    0.0      1.2954  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  17 14    0.0      2.5908  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  23 17    9.0678 -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN E SIDE SECTOR
COMPLEX  18  1    0.0      0.0     0.0   2 4 1  1.2954 1.2954 0.0
COMPLEX  18  8    2.5908   0.0     0.0   1 4 1  0.0    1.2954 0.0
COMPLEX  18 14    0.0      0.0     0.0   1 2 1  0.0    1.2954 0.0
COMPLEX  23 18    9.0678  -7.7724  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN NE CORNER SECTOR
COMPLEX  19  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  19  1    0.0      0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 19    9.0678  -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN N SIDE SECTOR
COMPLEX  20  1    0.0      0.0     0.0   4 2 1  1.2954 1.2954 0.0
COMPLEX  20  8    0.0      2.5908  0.0   4 1 1  1.2954 0.0    0.0
```

```
COMPLEX  23 20    3.8862  -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN W SIDE SECTOR
COMPLEX  21  1    1.2954   0.0     0.0   2 4 1  1.2954 1.2954 0.0
COMPLEX  21  8    0.0      0.0     0.0   1 4 1  0.0    1.2954 0.0
COMPLEX  23 21    0.0     -7.7724  0.0   1 1 1  0.0    0.0    0.0
/*TOP H2O IN CLUS
COMPLEX   7 25    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*BOT H2O IN CLUS
COMPLEX   7 26    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*BUNDLE IN CLUST
COMPLEX  24 23    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*INTO HALFCELL
COMPLEX   7 24    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 12    3.2094   3.8216  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 12    3.2904 -14.4344  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 13    0.0    -14.1174  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 13    0.0      3.6626  0.0   1 1 1  0.0    0.0    0.0
/*HALFCELL IN RA
COMPLEX   5  7  -14.6414   5.2274  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   5  7    3.1406   5.2274  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   5  2    0.0     -0.523   0.0   1 1 1  0.0    0.0    0.0
COMPLEX   5  3  -15.718   -0.523   0.0   1 1 1  0.0    0.0    0.0
COMPLEX   5  4   15.718   -0.523   0.0   1 1 1  0.0    0.0    0.0
COMPLEX   5 22    0.0      0.0    -0.159 1 1 1  0.0    0.0    0.0
COMPLEX   5 22    0.0      0.0   441.96  1 1 1  0.0    0.0    0.0
END GEOM
*END GEMER*
```

8.1.3 Sample Undamaged Package Array (GN8NX000)

```
RA-OUT,      ,350 , 5.000,WTOF0.000,G,000,  0,I,CE
   200  /* # BATCHES
  2500  /* # NEUTRONS PER BATCH
    50  /* # BATCHES TO SKIP
     0  /* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
   0   293     0    14
      3  293 0 0 U(4.51)O2 RHO = 10.96 X .980 X .9780
  2351   1.07006131E-03
  2381   2.23701734E-02
    16   4.68804695E-02
      2  293 0 0 MOD IN BUNDLE (0.0%)
     1   1.000000E-10
    16   1.000001E-10
      2  293 0 0 HIGH DENSITY POLYETHYLENE
     1   6.863830E-02
    12   3.431917E-02
      4  293 0 0 U(4.51)O2+GD2O3(2.78,*0.965*0.9780)RHOUO2=10.96*0.980*0.9780
  2351   1.07006131E-03
  2381   2.23701734E-02
   641   9.55560038E-04
    16   4.83138095E-02
      2  293 0 0 CARBON STEEL
    12   3.921000E-03
    26   8.349100E-02
      2  293 0 0 FULL DENSITY ETHAFOAM
     1   3.030000E-03
    12   1.515000E-03
      3  293 0 0 50% DENSITY HONEYCOMB
     1   1.506550E-03
    12   1.046450E-03
    16   6.109880E-04
      2  293 0 0 0.00 (0.0%) INT H2O OS BUN/IN IC
     1   1.000000E-10
    16   1.000001E-10
      2  293 0 0 FULL DENSITY WATER
```

```
     1   6.691110E-02
    16   3.345560E-02
      3  293 0 0 FULL DENSITY WOOD
     1   2.133400E-02
    12   1.185800E-02
    16   8.593300E-03
      2  293 0 0 85% CARBON STEEL
    12   3.332900E-03
    26   7.096750E-02
      2  293 0 0 HALF DENSITY ETHAFOAM
     1   1.515000E-09
    12   7.575000E-09
      1  293 0 0 ZIRC (MIX 13)
   401   4.070910E-02
      3  293 0 0 U(5.00)O2 RHO=10.96*0.980*0.9780
  2351   1.18632074E-3
  2381   2.22553825E-2
    16   4.68834064E-2
KENO GEOM
     0  /* "KREFM"
     0  /* "NBOX"
    16  /* "NBXMAX"
    19  /* "NBYMAX"
     2  /* "NBZMAX"
     1  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
-1.0 -1.0 -1.0 -1.0 -1.0 -1.0
BOX TYPE     1 /* FUEL ROD W/ LOWER ENRICHMENT
CYLINDER     1   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     2   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477 -.6477    0.6477  -0.6477 411.48 30.48  16*0.5
BOX TYPE     2 /* 85% CARBON STEEL BASKET, VERTICAL BETWEEN BUNDLES
CUBOID      11   0.159  -0.159    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8   0.159  -0.159   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5   0.159  -0.159   14.652  -13.606  441.96  0.00  16*0.5
CUBOID      12   0.159  -0.159   19.732  -18.686  441.96  0.00  16*0.5
CUBOID       7   0.159  -0.159   27.352  -26.306  449.58 -7.62  16*0.5
CUBOID      10   0.159  -0.159   28.622  -27.576  450.85 -8.89  16*0.5
BOX TYPE     3 /* LEFT SIDE VERTICAL BASKET, LEFT SIDE INNER CONTAINER
CUBOID       5  -2.063  -2.380    5.603   -4.557  441.96  0.00  16*0.5
CUBOID       8  -2.063  -2.380    9.572   -8.367  441.96  0.00  16*0.5
CUBOID      11  -1.905  -2.380    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8  -1.905  -7.143   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5  -1.905  -7.302   14.652  -13.606  441.96  0.00  16*0.5
CUBOID       0  -1.905  -9.842   14.652  -13.606  441.96  0.00  16*0.5
CUBOID      12  -1.905  -9.842   19.732  -18.686  441.96  0.00  16*0.5
CUBOID       7  -1.905  -9.842   27.352  -26.306  449.58 -7.62  16*0.5
CUBOID      10  -1.905  -9.842   28.622  -27.576  450.85 -8.89  16*0.5
BOX TYPE     4 /* RIGHT SIDE VERTICAL BASKET, RIGHT SIDE INNER CONTAINER
CUBOID       5   2.380   2.063    5.603   -4.557  441.96  0.00  16*0.5
CUBOID       8   2.380   2.063    9.572   -8.367  441.96  0.00  16*0.5
CUBOID      11   2.380   1.905    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8   7.143   1.905   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5   7.302   1.905   14.652  -13.606  441.96  0.00  16*0.5
CUBOID       0   9.842   1.905   14.652  -13.606  441.96  0.00  16*0.5
CUBOID      12   9.842   1.905   19.732  -18.686  441.96  0.00  16*0.5
CUBOID       7   9.842   1.905   27.352  -26.306  449.58 -7.62  16*0.5
CUBOID      10   9.842   1.905   28.622  -27.576  450.85 -8.89  16*0.5
BOX TYPE     5 /* LEFT SIDE OF OUTER
CUBOID      12   0.0    -1.27    14.652  -13.606  441.96  0.00  16*0.5
CUBOID       7   0.0    -6.35    14.652  -13.606  449.58 -7.62  16*0.5
CUBOID       0   0.0    -6.35    27.352  -26.306  449.58 -7.62  16*0.5
CUBOID      10   0.0    -7.62    28.622  -27.576  450.85 -8.89  16*0.5
BOX TYPE     6 /* RIGHT SIDE OF OUTER
CUBOID      12   1.27    0.0     14.652  -13.606  441.96  0.00  16*0.5
CUBOID       7   6.35    0.0     14.652  -13.606  449.58 -7.62  16*0.5
CUBOID       0   6.35    0.0     27.352  -26.306  449.58 -7.62  16*0.5
CUBOID      10   7.62    0.0     28.622  -27.576  450.85 -8.89  16*0.5
```

```
BOX TYPE     7 /* HALF RA INNER WITH TOP AND BOTTOM STEEL
CUBOID       8  14.4824 -2.9816   4.1386 -14.4344 441.96  0.0   16*0.5
CUBOID       8  14.4824 -2.9816   8.7426 -19.1974 441.96  0.0   16*0.5
CUBOID       5  14.4824 -2.9816   8.9016 -19.3564 441.96  0.0   16*0.5
CUBOID      12  14.4824 -2.9816  13.9816 -24.4364 441.96  0.0   16*0.5
CUBOID       7  14.4824 -2.9816  21.6016 -32.0564 449.58 -7.62  16*0.5
CUBOID      10  14.4824 -2.9816  22.8716 -33.3264 450.85 -8.89  16*0.5
BOX TYPE     8 /* PEAK ENRICHMENT FUEL ROD
CYLINDER    14   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     2   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477 -0.6477   0.6477  -0.6477 411.48 30.48  16*0.5
BOX TYPE     9 /* WATER ROD
CYLINDER     2   1.1684 411.48   30.48 16*0.5
CYLINDER    13   1.2446 411.48   30.48 16*0.5
CUBOID       2   1.2446 -1.2954   1.2954  -1.2954 411.48 30.48  16*0.5
BOX TYPE    10 /* NW CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    11 /* CENTRAL SECTOR
CUBOID       2   4.5339 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    12 /* STEEL REINFORCEMENT BAND
CUBOID       5   5.082   0.0       .3170   0.0    441.96  0.0   16*0.5
BOX TYPE    13 /* STEEL REINFORCEMENT BAND
CUBOID      11  14.8424 -2.9816   0.159    0.0    441.96  0.0   16*0.5
BOX TYPE    14 /* GAD ROD
CYLINDER     4   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     2   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477  -0.6477  0.6477  -0.6477 441.96  0.0   16*0.5
BOX TYPE    15 /* SW CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    16 /* S SIDE SECTOR
CUBOID       2   4.5339 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    17 /* SE CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    18 /* E SIDE SECTOR
CUBOID       2   3.2385 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    19 /* NE CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    20 /* N SIDE SECTOR
CUBOID       2   4.5339 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    21 /* W SIDE SECTOR
CUBOID       2   3.2385 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    22 /* RA INNER CONTAINER ENDPLATE
CUBOID       5  23.020 -23.020   14.129  -14.129    0.159 0.0   16*0.5
BOX TYPE    23 /* LATTICE-BUILDING BOX
CUBOID       2  12.3063 -0.6477   0.6477 -12.3063 411.48 30.48  16*0.5
BOX TYPE    24 /* CLUSTER SEPARATOR
CUBOID       2  12.6898 -1.0312   1.0312 -12.6898 411.48 30.48  16*0.5
BOX TYPE    25 /* TOP WATER
CUBOID       2  12.6898 -1.0312   1.0312 -12.6898 441.96 411.48 16*0.5
BOX TYPE    26 /* BOTTOM WATER
CUBOID       2  12.6898 -1.0312   1.0312 -12.6898  30.48  0.0   16*0.5
BOX TYPE    27 /* COMPLETE RA-3 CONTAINER
CUBOID       0  33.180 -33.180  22.8716  -33.3264 450.85 -8.89  16*0.5
CORE BDY     0 530.88 -530.88  533.880  -533.880  459.74 -459.74 16*0.5
CUBOID       9 576.60 -576.60  579.600  -579.600  505.46 -505.46 16*0.5
27 1 16 1  1 19 1  1 2 1  1
BEGIN COMPLEX
/* RODS IN NW CORNER SECTOR
COMPLEX  10  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  10  1    1.2954   0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 10    0.0     -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN CENTRAL SECTOR
COMPLEX  11  1    0.0      0.0     0.0   4 4 1  1.2954 1.2954 0.0
COMPLEX  11 14    2.5908   0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  11 14    0.0      2.5908  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  11  1    0.0      3.8862  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  11  9    0.6477   0.6477  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  11  9    3.2385   3.2385  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  23 11    3.8862  -7.7724  0.0   1 1 1  0.0    0.0    0.0
```

```
/* RODS IN SW CORNER SECTOR
COMPLEX  15  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  15  1    1.2954   1.2954  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 15    0.0    -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN S SIDE SECTOR
COMPLEX  16  1    0.0      1.2954  0.0   4 2 1  1.2954 1.2954 0.0
COMPLEX  16  8    0.0      0.0     0.0   4 1 1  1.2954 0.0    0.0
COMPLEX  16 14    2.5908   2.5908  0.0   2 1 1  1.2954 0.0    0.0
COMPLEX  23 16    3.8862 -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN SE CORNER SECTOR
COMPLEX  17  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  17  1    0.0      1.2954  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  17 14    0.0      2.5908  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  23 17    9.0678 -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN E SIDE SECTOR
COMPLEX  18  1    0.0      0.0     0.0   2 4 1  1.2954 1.2954 0.0
COMPLEX  18  8    2.5908   0.0     0.0   1 4 1  0.0    1.2954 0.0
COMPLEX  18 14    0.0      0.0     0.0   1 2 1  0.0    1.2954 0.0
COMPLEX  23 18    9.0678  -7.7724  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN NE CORNER SECTOR
COMPLEX  19  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  19  1    0.0      0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 19    9.0678  -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN N SIDE SECTOR
COMPLEX  20  1    0.0      0.0     0.0   4 2 1  1.2954 1.2954 0.0
COMPLEX  20  8    0.0      2.5908  0.0   4 1 1  1.2954 0.0    0.0
COMPLEX  23 20    3.8862  -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN W SIDE SECTOR
COMPLEX  21  1    1.2954   0.0     0.0   2 4 1  1.2954 1.2954 0.0
COMPLEX  21  8    0.0      0.0     0.0   1 4 1  0.0    1.2954 0.0
COMPLEX  23 21    0.0     -7.7724  0.0   1 1 1  0.0    0.0    0.0
/*TOP H2O IN CLUS
COMPLEX   7 25    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*BOT H2O IN CLUS
COMPLEX   7 26    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*BUNDLE IN CLUST
COMPLEX  24 23    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*INTO HALFCELL
COMPLEX   7 24    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 12    3.2094   3.8216  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 12    3.2904 -14.4344  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 13    0.0    -14.1174  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 13    0.0      3.6626  0.0   1 1 1  0.0    0.0    0.0
/* COMPLETE RA-3
COMPLEX  27  5  -25.56    -5.7494  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  27  3  -15.718   -5.7494  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  27  7  -14.6414   0.0     0.0   1 1 1  0.0    0.0    0.0
COMPLEX  27  2    0.0     -5.7494  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  27  7    3.1406   0.0     0.0   1 1 1  0.0    0.0    0.0
COMPLEX  27  4   15.718   -5.7494  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  27  6   25.56    -5.7494  0.0   1 1 1  0.0    0.0    0.0
END GEOM
*END GEMER*
```

8.1.4 Sample Damaged Package Array (GN8A-007)

```
RA-INN,      ,350 , 5.000,WTOF0.000,G,000,  7,I,CE
   200  /* # BATCHES
  2500  /* # NEUTRONS PER BATCH
    50  /* # BATCHES TO SKIP
     0  /* INITIAL "SEED" (IF NON-ZERO)
     0  /* "IDUMP"
     0  /* "NRSTRT"
     0  /* "NBTED" (NON-ZERO IS PRINT EDITS)
     0  /* "KRED" (NUMBER OF COMBINED REGIONS IN EDITS)
   0   293     0    14
      3  293 0 0 U(4.51)O2 RHO = 10.96 X .980 X .9780
  2351   1.07006131E-03
  2381   2.23701734E-02
    16   4.68804695E-02
      2  293 0 0 MOD IN BUNDLE (7.5%)
     1   5.018333E-03
    16   2.509167E-03
      2  293 0 0 HIGH DENSITY POLYETHYLENE
     1   6.863830E-02
    12   3.431917E-02
      4  293 0 0 U(4.51)O2+GD2O3(2.78,*0.965*0.9780)RHOUO2=10.96*0.980*0.9780
  2351   1.07006131E-03
  2381   2.23701734E-02
   641   9.55560038E-04
    16   4.83138095E-02
      2  293 0 0 CARBON STEEL
    12   3.921000E-03
    26   8.349100E-02
      2  293 0 0 FULL DENSITY ETHAFOAM
     1   3.030000E-03
    12   1.515000E-03
      3  293 0 0 FULL DENSITY HONEYCOMB
     1   3.013100E-03
    12   2.092900E-03
    16   1.221970E-03
      2  293 0 0 0.00 (7.5%) INT H2O OS BUN/IN IC
     1   5.018333E-03
    16   2.509167E-03
      2  293 0 0 FULL DENSITY WATER
     1   6.691110E-02
    16   3.345560E-02
      3  293 0 0 FULL DENSITY WOOD
     1   2.133400E-02
    12   1.185800E-02
    16   8.593300E-03
      2  293 0 0 85% CARBON STEEL
    12   3.332900E-03
    26   7.096750E-02
      2  293 0 0 HALF DENSITY ETHAFOAM
     1   1.515000E-03
    12   7.575000E-04
      1  293 0 0 ZIRC (MIX 13)
   401   4.070910E-02
      3  293 0 0 U(5.00)O2 RHO=10.96*0.980*0.9780
  2351   1.18632074E-3
  2381   2.22553825E-2
    16   4.68834064E-2
KENO GEOM
     0  /* "KREFM"
     0  /* "NBOX"
     1  /* "NBXMAX"
     1  /* "NBYMAX"
     1  /* "NBZMAX"
     0  /* "NXX"
     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
```

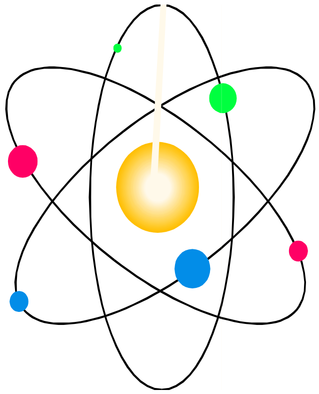
```
BOX TYPE     1 /* FUEL ROD W/ LOWER ENRICHMENT
CYLINDER     1   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     3   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477 -.6477    0.6477  -0.6477 411.48 30.48  16*0.5
BOX TYPE     2 /* 85% CARBON STEEL BASKET, VERTICAL BETWEEN BUNDLES
CUBOID      11   0.159  -0.159    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8   0.159  -0.159   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5   0.159  -0.159   14.652  -13.606  441.96  0.00  16*0.5
BOX TYPE     3 /* LEFT SIDE VERTICAL BASKET, LEFT SIDE INNER CONTAINER
CUBOID       5  -2.063  -2.380    5.603   -4.557  441.96  0.00  16*0.5
CUBOID       8  -2.063  -2.380    9.572   -8.367  441.96  0.00  16*0.5
CUBOID      11  -1.905  -2.380    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8  -1.905  -7.143   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5  -1.905  -7.302   14.652  -13.606  441.96  0.00  16*0.5
BOX TYPE     4 /* RIGHT SIDE VERTICAL BASKET, RIGHT SIDE INNER CONTAINER
CUBOID       5   2.380   2.063    5.603   -4.557  441.96  0.00  16*0.5
CUBOID       8   2.380   2.063    9.572   -8.367  441.96  0.00  16*0.5
CUBOID      11   2.380   1.905    9.572   -8.367  441.96  0.00  16*0.5
CUBOID       8   7.143   1.905   14.493  -13.447  441.96  0.00  16*0.5
CUBOID       5   7.302   1.905   14.652  -13.606  441.96  0.00  16*0.5
BOX TYPE     5 /* INDIVIDUAL RA-3 UNIT
CUBOID       0  23.020 -23.020   14.129  -14.129  442.119 -.159 16*0.5
BOX TYPE     6 /* BOX FOR 260 UNIT ARRAY
CUBOID       2 230.20 -230.20   226.064 -226.064  442.119 -.159 16*0.5
BOX TYPE     7 /* HALF RA INNER WITH TOP AND BOTTOM STEEL
CUBOID       8  14.4824 -2.9816   4.1386 -14.4344 441.96  0.0   16*0.5
CUBOID       8  14.4824 -2.9816   8.7426 -19.1974 441.96  0.0   16*0.5
CUBOID       5  14.4824 -2.9816   8.9016 -19.3564 441.96  0.0   16*0.5
BOX TYPE     8 /* PEAK ENRICHMENT FUEL ROD
CYLINDER    14   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     3   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477 -0.6477   0.6477  -0.6477 411.48 30.48  16*0.5
BOX TYPE     9 /* WATER ROD
CYLINDER     2   1.1684 411.48   30.48 16*0.5
CYLINDER    13   1.2446 411.48   30.48 16*0.5
CUBOID       2   1.2954 -1.2954   1.2954  -1.2954 411.48 30.48  16*0.5
BOX TYPE    10 /* NW CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    11 /* CENTRAL SECTOR
CUBOID       2   4.5339 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    12 /* STEEL REINFORCEMENT BAND
CUBOID       5   5.082   0.0       .3170   0.0    441.96  0.00  16*0.5
BOX TYPE    13 /* STEEL REINFORCEMENT BAND
CUBOID      11  14.8424 -2.9816   0.159    0.0    441.96  0.00  16*0.5
BOX TYPE    14 /* GAD ROD
CYLINDER     4   0.45050 411.48  30.48                          16*0.5
CYLINDER    13   0.50250 411.48  30.48                          16*0.5
CYLINDER     3   0.55167 411.48  30.48                          16*0.5
CUBOID       2   0.6477  -0.6477  0.6477  -0.6477 411.48 30.48  16*0.5
BOX TYPE    15 /* SW CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    16 /* S SIDE SECTOR
CUBOID       2   4.5339 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    17 /* SE CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    18 /* E SIDE SECTOR
CUBOID       2   3.2385 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    19 /* NE CORNER SECTOR
CUBOID       2   3.2385 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    20 /* N SIDE SECTOR
CUBOID       2   4.5339 -0.6477   3.2385  -0.6477 411.48 30.48  16*0.5
BOX TYPE    21 /* W SIDE SECTOR
CUBOID       2   3.2385 -0.6477   4.5339  -0.6477 411.48 30.48  16*0.5
BOX TYPE    22 /* RA INNER CONTAINER ENDPLATE
CUBOID       5  23.020 -23.020   14.129  -14.129    0.159 0.0   16*0.5
BOX TYPE    23 /* LATTICE-BUILDING BOX
CUBOID       2  12.3063 -0.6477   0.6477 -12.3063 411.48 30.48  16*0.5
BOX TYPE    24 /* CLUSTER SEPARATOR
CUBOID       3  12.6898 -1.0312   1.0312 -12.6898 411.48 30.48  16*0.5
```

```
BOX TYPE    25 /* TOP WATER
CUBOID       2  12.6898 -1.0312   1.0312 -12.6898 441.96 411.48 16*0.5
BOX TYPE    26 /* BOTTOM WATER
CUBOID       2  12.6898 -1.0312   1.0312 -12.6898  30.48  0.0   16*0.5
CORE BDY     0  230.20 -230.20  226.064 -226.064 442.119 -0.159 16*0.5
CUBOID       9  275.92 -275.92  271.784 -271.784 487.839 -45.879 16*0.5
6  1 1 1  1 1 1  1 1 1  1
BEGIN COMPLEX
/* RODS IN NW CORNER SECTOR
COMPLEX  10  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  10  1    1.2954   0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 10    0.0     -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN CENTRAL SECTOR
COMPLEX  11  1    0.0      0.0     0.0   4 4 1  1.2954 1.2954 0.0
COMPLEX  11 14    2.5908   0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  11 14    0.0      2.5908  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  11  1    0.0      3.8862  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  11  9    0.6477   0.6477  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  11  9    3.2385   3.2385  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  23 11    3.8862  -7.7724  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN SW CORNER SECTOR
COMPLEX  15  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  15  1    1.2954   1.2954  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 15    0.0    -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN S SIDE SECTOR
COMPLEX  16  1    0.0      1.2954  0.0   4 2 1  1.2954 1.2954 0.0
COMPLEX  16  8    0.0      0.0     0.0   4 1 1  1.2954 0.0    0.0
COMPLEX  16 14    2.5908   2.5908  0.0   2 1 1  1.2954 0.0    0.0
COMPLEX  23 16    3.8862 -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN SE CORNER SECTOR
COMPLEX  17  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  17  1    0.0      1.2954  0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  17 14    0.0      2.5908  0.0   1 1 1  0.0    0.0    0.0
COMPLEX  23 17    9.0678 -11.6586  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN E SIDE SECTOR
COMPLEX  18  1    0.0      0.0     0.0   2 4 1  1.2954 1.2954 0.0
COMPLEX  18  8    2.5908   0.0     0.0   1 4 1  0.0    1.2954 0.0
COMPLEX  18 14    0.0      0.0     0.0   1 2 1  0.0    1.2954 0.0
COMPLEX  23 18    9.0678  -7.7724  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN NE CORNER SECTOR
COMPLEX  19  8    0.0      0.0     0.0   3 3 1  1.2954 1.2954 0.0
COMPLEX  19  1    0.0      0.0     0.0   2 2 1  1.2954 1.2954 0.0
COMPLEX  23 19    9.0678  -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN N SIDE SECTOR
COMPLEX  20  1    0.0      0.0     0.0   4 2 1  1.2954 1.2954 0.0
COMPLEX  20  8    0.0      2.5908  0.0   4 1 1  1.2954 0.0    0.0
COMPLEX  23 20    3.8862  -2.5908  0.0   1 1 1  0.0    0.0    0.0
/* RODS IN W SIDE SECTOR
COMPLEX  21  1    1.2954   0.0     0.0   2 4 1  1.2954 1.2954 0.0
COMPLEX  21  8    0.0      0.0     0.0   1 4 1  0.0    1.2954 0.0
COMPLEX  23 21    0.0     -7.7724  0.0   1 1 1  0.0    0.0    0.0
/*TOP H2O IN CLUS
COMPLEX   7 25    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*BOT H2O IN CLUS
COMPLEX   7 26    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*BUNDLE IN CLUST
COMPLEX  24 23    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
/*INTO HALFCELL
COMPLEX   7 24    0.0      0.0     0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 12    3.2094   3.8216  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 12    3.2904 -14.4344  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 13    0.0    -14.1174  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   7 13    0.0      3.6626  0.0   1 1 1  0.0    0.0    0.0
/*HALFCELL IN RA
COMPLEX   5  7  -14.6414   5.2274  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   5  7    3.1406   5.2274  0.0   1 1 1  0.0    0.0    0.0
COMPLEX   5  2    0.0     -0.523   0.0   1 1 1  0.0    0.0    0.0
COMPLEX   5  3  -15.718   -0.523   0.0   1 1 1  0.0    0.0    0.0
COMPLEX   5  4   15.718   -0.523   0.0   1 1 1  0.0    0.0    0.0
COMPLEX   5 22    0.0      0.0    -0.159 1 1 1  0.0    0.0    0.0
COMPLEX   5 22    0.0      0.0   441.96  1 1 1  0.0    0.0    0.0
```

```
/* 160 ARRAY
COMPLEX   6  5 -207.18  -211.935   0.0  10 16 1 46.04 28.258  0.0
END GEOM
*END GEMER*
```

Global Nuclear Fuel
A Joint Venture of GE, Toshiba, & Hitachi

Nuclear Safety Engineering



GEMER Monte Carlo Validation Report: RA-3 Analysis with GNF2 Fuel November 2004

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ABSTRACT

This document validates the GEMER Version 1.0 Monte Carlo program for analysis of the RA-3 shipping container with GNF2 design fuel bundles and establishes a calculational bias to be applied to the analytical results. This validation can also be applied to other low-enriched fuel designs in the RA-3 container provided they contain no significant nuclides not included in the GNF2 design.

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1 INTRODUCTION

Criticality safety of fissile systems is normally demonstrated by analytical methods, typically Monte Carlo neutronics programs. To assure that the system demonstrated to be subcritical is actually subcritical, the method must be validated against appropriate critical experiments and the analytical results adjusted for any bias in the method and to include an arbitrary safety margin. Providing the geometry treatment is “correct”, in principle the calculational bias is a function only of the cross-sections and cross-section treatment. In actual application, it is also a function of the calculational uncertainty, degree of convergence, choice of representative critical experiments, errors in description of the critical experiment conditions, and development of a fit and uncertainty of that fit.

1.1 GEMER Analytical Technique

GEMER is a Monte Carlo neutronics program used to estimate k_{eff} for fissile systems. The cross-section library is based on ENDF/B-IV data. GEMER uses a 190 energy group structure to represent smooth cross-sections. The cross-section library provides cross-section adjustment for temperature and potential scattering. In addition, resolved resonances are explicitly represented and both the neutron energy group and neutron energy are tracked. When a collision occurs in an energy group and region containing nuclides having resolved resonances, the cross-sections for those nuclides are calculated for that collision using the Breit-Wigner single level resonance equation. This allows GEMER to accurately calculate k_{eff} for heterogeneous fuel and moderator systems without adjusting the cross-sections for self-shielding.

GEMER also allows interpolation on temperature and potential scattering in certain energy groups. Because of the relatively fine group structure, this interpolation produces small changes in the group cross-sections.

GEMER also allows for a Dancoff-Ginsberg correction for heterogeneity (e.g.- rod lattices). Because of the explicit resonance treatment, the effect of the Dancoff-Ginsberg correction is very small in GEMER. This treatment is defaulted in all calculations to minimize potential scattering, thus maximizing k_{eff} .

1.2 Traditional Statistical Analysis

The relationship of a fissile system to the condition of criticality is generally represented by the effective neutron multiplication factor (k_{eff}). k_{eff} is 1.0 for critical systems and less than 1.0 for subcritical systems. Since k_{eff} is 1.0 for critical experiments, the calculational bias is the analytical k_{eff} minus 1.0. Therefore, a negative bias indicates that the method underpredicts k_{eff} , which is non-conservative. To assure safety, the allowable limit for analytical k_{eff} must be adjusted for negative bias (i.e.- adjusted limit = limit + bias). For conservatism, a positive bias is assigned a value of zero.

Analytical methods typically produce a range of k_{eff}’s for similar critical experiments. This results in uncertainty in the actual bias. The limit for analytical k_{eff} must be reduced to account for this uncertainty. To account for unknowns, the limit for analytical k_{eff} is normally reduced by an arbitrary safety margin. The arbitrary safety margin assigned to GNF-A shipping containers is 0.05.

Traditional statistical analysis of results is performed to determine calculational bias in order to establish an acceptable Upper Subcritical Limits (USL). Consistent with the requirements of ANSI/ANS-8.1 [1] and ANSI/ANS-8.17 [2] the criteria to establish subcriticality requires that for a system or process to be considered subcritical the calculated k_{eff} must be less than or equal to an established maximum allowable k_{eff} based on benchmark calculations and uncertainties, that is,

$$k_s \le k_c - \Delta k_s - \Delta k_c - \Delta k_m \tag{1}$$

where

k_s = the calculated allowable maximum k_{eff} of a system or process being evaluated for normal or credible abnormal conditions or events;

k_c = the mean k_{eff} that results from the calculation of critical benchmark experiments using a particular computational method;

Δk_s = the uncertainty in k_s that is an allowance for

- statistical and/or convergence uncertainties in the computation of k_s;
- uncertainties due to limitations in the geometric, material and/or neutronic representations used in the computation method;
- material and fabrication tolerances;

Δk_c = the uncertainty in k_c that is allowance for

- uncertainties in criticality experiments;
- statistical and/or convergence uncertainties in the computation of k_s;
- uncertainties due to limitations in the geometric, material and/or neutronic representations used in the computation method;
- uncertainties due to extrapolation beyond the range of experimental data;

Δk_m= the arbitrary safety margin to ensure subcriticality

Uncertainties due to other than statistical error sources in Δk_c compose the computational bias (b), a systematic difference between calculated results and experimentally measured values. Bias and its associated uncertainty (Δb) can be related to k_c as follows,

$$b = k_c - 1 \tag{2}$$

$$\Delta b = \Delta k_c \tag{3}$$

Thus, the condition for subcriticality in Eq. (1) can be rewritten as,

$$k_s + \Delta k_s \le 1 + b - \Delta b - \Delta k_m \tag{4}$$

A system or process is acceptably subcritical if a calculated k_{eff} plus calculational uncertainty lies at or below the USL.

$$k_s + \Delta k_s \le USL \tag{5}$$

Therefore, the USL can be written as,

$$USL = k_L - \Delta k_m \tag{6}$$

where, k_L is the lower limit of k_{eff} determined from the critical benchmark calculation by statistical analysis and given by

$$k_L = 1 + b - \Delta b \tag{7}$$

1.3 History of GEMER Bias

The forerunner of the GEMER program was the MERIT program, which ran on HONEYWELL 3000 and CDC 7600 platforms, and which used a 190 multigroup structure and explicit resonance treatment to generate cross-sections from the ENDFB-IV cross-section data. Since MERIT was used mainly for reactor physics calculations, the validation used mainly reactor experiments having a typical fuel assembly water-to-fuel ratio. The MERIT program validation claimed an expected bias of approximately –0.005 (defined to be kcalc –1.0) with a 3σ uncertainty of 0.006.

The GEMER program was developed in 1980 to run on PRIME mini-computers. GEMER uses the same cross-sections and treatment as MERIT. Therefore, the calculational bias is in principle the same as MERIT. The original GEMER program was validated using 120 critical experiments representing a wide range of conditions (fuel type, enrichment, structure, geometry, moderation, and reflection). This validation produced a calculational bias that was a function of the hydrogen-to-U235 ratio and was represented as the lower 3σ confidence limit on a second order linear fit. This fit is provided in Figure 1.

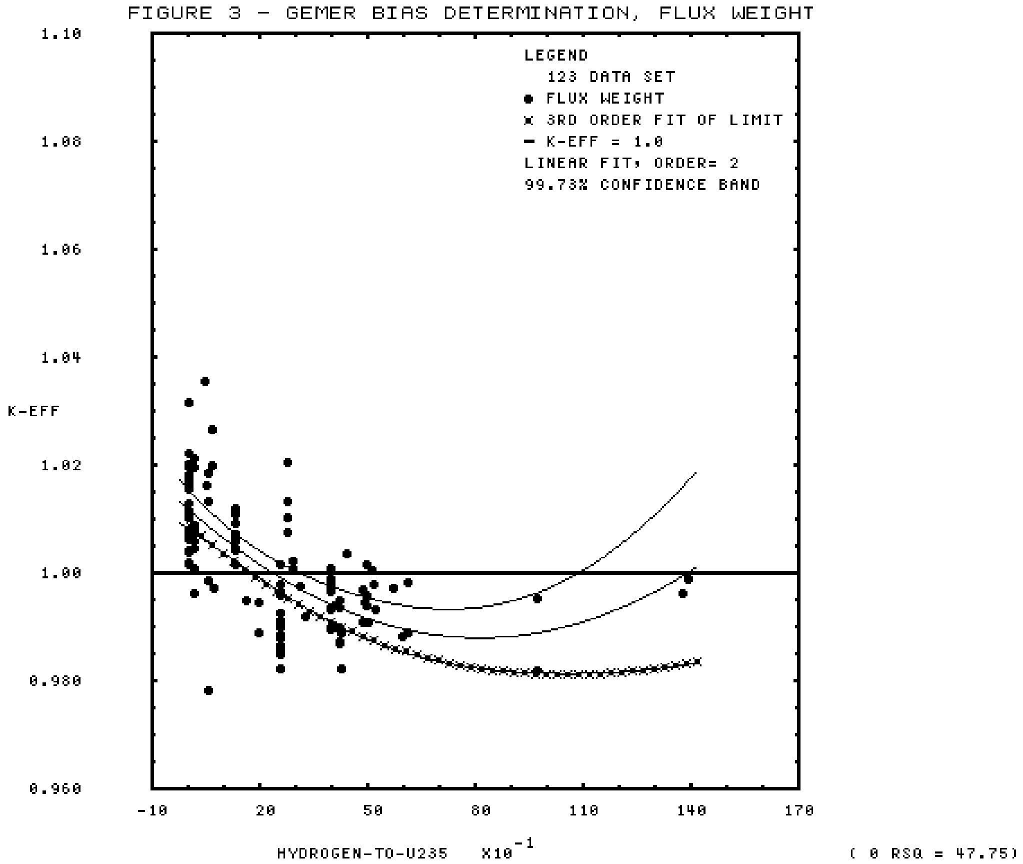

Figure 1. Historical Flux Weighted GEMER Bias

A revision to the GEMER program was made in 1988 which produced GEMER.4. The validation for this program produced a similar calculational bias fit.. Differences are attributed to calculational uncertainty and convergence. Naturally, the Central Limit Theorem says that the calculational uncertainty should pretty much disappear from the fit because of the number of calculations. The GEMER and GEMER.4 fits were compared, and the more conservative fit was selected. This enabled both programs to be used in analysis with the same bias correction.

In 1990 a version of GEMER.4 was created in San Jose to run on a DEC VAX platform. This version was named GEMER01V and was validated in San Jose using the same 120 set of critical experiments. The requirement for acceptance of this validation was agreement with the GEMER.4 validation results based on review of the results in Wilmington. This agreement was achieved.

In 1994, GEMER.4 was converted to run on an 80X86 compatible PC using Lahey FORTRAN 77. The resulting compilation was named GEMER0.0. The same set of 120 critical experiments was used to validate GEMER0.0 with the same selection of most conservative bias fit as was used before. Two subsequent revisions (GEMER0.1 and GEMER0.2) were developed. In 2003, GEMER0.2 was converted to Lahey FORTRAN 90 and released as GEMER1.0. GEMER1.0 was validated with the same 120 critical experiments. For all of these versions, the validations produced similar fits as would be expected since all of these versions use the same cross-section library.

To assure that the validation would apply to PC's and operating systems other than the one the validation was performed on, a set of verification cases were run on any new computer and/or operating system prior to use of that computer/system for criticality safety analysis. The verification cases all included a starting seed for the pseudo-random number generator, thus forcing the calculation to produce identical results each time it is run. Therefore, acceptance of the verification of a new computer/system required identical results for the verification cases to the results on the computer/system where the validation was performed.

In 2004, a new validation was performed for GEMER Version 1.0 Monte Carlo code [3]. This validation used subsets of 284 critical experiments to develop bias fits for low enriched uranium (LEU) solution systems, HEU solution systems, non-solution systems, **LEU lattice systems without poisons**, LEU lattice systems with cadmium, and **LEU lattice systems with boron and gadolinium.** The systems in bold type are of interest in the current validation.

2 SELECTION OF BENCHMARKS

The applicable critical experiments evaluated in this GEMER validation effort are taken directly from Reference 3 and provided in Appendix A. Of the 284 experiments included in **Reference 3**, only 138 are shown in Appendix A. High enriched, powder, and solution experiments are left out except for a group of solution experiments containing gadolinium.

2.1 Area of Applicability

One of the keys to performing a validation is to determine the significant materials, parameters, and ranges for the variables to define appropriate area of applicability. Calculations of the GNF2 fuel design in RA-3 containers were performed [4]. Figure 2 shows a cross-sectional plot of a single undamaged RA-3 package.

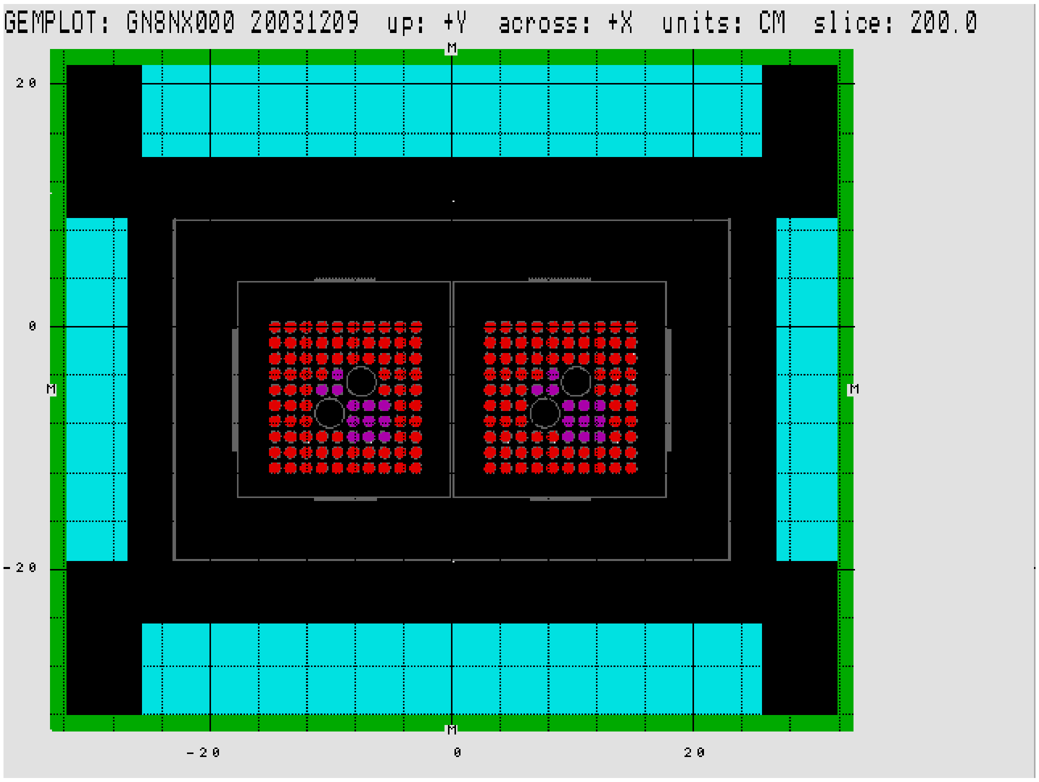

Figure 2. Cross-Sectional Plot: Single Undamaged RA-3 Package.

The red regions represent UO2 rods. The violet regions represent UO2-Gd2O3 rods. The center-most gray regions represent the carbon steel inner basket. The outer-most gray regions represent the carbon steel inner container wall. The green region represents the wooden outer container wall.

Table 1 shows the important materials and their ranges of percent neutron absorption in these calculations[1].

Table 1. Percent Neutron Absorption: RA-3 Package

Model	Material				
	U235	U238	HYDROGEN	GAD	IRON
Single Inner Container	14 – 31%	7 – 10%	41 – 67%	2 - 5%	9 – 12%
Single Outer Container	10 – 31%	5 – 10%	42 – 76%	1 - 5%	7 – 11%
Undamaged Container Array	32 – 42%	10 – 18%	9 – 37%	5 - 6%	15 – 27%
Damaged Container Array	33 – 41%	10 – 28%	11 – 35%	5 - 6%	12 – 16%

The spatial location of the materials is also important. Naturally, the U235 and U238 are located together in the fuel rods. The gadolinium is mixed with the uranium, but only in a small number of rods per bundle. The iron is located outside of the fuel bundles with some hydrogen in between. All hydrogen is not equal. The hydrogen within the bundles is more important than other hydrogen within the inner container which in turn is more important than the hydrogen outside of the inner container.

Since a validation is mainly about addressing errors in cross-sections or cross-section treatment, calculations were run to examine a 10% reduction in a specific nuclide number density. The model used for this study was the most reactive damaged array model (GN8A-007) [4]. Table 2 shows the result of these calculations, and suggests that a uniform error in the iron cross-sections would have double the effect of a proportional, uniform error in the gadolinium cross-sections.

Table 2. RA-3 Reactivity Effect: 10% Reduction in Specific Nuclide Number Density

REDUCED NUCLIDE	% ABS	ORIGINAL k_{eff}	NEW k_{eff}	% CHANGE
U235	43.8	0.93928 ± 0.00081	0.91231 ± 0.00074	-2.87
U238	21.1	0.93928 ± 0.00081	0.94895 ± 0.00082	1.03
GADOLINIUM	5.7	0.93928 ± 0.00081	0.94352 ± 0.00085	0.45
IRON	19.8	0.93928 ± 0.00081	0.94793 ± 0.00079	0.92

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[1] In this evaluation, the terms “% absorption” and “% removal” are used. Traditionally in neutronics, we designate (n,γ) reactions as capture, (n,n) reactions as scatter, and other reactions as absorption. Herein, % absorption includes all reactions except scatter, and % removal includes % absorption + % leakage.

2.2 LEU Lattices Containing Gadolinium

There are very few critical experiments with low enriched uranium lattices containing gadolinium in the fuel. These experiments all fall in a very narrow range of moderation (e.g.- hydrogen-to-U235 atom ratio). The 6 benchmarks used in the recent GEMER validation [3] produce the following analytical results, as shown in Table 3.

Table 3. GEMER Results: LEU Lattices Containing Gadolinium

NAME	H/U235	Enr	% Removal							KEFF	SIGMA
			Leak	U235	U238	Hyd	Gad	B10	Iron		
CR610242	119.06	4.02	1.7	45.5	21.6	5.8	-	22.7	1.1	0.97974	0.00045
CR610243	119.09	4.02	1.8	45.5	21.8	6.1	1.3	21	1	0.98108	0.00042
CR610244	119.1	4.02	1.9	45.5	21.8	6.3	1.6	20.5	0.9	0.98106	0.00042
CR636131	216.28	2.46	2.5	45.3	22.7	7.7	0.8	19.9	-	0.98129	0.00046
CR636132	216.3	2.46	2.6	45.3	22.7	7.9	1.4	19.1	-	0.98140	0.00045
CR636133	119.1	4.02	1.9	45.5	21.6	6.6	1.4	20.3	-	0.98255	0.00040

The similarity of the results is not surprising since there is little difference in the absorptions. High absorptions in boron could easily overwhelm other bias effects. Of note is the slight reduction in k_{eff} with no gad.

2.3 HEU Solution Systems Containing Gadolinium

A set of high enriched solution critical experiments are included in the recent GEMER validation that cover a wide range of gad and moderation [3]. These produce the following results, as shown in Table 4.

Table 4. GEMER Results: HEU Solution Systems Containing Gadolinium

NAME	H/U235	Enr	% Removal							KEFF	SIGMA
			Leak	U235	U238	Hyd	Gad	B10	Iron		
HST14-01	405	89.04	16.8	48.6	0.2	27.1	-	-	3.8	0.99016	0.00086
HST14-02	418.13	89.04	11.3	49.4	0.2	26.1	6.6	-	3.2	1.00629	0.00076
HST14-03	420.78	89.04	9.5	49.9	0.3	22.7	12.7	-	2.4	1.01498	0.00070
HST15-01	278.39	89.04	31	49.1	0.3	14.9	-	-	2.3	0.99568	0.00096
HST15-02	278.39	89.04	18.1	48.7	0.3	25.5	-	-	3.8	0.98801	0.00096
HST15-03	282.56	89.04	26.6	49.6	0.3	11.8	8.3	-	1.4	1.00364	0.00072
HST15-04	282.56	89.04	14.4	49.9	0.3	21.3	8.5	-	2.7	1.01161	0.00076
HST15-05	294.66	89.04	9.6	49.7	0.4	17.9	17.4	-	2.4	1.00513	0.00065
HST16-01	175.2	89.04	22.6	49.1	0.4	21.4	-	-	3.2	0.98911	0.00101
HST16-02	192.42	89.04	15.5	49.8	0.4	20.4	8.2	-	2.7	1.00271	0.00077
HST16-03	191.41	89.04	11	50.9	0.5	17.4	14.2	-	2.9	1.02120	0.00077
HST17-01	132.79	89.04	15.5	49.2	0.5	29.3	-	-	2.6	0.98725	0.00097
HST17-02	132.79	89.04	32.9	48.8	0.5	13.1	-	-	2.1	0.97592	0.00099
HST17-03	132.79	89.04	23.5	48.7	0.5	21.1	-	-	3.1	0.97491	0.00105
HST17-04	137.43	89.04	7.1	49.7	0.5	31.9	5.6	-	2.4	0.99427	0.00084
HST17-05	140.73	89.04	4.9	50.2	0.5	30.3	9.5	-	2.1	1.00194	0.00076
HST17-06	140.73	89.04	27.5	50.1	0.6	8.4	9.1	-	1.9	0.99788	0.00092
HST17-07	140.73	89.04	12.5	50.3	0.6	19.5	9.3	-	3.9	1.00286	0.00077

HST17-08	146.62	89.04	24.9	50.2	0.6	6.5	14.6	-	1.2	0.99870	0.00068
HST18-01	86.03	89.04	15.5	49.8	0.6	29	-	-	2.4	0.98647	0.00098
HST18-02	86.03	89.04	32.8	49.8	0.7	12.2	-	-	1.9	0.98460	0.00093
HST18-03	86.03	89.04	24.2	49.9	0.7	19.5	-	-	2.7	0.98690	0.00103
HST18-04	88.65	89.04	4.9	50.3	0.7	33.4	5.6	-	2.3	0.99474	0.00082
HST18-05	88.65	89.04	29.8	50.5	0.8	8.8	5.2	-	2.2	0.99223	0.00086
HST18-06	88.65	89.04	18.9	50.2	0.7	16.9	5.3	-	3.9	0.98943	0.00100
HST18-07	91.91	89.04	5	50.9	0.7	28.4	10.9	-	1.7	1.00282	0.00071
HST18-08	91.91	89.04	26.9	51.3	0.8	6.8	10.3	-	1.6	1.00738	0.00086
HST18-09	91.91	89.04	14.5	51	0.8	16.4	10.6	-	3.3	1.00227	0.00075
HST18-10	91.19	89.04	25	52.1	0.9	4.9	14.2	-	1	1.01831	0.00075
HST18-11	91.19	89.04	10.2	52.1	0.8	16.2	14.8	-	2.7	1.02098	0.00074
HST18-12	93.62	89.04	8.9	51.8	0.9	14	20	-	1.9	1.01250	0.00064
HST19-01	54.72	89.04	15.5	50.9	0.8	27.9	-	-	2.1	0.99654	0.00102
HST19-02	63.09	89.04	7.9	51.1	0.8	30.9	4.7	-	2	0.99811	0.00088
HST19-03	61.16	89.04	5.7	51	0.9	30.2	7.9	-	1.8	0.99335	0.00078
HST14-01	405	89.04	16.8	48.6	0.2	27.1	-	-	3.8	0.99016	0.00086

These data are very useful because of the number of experiments and the range of data. It is noted that GEMER significantly overestimates the cases containing high gad. If we do a first order linear fit on the data, the R-squared on gad is 68% versus only 15% on leakage and 5% on hydrogen. It is also noted that the MCNP Monte Carlo program shows similar results. Therefore, the problem most likely lies in the basic ENDF data or in the description of the experiments themselves.

Fortunately, based on these comparisons, it appears that GEMER tends to overestimate k_{eff} when gad is present. Therefore, if we do not use gad containing critical experiments to generate our bias, *the bias should be conservative* when applied to analyses of gad containing systems. This is a very important conclusion since it allows us to cover a much wider range of moderation and geometries.

2.4 LEU Lattices Without Poisons

The recent GEMER validation develops a bias for LEU lattice systems without poisons using 71 critical experiments [3]. These produce the following results, as shown in Table 5.

Table 5. GEMER Results: LEU Lattices Without Poisons

NAME	H/U235	Enr	% Removal							KEFF	SIGMA
			Leak	U235	U238	Hyd	Gad	B10	Iron		
LCT09-01	256.51	4.31	0.4	46.9	10.4	40.1	0.0*	-	0.9	0.99135	0.00081
LCT09-24	256.51	4.31	0.4	46.8	10.3	41.5	0	-	0	0.99054	0.00075
LCT09-27	256.51	4.31	0.4	46.9	10.3	41.4	0	0.2	0	0.99158	0.00071
LCT10-08	256.51	4.31	0.5	45.2	20.9	32.7	0	-	0	0.99115	0.00069
LCT10-09	256.51	4.31	0.9	47.5	11.1	24.5	0	-	13.6*	1.00174	0.00078
LCT10-14	105.52	4.31	0.8	47	16.1	25.2	0	-	9.0*	1.00066	0.00074
LCT16-31	399.18	2.35	0.5	46.4	16.2	35.4	0	0.2	0	0.99143	0.00063
LCT16-32	399.18	2.35	0.5	46.5	16.2	35.4	0	0.2	0	0.99164	0.00061
LCT17-01	398.96	2.35	0.7	46.8	16.7	32	0	-	0	0.99875	0.00063
LCT17-04	398.96	2.35	0.4	44.4	27.9	26.3	0	-	0	0.99154	0.00061
LCT17-10	398.96	2.35	0.6	46.7	16.9	25	0	-	8.5*	0.99623	0.00062
LCT17-15	218.71	2.35	0.7	46.3	21.3	19.8	0	-	9.3*	0.99659	0.00060
LCT18-09	118.39	7	4.1	47.8	10.3	34.6	0	-	1.4	0.99708	0.00082
LCT19-01	103.13	5	0.4	48.2	17.5	25	0	-	5.5	1.01024	0.00077
LCT19-02	161.89	5	0.5	48	13.7	29.2	0	-	5.4	1.00297	0.00072

LCT19-03	678.95	5	0.3	48.1	7.4	35.9	0	-	5.2	0.99985	0.00056
LCT20-01	450.89	5	13.3	47.3	9.1	22.9	0	0.9	5.7*	0.98927	0.00080
LCT20-02	450.89	5	9.4	47.6	8.6	28.7	0	0.8	4.1*	0.99366	0.00069
LCT20-03	450.89	5	7.9	47.7	8.5	30.9	0	0.8	3.5*	0.99612	0.00071
LCT20-04	450.89	5	7.1	47.7	8.5	32	0	0.8	3.1*	0.99622	0.00073
LCT20-05	450.89	5	6	47.8	8.4	33.7	0	0.8	2.6*	0.99641	0.00079
LCT20-06	450.89	5	5.4	47.7	8.4	34.7	0	0.8	2.3*	0.99510	0.00080
LCT20-07	450.89	5	0.5	47.8	8.2	40.4	0	0.8	1.5*	0.99649	0.00078
LCT22-01	50.08	9.83	0.6	48.6	13.2	31.6	0	-	2.9	0.99713	0.00081
LCT22-02	79.64	9.83	0.7	48.6	10.2	34.7	0	-	2.9	0.99994	0.00080
LCT22-03	150.59	9.83	0.7	48.6	7.2	37.9	0	-	2.8	1.00160	0.00081
LCT22-04	246.83	9.83	0.6	48.5	5.6	39.7	0	-	2.8	1.00119	0.00078
LCT22-05	339.77	9.83	0.6	48.3	4.9	40.9	0	-	2.8	0.99729	0.00077
LCT22-06	613.49	9.83	0.4	48	3.9	42.3	0	-	2.7	0.99367	0.00062
LCT22-07	629.47	9.83	0.4	48.1	3.9	42.2	0	-	2.8	0.99608	0.00058
LCT23-01	339.77	9.83	12.8	47.8	5.4	27.6	0	-	2.8	0.99049	0.00074
LCT23-02	339.77	9.83	10	47.9	5.2	30.7	0	-	2.8	0.99179	0.00080
LCT23-03	339.77	9.83	8.6	48	5.1	32.3	0	-	2.7	0.99244	0.00074
LCT23-04	339.77	9.83	6.9	48.1	5	34.1	0	-	2.7	0.99543	0.00073
LCT23-05	339.77	9.83	5.1	48.1	5	36.1	0	-	2.7	0.99576	0.00074
LCT23-06	339.77	9.83	3.2	48.2	4.9	38.4	0	-	2.6	0.99600	0.00075
LCT24-01	40.99	9.83	0.5	48.6	14.4	30.5	0	-	3	0.99635	0.00066
LCT24-02	105.02	9.83	0.4	48.5	7.7	37.9	0	-	2.8	0.99937	0.00077
LCT25-01	71.97	7.41	0.6	47.3	14.4	30.1	0	-	3.9	0.98152	0.00078
LCT25-02	114.46	7.41	0.6	47.7	11.3	33	0	-	3.9	0.98801	0.00072
LCT25-03	216.42	7.41	0.6	47.9	8.1	36.2	0	-	3.8	0.99152	0.00068
LCT25-04	354.76	7.41	0.6	48	6.5	37.8	0	-	3.8	0.99459	0.00063
LCT26-01	106.6	4.92	0.1	47.2	14.5	34.8	0	0.7	1.2	0.99490	0.00080
LCT26-02	88.32	4.92	0.4	47.2	16.2	32	0	0.8	1.6	0.99391	0.00078
LCT26-03	50.06	4.92	0.2	47	21.6	27.1	0	1.2	1.3	0.99880	0.00078
LCT26-04	43.13	4.92	0.8	46.8	23.6	24.2	0	1.3	1.5	0.99573	0.00073
LCT26-05	80.19	4.92	0.1	47.1	16.7	32.7	0	0.9	1.1	0.99557	0.00080
LCT26-06	85.14	4.92	0.5	47.2	17.8	30.7	0	1	1.4	0.99596	0.00076
PDK15-01	1269.36	4.89	15.2	47.1	11	26.4	0.0*	-	-	0.98592	0.00065
PDK15-02	1571.29	4.89	9.8	47.4	10.1	31.6	0.0*	-	-	0.99131	0.00055
PDK15-03	1560.69	4.89	10.8	47.3	10.5	30.9	0.0*	-	-	0.98978	0.00055
PDK15-04	1561.3	4.89	10.4	47.2	10.4	31.6	0.0*	-	-	0.98695	0.00058
PDK15-23	76.19	4.89	9.6	46.1	13.3	30.7	-	-	-	0.99081	0.00084
PDK15-24	231.34	4.89	9	46.3	8.8	35.7	-	-	-	0.98212	0.00082
PDK15-25	76.19	4.89	11.4	46.4	15.5	25.8	0.0*	-	-	0.99922	0.00079
PDK15-27	23.42	3.85	2.5	41.4	27.3	27.9	0.0*	-	0.8*	0.99278	0.00070
PDK15-28	41.19	3.85	3	41.9	22	32	0.0*	-	0.9*	0.99011	0.00076
PDK15-29	80.81	3.85	2.6	42	18	36.2	0.0*	-	0.9*	0.98427	0.00069
PDK15-36	99.02	5.74	3	47.2	13.3	32.7	0	-	1.9	0.99425	0.00079
PDK15-37	259.53	5.74	2.4	47.5	8.4	37.9	0	-	1.9	0.99500	0.00072
PDK16-12	158.62	4.89	4.4	46.2	10.5	38.7	-	-	-	0.99255	0.00077
PDK16-13	296.17	4.89	2.9	46	8.7	42.2	-	-	-	0.98503	0.00075
PDK16-14	158.62	4.89	4.4	46.3	10.5	38.4	-	-	-	0.99518	0.00083
PDK16-15	198.1	4.89	2.7	45.3	10.1	41.6	-	-	-	0.98719	0.00078
PDK16-16	62.52	4.89	4.5	44.8	15.1	35.3	-	-	-	0.99420	0.00085
PDK17-01	9.9	3.85	2.6	38.4	38.5	19.3	0.0*	-	0.9*	0.99715	0.00063
PDK17-07	6.54	3.85	2.7	38	42.4	15.7	0.0*	-	0.9*	0.98418	0.00064
WAP931-1	278.66	1.29	0	45.8	26.3	26.4	-	-	-	0.99566	0.00043
WAP931-2	429.55	1.29	0	44.8	26.3	28	-	-	-	0.99168	0.00052
WAP931-3	251.1	1.29	0	43.9	31.5	23.7	-	-	-	0.99184	0.00055

* For carbon, star indicates non-zero capture.
* For iron, star indicates model contains little or no chromium and nickel.

Table 6 compares the important materials and their ranges of percent neutron absorption in these calculations with those in the RA-3 container analysis.

Table 6. Percent Neutron Absorptions: RA-3 Package vs. Experiment

Model	Material				Enr (%)	H/U235	
	U235	U238	HYDROGEN	IRON		Lattice	Inner
Single Inner Container	14 – 31%	7 – 10%	41 – 67%	9 – 12%	4.5 – 5.0	≤ 102	≤ 546
Single Outer Container	10 – 31%	5 – 10%	42 – 76%	7 – 11%	4.5 – 5.0	≤ 102	≤ 546
Undamaged Container Array	32 – 42%	10 – 18%	9 – 37%	15 – 27%	4.5 – 5.0	≤ 102	≤ 546
Damaged Container Array	33 – 41%	10 – 28%	11 – 35%	12 – 16%	4.5 – 5.0	≤ 102	≤ 546
Unpoisoned, low enriched, lattice validation cases	38 – 49%	5 – 42%	16 – 42%	0 – 14%	1.3 – 9.8%	7 – 1571	

This comparison shows that the 71 lattice benchmarks do a very good job of representing the RA-3 container. While many of the RA-3 cases result in significantly lower absorption in U235, this is due to the lower k_{eff} values produced by the RA-3 cases. The hydrogen absorptions are higher for the same reason. A significant amount of iron is present in 48 of the cases, with four cases having more than 8% of the absorptions in iron. Because of the importance of iron in the RA-3 analysis, iron was examined for a possible correlation along with H/U235 and U235 enrichment.

Figure 3 shows a first order, linear regression fit of k_{eff} versus absorptions in iron, using the 71 lattice benchmarks. Also shown on this figure is the 99% confidence interval and the 99% prediction interval.

In the lower right corner is the r^2 of the fit showing that 19% of the variation in the data is accounted for by the fit. Because this fit is driven by a handful of benchmarks, the functionality may or may not exist. However, if it does, we must consider this fit and its extrapolation to higher absorptions in iron in the RA-3 container analysis. Fortunately, k_{eff} appears to increase with increasing iron. Therefore, the increased iron absorption in the RA-3 containers would be conservative based on a validation using these 71 benchmarks with no specified functionality on iron absorptions.

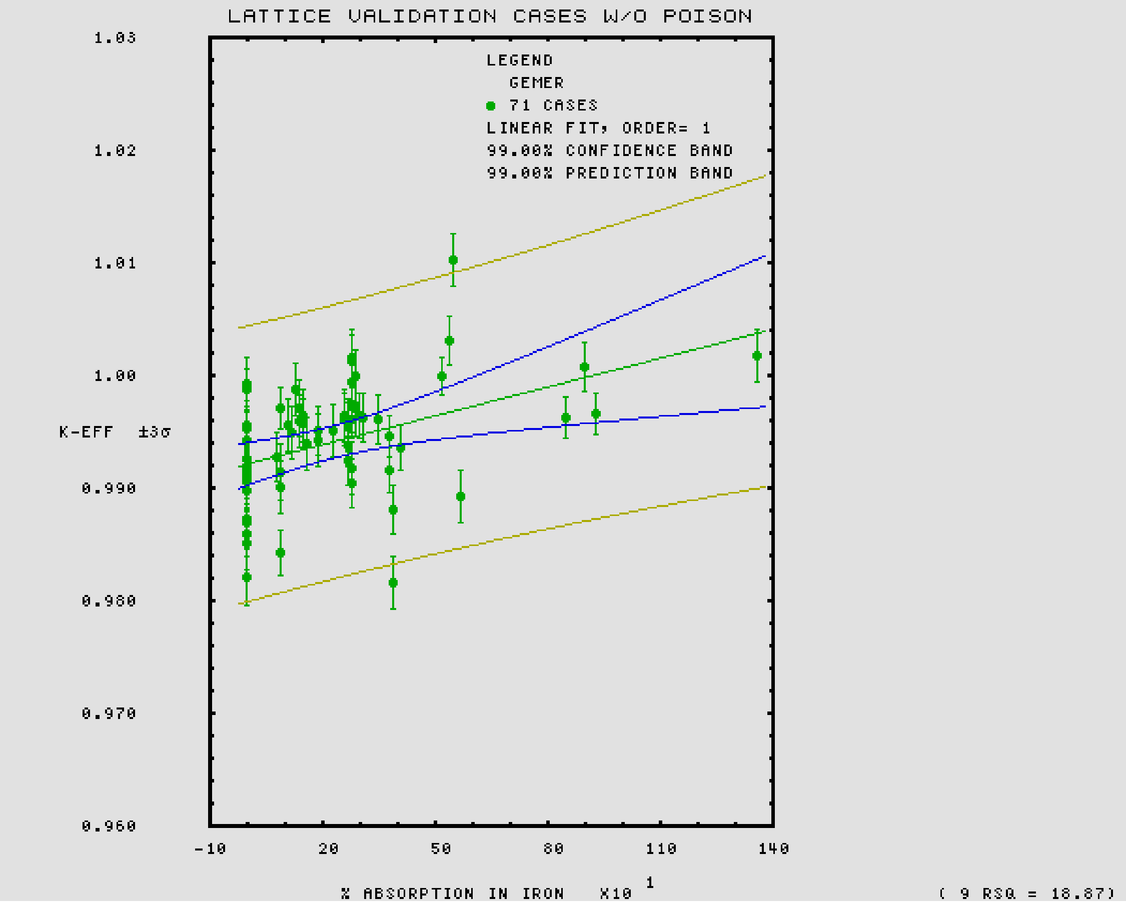

Figure 3. k_{eff} verses Absorptions in Iron (71 lattice benchmarks)

Figure 4 shows a first order, linear regression fit of k_{eff} versus % U235 enrichment, using the 71 lattice benchmarks. In the lower right corner is the r^2 of the fit showing that only 3% of the variation in the data is accounted for by the fit. This r^2 is not considered significant.

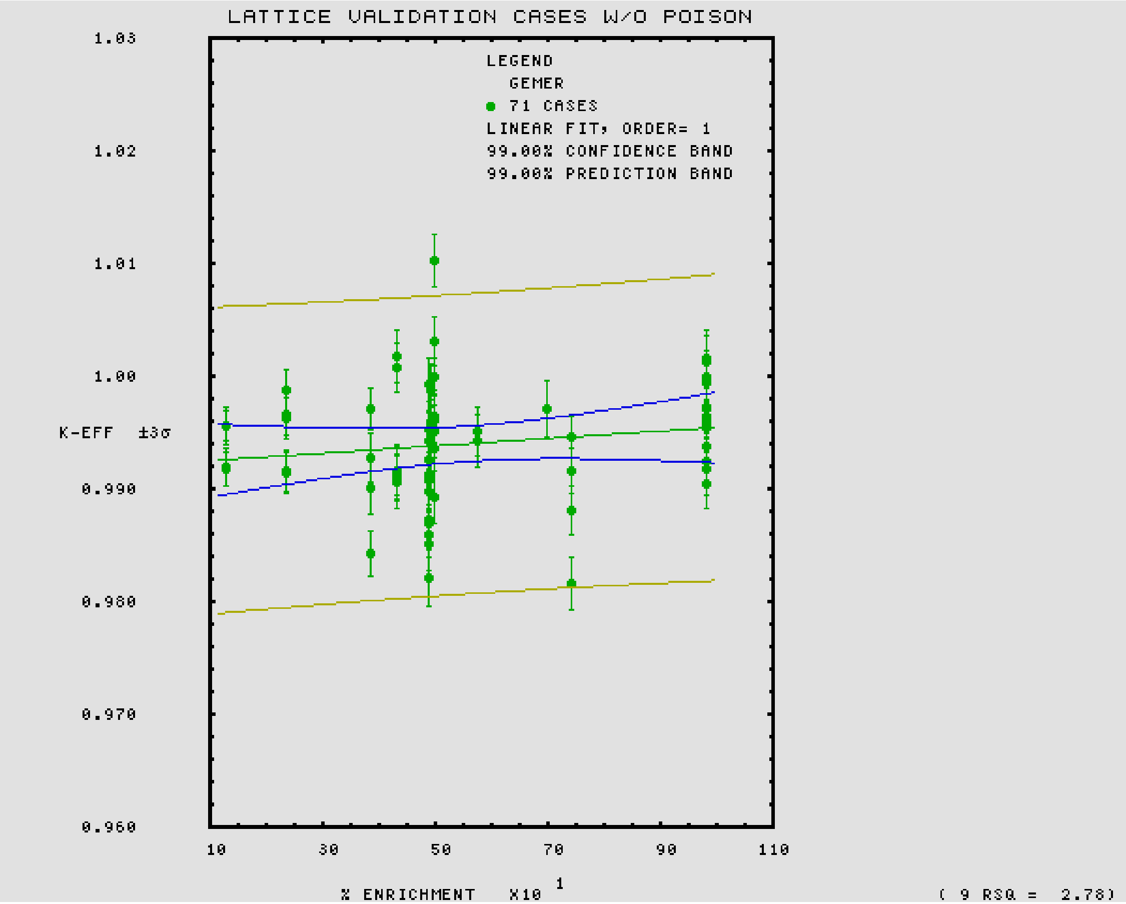

Figure 4. k_{eff} verses %U235 Enrichment (71 lattice benchmarks)

Figure 5 shows a first order, linear regression fit of k_{eff} versus the ratio of hydrogen to uranium-235 nuclei, using the 71 lattice benchmarks.

H/U235 has been the most significant fit parameter in previous GEMER validations, accounting for about half of the data variation. However, those validations have included unmoderated, high enriched benchmarks and the low-moderation Rocky Flats "Green Block" benchmarks, all of which produced relatively high k_{eff}'s. In the lower right corner of this fit is the r^2 showing that only 5% of the variation in the data is accounted for by the fit. It is noted that the fit is driven by only four data points at high H/U235 values.

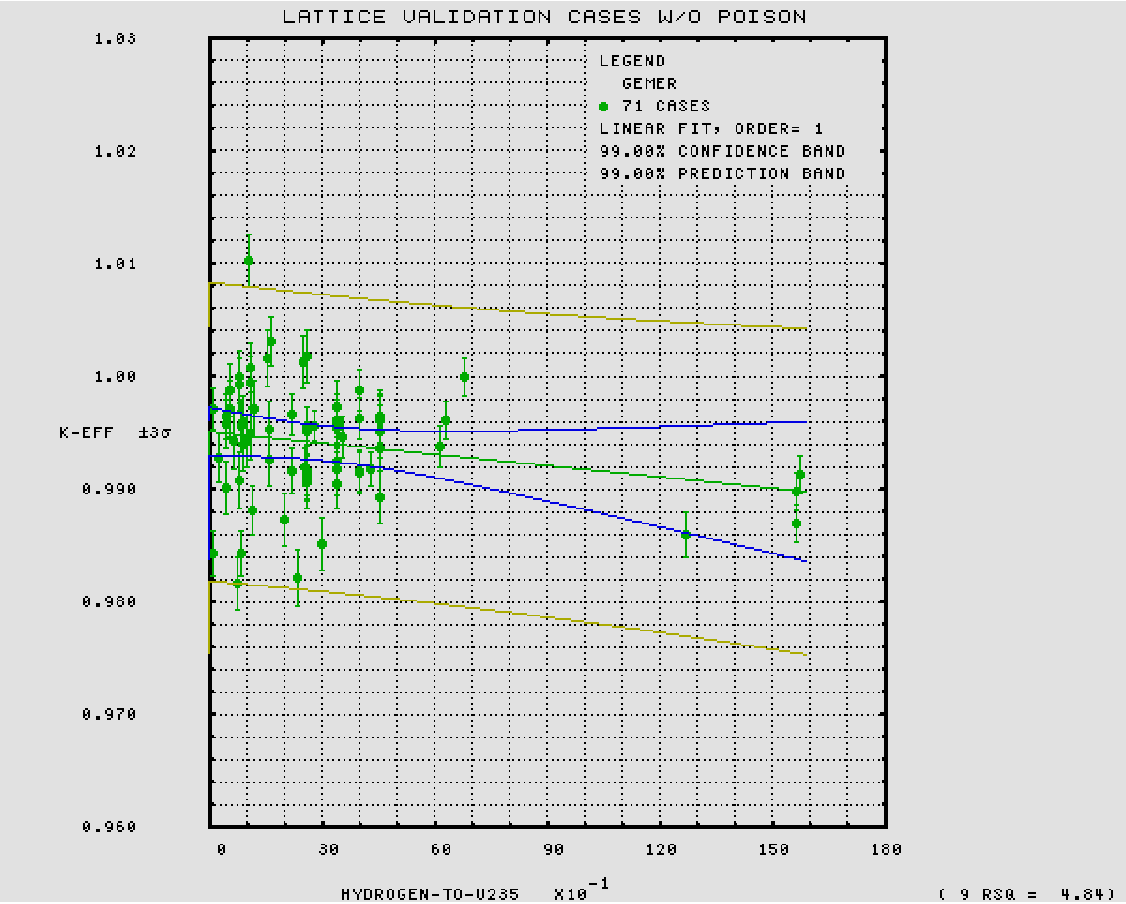

Figure 5. k_{eff} verses H-TO-U235 Atomic Ratio (71 lattice benchmarks)

Therefore, there is no basis for representing the calculational bias as a fit on any of these parameters. For purposes of developing a bias for analysis of the RA-3 container, it is considered appropriate to treat these 71 benchmarks as a non-functional data set from the same sample space. The presence of gadolinium and increased iron in the RA-3 container appears to be conservative for a bias based on this set of benchmarks.

3 RA-3 BIAS DETERMINATION

In this section, a conservative calculational bias is developed for use in RA-3 analyses. As was seen in previous sections, GEMER tends to underestimate k_{eff} for low enriched uranium lattice systems without nuclear poisons. Therefore, a calculational bias must be assigned to these calculations to insure a conservative result.

3.1 Statistical Analysis Used

First, the 71 lattice benchmarks are tested for normality using the Anderson-Darling test. The results are shown in Figure 6 which was taken from the recent GEMER validation [3]. The analysis indicates that the P-value for normality hypothesis test is greater than 0.05. Therefore, the data can be treated as being a sample set from a normal distribution.

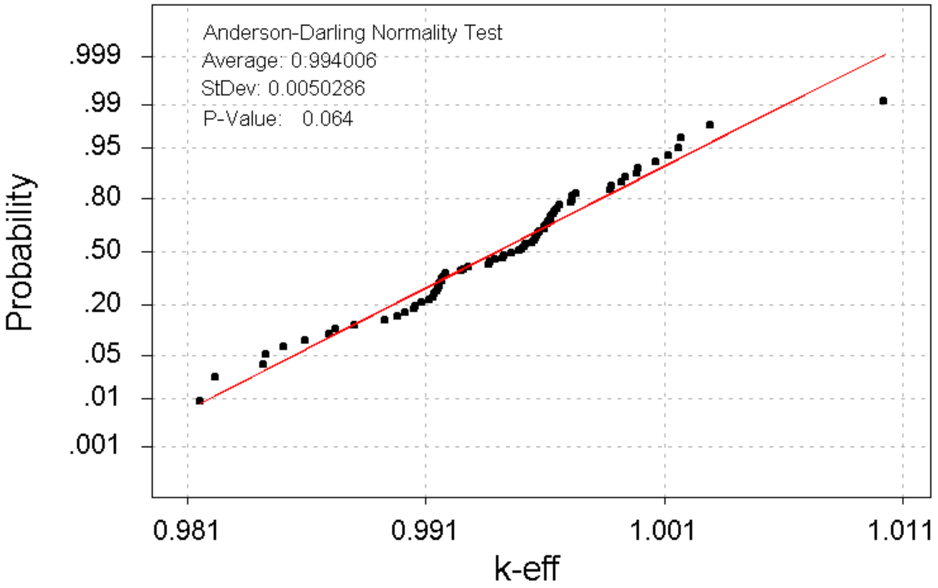

Figure 6. Normal Probability Plot of k_{eff} Data for LEU Lattice Systems without Poisons

The acceptable Upper Subcritical Limit (USL) may also be established by statistical analysis based on either predication intervals or tolerance intervals and an assigned safety margin, i.e.

$$USL = k_L - \Delta k_m \tag{8}$$

where, k_L is the lower limit of k_{eff} determined from the critical benchmark calculation by statistical analysis, Δk_m is an assigned arbirtrary safety margin (0.05 in this validation).

3.1.1 Method 1: Predication Interval – Based k_L

For normally distributed data, the two-sided predication interval for single future observation can be computed using the following conservative approximation [5]

$$k_L = \bar{k} - t_{1-\alpha/2}(n-1)s\sqrt{1+1/n} \tag{9}$$

$$k_U = \bar{k} + t_{1-\alpha/2}(n-1)s\sqrt{1+1/n} \tag{10}$$

where, k_L and k_U are lower and upper predication limits of k_{eff}, $\bar{k}$ is the mean of k_{eff} values from benchmark calculations, s is standard deviation of calculated k_{eff}, n is the number of benchmarks, $t_{1-\alpha/2}(\nu)$ is a 100(1- $\alpha/2$)% of the inverse of t cumulative distribution with v degrees of freedom.

3.1.2 Method 2: Tolerance Interval – Based k_L

For normally distributed data, the tolerance interval that contains at least proportion of p of future observations can be obtained by exact one-sided limits computed as [6]

$$k_L = \bar{k} - g'(p,n,1-\alpha)s \tag{11}$$

$$k_U = \bar{k} + g'(p,n,1-\alpha)s \tag{12}$$

where

$$g'(p,n,1-\alpha) = \frac{1}{\sqrt{n}} t'_{1-\alpha}(z_p\sqrt{n}, n-1) \tag{12}$$

$t'_{1-\alpha}(\delta,\nu)$ is a 100(1- α)% of the inverse of noncentral t cumulative distribution with noncentrality parameters δ and v degrees of freedom, z_P is 100p% of the inverse of standard normal cumulative distribution.

For 71 critical benchmarks with heterogeneous LEU lattice systems without poisons,

$\bar{k} = 0.99401$ $s = 0.00503$ $n = 71$

For α=0.05 (95% confidence level), Method 1 produces

$$\begin{aligned} k_L &= 0.99401 - 1.9944 \times 0.00503 \times \sqrt{1+1/71} \\ &= 0.9839 \end{aligned}$$

For α = 0.01 (99% confidence level) and p = 0.95, Method 2 produces

$$\begin{aligned} k_L &= 0.99401 - \sqrt{1/71} \times t'_{1-0.01}(1.6449\sqrt{71}, 70) \times 0.00503 \\ &= 0.99401 - 0.11868 \times 18.0126 \times 0.00503 \\ &= 0.9832 \end{aligned}$$

Providing a range of confidence and tolerance is more informative than a single value. It is noted that the confidence on the tolerance interval is more sensitive to the sample size than is the range of the interval. Since 71 observations is a relatively large sample size, the tolerance interval changes little with increasing confidence. Based on above calculation, we can say with 99% confidence that 95% of all future observations will fall above 0.9832.

For conservatism, the USL is determined from tolerance interval – based method:

$$USL = k_L - \Delta k_m = 0.9832 - 0.05 = 0.933$$

4 RA-3 VALIDATION SUMMARY

This validation report on the RA-3 shipping container may be summarized as follows:

- A bias is developed based on 71 critical experiments of low enriched uranium lattices containing no poisons.
- The presence of gadolinium in the RA-3 analyses is conservatively represented by this established bias without gad.
- The expected value of k_{eff} for these experiments is 0.994 which is consistent with previous validations of GEMER.
- A bias is established that is not a function of one or more system variables.
- An Upper Safety Limit (USL) of 0.933 is established based on 99% confidence on a 90% tolerance interval and an assigned safety margin of 0.05. This USL reduces the allowable calculated $k_{eff} + 2\sigma$ from 0.945 in previous RA-3 analyses to 0.933.

5 References

1. ANSI/ANS, “Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors,” ANSI/ANS-8.1-1998 (1998).

2. ANSI/ANS, “Criticality Criteria for Handling, Storage, and Transportation of LWR Fuel Outside Reactors,” ANSI/ANS-8.17 (1984, R1997).

3. J. Degolyer, Q. Ao, and L. Paulson, *GEMER Monte Carlo Validation Report (Rev. 01)*, August 2004.

4. J. Taylor, “CRITICALITY SAFETY ANALYSIS, RA-3 SHIPPING CONTAINER FOR USE WITH THE GNF2 FUEL DESIGN”, eDRF-0000-0024-2885, December 2003, as amended.

5. G. Hann, and W. Meeker, *Statistical Intervals – A Guide for Practitioners*, John Wiley & Sons (1991).

6. R. Odeh, *Tables for Normal Tolerance Limits, Sampling Plans, and Screening*, Marcel Dekker, Inc. (1980).

6 Appendix A – Critical Benchmark Tabulated Description(s)

Input Name	Reference (Case #)	H/U-235	Enrichment	Form	Geometry	Moderator	Reflector	Poisons	OTHER	Old Name
CR067401	NUREG/CR-0674 (1)	4.97	4.46	U3O8	CUBOID	H2O	CONCRETE	-	AL	RFLA-1
CR067402	NUREG/CR-0674 (2)	4.99	4.46	U3O8	CUBOID	H2O	PLASTIC	-	AL, CL, STEEL	RFLA-2
CR067403	NUREG/CR-0674 (3)	3.80	4.46	U3O8	CUBOID	H2O	STEEL	-	AL	RFLA-3
CR067404	NUREG/CR-0674 (4)	23.75	4.46	U3O8	CUBOID	H2O	CONCRETE	-	AL	RFLA-4
CR067405	NUREG/CR-0674 (5)	25.13	4.46	U3O8	CUBOID	H2O	PLASTIC	-	AL, CL	RFLA-5
CR067406	NUREG/CR-0674 (6)	36.64	4.46	U3O8	CUBOID	H2O	STEEL	-	AL	RFLA-6
CR067407	NUREG/CR-0674 (7)	90.25	4.46	U3O8	CUBOID	H2O	CONCRETE	-	AL, STEEL	RFLA-7
CR067408	NUREG/CR-0674 (8)	97.52	4.46	U3O8	CUBOID	H2O	PLASTIC	-	AL, CL	RFLA-8
CR067409	NUREG/CR-0674 (9)	98.58	4.46	U3O8	CUBOID	H2O	PLASTIC	-	AL, CL	RFLA-9
CR067410	NUREG/CR-0674 (10)	146.84	4.46	U3O8	CUBOID	H2O	STEEL	-	AL	RFLA-10
CR610242	NUREG/CR-6102 (42)	119.06	4.02	UO2	S LATTICE	H2O	H2O	B	AL, SS304	BNW1810A
CR610243	NUREG/CR-6102 (43)	119.09	4.02	UO2	S LATTICE	H2O	H2O	GD, B	AL, SS304	BNW1810B
CR610244	NUREG/CR-6102 (44)	119.10	4.02	UO2	S LATTICE	H2O	H2O	GD, B	AL, SS304	BNW1810C
CR636131	NUREG/CR-6361 (31)	216.28	2.46	UO2	S LATTICE	H2O	H2O	GD, B	AL	BW1810A
CR636132	NUREG/CR-6361 (32)	216.30	2.46	UO2	S LATTICE	H2O	H2O	GD, B	AL	BW1810B
CR636133	NUREG/CR-6361 (33)	119.10	4.02	UO2	S LATTICE	H2O	H2O	GD, B	AL, SS304	BW1810C
HMF01-01	HEU-MET-FAST-001 (1)	0.00	93.71	U-MET	SPHERE	NONE	BARE	-	-	HH-A1
HMF04-01	HEU-MET-FAST-004 (1)	0.00	97.67	GG*	SPHERE	NONE	H2O/PLEXIGLAS	-	-	HH-A20
HMF23-06	HEU-MET-FAST-023 (6)	0.00	93.20	U-MET	CYLINDER	NONE	BARE	-	SS	HH-B4
HMF23-29	HEU-MET-FAST-023 (29)	0.00	93.20	U-MET	CYLINDER	NONE	BARE	-	SS	HH-B5
HST01-02	HEU-SOL-THERM-001 (2)	70.60	93.17	UNH	CYLINDER	H2O	BARE	-	SS	HH-A21
HST07-04	HEU-SOL-THERM-007 (4)	66.78	93.17	UNH	CYLINDER	H2O	CONCRETE	-	SS, AL	HH-B22
HST08-04	HEU-SOL-THERM-008 (4)	68.75	93.17	UNH	CYLINDER	H2O	PLEXIGLAS	-	SS, AL	HH-B21
HST13-01	HEU-SOL-THERM-013 (1)	1374.65	93.18	UNH	SPHERE	H2O	BARE	-	AL	HH-A5
HST14-01	HEU-SOL-THERM-014 (1)	405.00	89.04	U NITRATE	CYLINDER	H2O	H2O	-	SS	HB2-1401
HST14-02	HEU-SOL-THERM-014 (2)	418.13	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1402
HST14-03	HEU-SOL-THERM-014 (3)	420.78	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1403
HST15-01	HEU-SOL-THERM-015 (1)	278.39	89.04	U NITRATE	CYLINDER	H2O	H2O	-	SS	HB2-1501
HST15-02	HEU-SOL-THERM-015 (2)	278.39	89.04	U NITRATE	CYLINDER	H2O	H2O	-	SS	HB2-1502

HST15-03	HEU-SOL-THERM-015 (3)	282.56	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1503
HST15-04	HEU-SOL-THERM-015 (4)	282.56	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1504
HST15-05	HEU-SOL-THERM-015 (5)	294.66	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1505
HST16-01	HEU-SOL-THERM-016 (1)	175.20	89.04	U NITRATE	CYLINDER	H2O	H2O	-	SS	HB2-1601
HST16-02	HEU-SOL-THERM-016 (2)	192.42	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1602
HST16-03	HEU-SOL-THERM-016 (3)	191.41	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1603
HST17-01	HEU-SOL-THERM-017 (1)	132.79	89.04	U NITRATE	CYLINDER	H2O	H2O	-	SS	HB2-1701
HST17-02	HEU-SOL-THERM-017 (2)	132.79	89.04	U NITRATE	CYLINDER	H2O	H2O	-	SS	HB2-1702
HST17-03	HEU-SOL-THERM-017 (3)	132.79	89.04	U NITRATE	CYLINDER	H2O	H2O	-	SS	HB2-1703
HST17-04	HEU-SOL-THERM-017 (4)	137.43	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1704
HST17-05	HEU-SOL-THERM-017 (5)	140.73	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1705
HST17-06	HEU-SOL-THERM-017 (6)	140.73	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1706
HST17-07	HEU-SOL-THERM-017 (7)	140.73	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1707
HST17-08	HEU-SOL-THERM-017 (8)	146.62	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1708
HST18-01	HEU-SOL-THERM-018 (1)	86.03	89.04	U NITRATE	CYLINDER	H2O	H2O	-	SS	HB2-1801
HST18-02	HEU-SOL-THERM-018 (2)	86.03	89.04	U NITRATE	CYLINDER	H2O	H2O	-	SS	HB2-1802
HST18-03	HEU-SOL-THERM-018 (3)	86.03	89.04	U NITRATE	CYLINDER	H2O	H2O	-	SS	HB2-1803
HST18-04	HEU-SOL-THERM-018 (4)	88.65	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1804
HST18-05	HEU-SOL-THERM-018 (5)	88.65	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1805
HST18-06	HEU-SOL-THERM-018 (6)	88.65	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1806
HST18-07	HEU-SOL-THERM-018 (7)	91.91	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1807
HST18-08	HEU-SOL-THERM-018 (8)	91.91	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1808
HST18-09	HEU-SOL-THERM-018 (9)	91.91	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1809
HST18-10	HEU-SOL-THERM-018 (10)	91.19	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1810
HST18-11	HEU-SOL-THERM-018 (11)	91.19	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1811
HST18-12	HEU-SOL-THERM-018 (12)	93.62	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1812
HST19-01	HEU-SOL-THERM-019 (1)	54.72	89.04	U NITRATE	CYLINDER	H2O	H2O	-	SS	HB2-1901
HST19-02	HEU-SOL-THERM-019 (2)	63.09	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1902
HST19-03	HEU-SOL-THERM-019 (3)	61.16	89.04	U NITRATE	CYLINDER	H2O	H2O	GD	SS	HB2-1903
HST21-16	HEU-SOL-THERM-021 (16)	58.78	92.60	UNH	CYLINDER	H2O	BARE	-	WOOD, CS, CONCRETE, AL	HH-B13
HST21-22	HEU-SOL-THERM-021 (22)	58.78	92.60	UNH	CYLINDER	H2O	PARAFFIN	-	WOOD, CS, CONCRETE, AL	HH-B18
HST21-23	HEU-SOL-THERM-021 (23)	58.78	92.60	UNH	CYLINDER	H2O	PLEXIGLAS	-	WOOD, CS, CONCRETE, AL	HH-B19
HST21-26	HEU-SOL-THERM-021 (26)	58.78	92.60	UNH	CYLINDER	H2O	BARE	-	WOOD, CS, CONCRETE, AL	HH-B17
HST21-32	HEU-SOL-THERM-021 (32)	435.08	92.60	UNH	CYLINDER	H2O	BARE	-	WOOD, CS, CONCRETE, AL	HH-B14

HST40-11	HEU-SOL-THERM0-040 (11)	51.01	93.17	UNH	CYLINDER	H2O	BARE	-	SS	HH-B20
HST43-03	HEU-SOL-THERM-043 (3)	1392.13	93.20	UO2F2	SPHERE	H2O	BARE	-	AL	HH-A4
IMF02-01	IEU-MET-FAST-002 (1)	0.00	16.19	U-MET	CYLINDER	NONE	NATURAL U	-	-	JEMIMA
IMF07-01	IEU-MET-FAST-007 (1)	0.00	10.06	U-MET	CYLINDER	NONE	DepU	-	-	BIGTEN
IMF10-01	IEU-MET-FAST-010 (1)	0.01	9.00	U-MET	CYLINDER	NONE	DEP U/SS	-	-	U9
LCT09-01	LEU-COMP-THERM-009 (1)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	-	AL	BIER-26
LCT09-06	LEU-COMP-THERM-009 (6)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	B	AL	BIER-21
LCT09-08	LEU-COMP-THERM-009 (8)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	B	AL	BIER-23
LCT09-09	LEU-COMP-THERM-009 (9)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	B	AL	BIER-43
LCT09-14	LEU-COMP-THERM-009 (14)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	CD, B	AL, CU	BIER-32
LCT09-15	LEU-COMP-THERM-009 (15)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	CD, B	AL, CU	BIER-31
LCT09-16	LEU-COMP-THERM-009 (16)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	CD	AL	BIER-38
LCT09-17	LEU-COMP-THERM-009 (17)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	CD	AL	BIER-37
LCT09-18	LEU-COMP-THERM-009 (18)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	CD	AL	BIER-40
LCT09-19	LEU-COMP-THERM-009 (19)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	CD	AL	BIER-39
LCT09-20	LEU-COMP-THERM-009 (20)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	CD	AL	BIER-34
LCT09-21	LEU-COMP-THERM-009 (21)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	CD	AL	BIER-33
LCT09-22	LEU-COMP-THERM-009 (22)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	CD	AL	BIER-36
LCT09-23	LEU-COMP-THERM-009 (23)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	CD	AL	BIER-35
LCT09-24	LEU-COMP-THERM-009 (24)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	-	AL	BIER-18
LCT09-27	LEU-COMP-THERM-009 (27)	256.51	4.306	UO2	S-LATTICE	H2O	H2O	-	AL, ZR	BIER-41
LCT10-08	LEU-COMP-THERM-010 (8)	256.51	4.306	UO2	S-LATTICE	H2O	H2O, DepU	-	AL	BIER-12
LCT10-09	LEU-COMP-THERM-010 (9)	256.51	4.306	UO2	S-LATTICE	H2O	H2O, Steel	-	AL	-----
LCT10-14	LEU-COMP-THERM-010 (14)	105.52	4.306	UO2	S-LATTICE	H2O	H2O, Steel	-	AL	-----
LCT16-21	LEU-COMP-THERM-016 (21)	399.18	2.35	UO2	S LATTICE	H2O	H2O	CD	AL	RSIC-14
LCT16-22	LEU-COMP-THERM-016 (22)	399.18	2.35	UO2	S LATTICE	H2O	H2O	CD	AL	RSIC-26
LCT16-23	LEU-COMP-THERM-016 (23)	399.18	2.35	UO2	S LATTICE	H2O	H2O	CD	AL	RSIC-15
LCT16-24	LEU-COMP-THERM-016 (24)	399.18	2.35	UO2	S LATTICE	H2O	H2O	CD	AL	RSIC-24
LCT16-26	LEU-COMP-THERM-016 (26)	399.18	2.35	UO2	S LATTICE	H2O	H2O	CD	AL	RSIC-25
LCT16-31	LEU-COMP-THERM-016 (31)	399.18	2.35	UO2	S LATTICE	H2O	H2O	-	AL, ZR	RSIC-21
LCT16-32	LEU-COMP-THERM-016 (32)	399.18	2.35	UO2	S LATTICE	H2O	H2O	-	AL, ZR	RSIC-22
LCT17-01	LEU-COMP-THERM-017 (1)	398.96	2.35	UO2	S-LATTICE	H2O	H2O, Lead	-	AL	BIER-7
LCT17-04	LEU-COMP-THERM-017 (4)	398.96	2.35	UO2	S-LATTICE	H2O	H2O, DepU	-	AL	BIER-1
LCT17-10	LEU-COMP-THERM-017 (10)	398.96	2.35	UO2	S-LATTICE	H2O	H2O, Steel	-	AL	-----

LCT17-15	LEU-COMP-THERM-017 (15)	218.71	2.35	UO2	S-LATTICE	H2O	H2O, Steel	-	AL	-----
LCT18-09	LEU-COMP-THERM-018 (9)	118.39	7.00	UO2	S LATTICE	H2O	H2O	-	SS	DIMPLE
LCT19-01	LEU-COMP-THERM-019 (1)	103.13	5.00	UO2	H LATTICE	H2O	H2O	-	SS	KRUO2-1
LCT19-02	LEU-COMP-THERM-019 (2)	161.89	5.00	UO2	H LATTICE	H2O	H2O	-	SS	KRUO2-2
LCT19-03	LEU-COMP-THERM-019 (3)	678.95	5.00	UO2	H LATTICE	H2O	H2O	-	SS	KRUO2-3
LCT20-01	LEU-COMP-THERM-020 (1)	450.89	5.00	UO2	H LATTICE	H2O	H2O	-	ZR, SS	KZRUO2-1
LCT20-02	LEU-COMP-THERM-020 (2)	450.89	5.00	UO2	H LATTICE	H2O	H2O	-	ZR, SS	KZRUO2-2
LCT20-03	LEU-COMP-THERM-020 (3)	450.89	5.00	UO2	H LATTICE	H2O	H2O	-	ZR, SS	KZRUO2-3
LCT20-04	LEU-COMP-THERM-020 (4)	450.89	5.00	UO2	H LATTICE	H2O	H2O	-	ZR, SS	KZRUO2-4
LCT20-05	LEU-COMP-THERM-020 (5)	450.89	5.00	UO2	H LATTICE	H2O	H2O	-	ZR, SS	KZRUO2-5
LCT20-06	LEU-COMP-THERM-020 (6)	450.89	5.00	UO2	H LATTICE	H2O	H2O	-	ZR, SS	KZRUO2-6
LCT20-07	LEU-COMP-THERM-020 (7)	450.89	5.00	UO2	H LATTICE	H2O	H2O	-	ZR, SS	KZRUO2-7
LCT21-01	LEU-COMP-THERM-021 (1)	220.81	5.00	UO2	H LATTICE	H2O	H2O	B	SS, AL	KBUO2-1
LCT21-02	LEU-COMP-THERM-021 (2)	220.81	5.00	UO2	H LATTICE	H2O	H2O	B	SS, AL	KBUO2-2
LCT21-03	LEU-COMP-THERM-021 (3)	220.81	5.00	UO2	H LATTICE	H2O	H2O	B	SS, AL	KBUO2-3
LCT21-04	LEU-COMP-THERM-021 (4)	450.78	5.00	UO2	H LATTICE	H2O	H2O	B	SS, AL	KBUO2-4
LCT21-05	LEU-COMP-THERM-021 (5)	450.78	5.00	UO2	H LATTICE	H2O	H2O	B	SS, AL	KBUO2-5
LCT21-06	LEU-COMP-THERM-021 (6)	450.78	5.00	UO2	H LATTICE	H2O	H2O	B	SS, AL	KBUO2-6
LCT22-01	LEU-COMP-THERM-022 (1)	50.08	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-1
LCT22-02	LEU-COMP-THERM-022 (2)	79.64	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-2
LCT22-03	LEU-COMP-THERM-022 (3)	150.59	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-3
LCT22-04	LEU-COMP-THERM-022 (4)	246.83	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-4
LCT22-05	LEU-COMP-THERM-022 (5)	339.77	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-5
LCT22-06	LEU-COMP-THERM-022 (6)	613.49	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-6
LCT22-07	LEU-COMP-THERM-022 (7)	629.47	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-7
LCT23-01	LEU-COMP-THERM-023 (1)	339.77	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-A
LCT23-02	LEU-COMP-THERM-023 (2)	339.77	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-B
LCT23-03	LEU-COMP-THERM-023 (3)	339.77	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-C
LCT23-04	LEU-COMP-THERM-023 (4)	339.77	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-D
LCT23-05	LEU-COMP-THERM-023 (5)	339.77	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-E
LCT23-06	LEU-COMP-THERM-023 (6)	339.77	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-F
LCT24-01	LEU-COMP-THERM-024 (1)	40.99	9.83	UO2	S LATTICE	H2O	H2O	-	SS, AL	K10UO2-X
LCT24-02	LEU-COMP-THERM-024 (2)	105.02	9.83	UO2	H LATTICE	H2O	H2O	-	SS, AL	K10UO2-Y
LCT25-01	LEU-COMP-THERM-025 (1)	71.97	7.41	UO2	H LATTICE	H2O	H2O	-	SS	RUO2-01

LCT25-02	LEU-COMP-THERM-025 (2)	114.46	7.41	UO2	H LATTICE	H2O	H2O	-	SS	RUO2-02
LCT25-03	LEU-COMP-THERM-025 (3)	216.42	7.41	UO2	H LATTICE	H2O	H2O	-	SS	RUO2-03
LCT25-04	LEU-COMP-THERM-025 (4)	354.76	7.41	UO2	H LATTICE	H2O	H2O	-	SS	RUO2-04
LCT26-01	LEU-COMP-THERM-026 (1)	106.60	4.92	UO2	H LATTICE	H2O	H2O	-	ZR, SS	OT-1
LCT26-02	LEU-COMP-THERM-026 (2)	88.32	4.92	UO2	H LATTICE	H2O	H2O	-	ZR, SS	OT-2
LCT26-03	LEU-COMP-THERM-026 (3)	50.06	4.92	UO2	H LATTICE	H2O	H2O	-	ZR, SS	OT-3
LCT26-04	LEU-COMP-THERM-026 (4)	43.13	4.92	UO2	H LATTICE	H2O	H2O	-	ZR, SS	OT-4
LCT26-05	LEU-COMP-THERM-026 (5)	80.19	4.92	UO2	H LATTICE	H2O	H2O	-	ZR, SS	OT-5
LCT26-06	LEU-COMP-THERM-026 (6)	85.14	4.92	UO2	H LATTICE	H2O	H2O	-	ZR, SS	OT-6
LCT33-01	LEU-COMP-THERM-033 (1)	195.63	2.00	UF-4	CUBOID	PARAFFIN	PARAFFIN	-	PLEXIGLAS	HH-11
LCT33-05	LEU-COMP-THERM-033 (5)	294.36	2.00	UF-4	CUBOID	PARAFFIN	PARAFFIN	-	PLEXIGLAS	HH-13
LCT33-09	LEU-COMP-THERM-033 (9)	406.75	2.00	UF-4	CUBOID	PARAFFIN	PARAFFIN	-	PLEXIGLAS	HH-15
LCT33-10	LEU-COMP-THERM-033 (10)	496.21	2.00	UF-4	CUBOID	PARAFFIN	PARAFFIN	-	PLEXIGLAS	HH-16
LCT33-13	LEU-COMP-THERM-033 (13)	613.27	2.00	UF-4	CUBOID	PARAFFIN	POLY	-	PLEXIGLAS	HH-17
LCT33-14	LEU-COMP-THERM-033 (14)	972.77	2.00	UF-4	CUBOID	PARAFFIN	POLY	-	PLEXIGLAS	HH-19
LCT33-17	LEU-COMP-THERM-033 (17)	133.27	3.00	UF-4	CUBOID	PARAFFIN	PARAFFIN	-	PLEXIGLAS	HH-22
LCT33-18	LEU-COMP-THERM-033 (18)	133.27	3.00	UF-4	CUBOID	PARAFFIN	PARAFFIN	-	PLEXIGLAS	HH-23
LCT33-19	LEU-COMP-THERM-033 (19)	133.27	3.00	UF-4	CUBOID	PARAFFIN	PARAFFIN	-	PLEXIGLAS	HH-21
LCT33-20	LEU-COMP-THERM-033 (20)	133.27	3.00	UF-4	CUBOID	PARAFFIN	PARAFFIN	-	PLEXIGLAS	HH-24
LCT33-21	LEU-COMP-THERM-033 (21)	133.27	3.00	UF-4	CUBOID	PARAFFIN	PARAFFIN	-	PLEXIGLAS	HH-25
LCT33-22	LEU-COMP-THERM-033 (22)	277.21	3.00	UF-4	CUBOID	PARAFFIN	POLY	-	PLEXIGLAS	HH-29
LCT33-23	LEU-COMP-THERM-033 (23)	195.63	2.00	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-12
LCT33-26	LEU-COMP-THERM-033 (26)	294.36	2.00	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-14
LCT33-42	LEU-COMP-THERM-033 (42)	613.27	2.00	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-18
LCT33-45	LEU-COMP-THERM-033 (45)	972.77	2.00	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-20
LCT33-47	LEU-COMP-THERM-033 (47)	133.27	3.00	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-26
LCT33-48	LEU-COMP-THERM-033 (48)	133.27	3.00	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-27
LCT33-49	LEU-COMP-THERM-033 (49)	133.27	3.00	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-28
LCT33-50	LEU-COMP-THERM-033 (50)	277.21	3.00	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-30
LCT33-51	LEU-COMP-THERM-033 (51)	277.21	3.00	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-31
LCT33-52	LEU-COMP-THERM-033 (52)	277.21	3.00	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-32
LCT49-01	LEU-COMP-THERM-049 (1)	39.94	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC1
LCT49-02	LEU-COMP-THERM-049 (2)	39.94	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC2
LCT49-03	LEU-COMP-THERM-049 (3)	39.94	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC3

LCT49-04	LEU-COMP-THERM-049 (4)	39.94	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC4
LCT49-05	LEU-COMP-THERM-049 (5)	49.95	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC5
LCT49-06	LEU-COMP-THERM-049 (6)	49.95	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC6
LCT49-07	LEU-COMP-THERM-049 (7)	49.95	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC7
LCT49-08	LEU-COMP-THERM-049 (8)	49.95	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC8
LCT49-09	LEU-COMP-THERM-049 (9)	59.68	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC9
LCT49-10	LEU-COMP-THERM-049 (10)	59.68	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC10
LCT49-11	LEU-COMP-THERM-049 (11)	59.68	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC11
LCT49-12	LEU-COMP-THERM-049 (12)	59.68	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC12
LCT49-13	LEU-COMP-THERM-049 (13)	45.20	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC13
LCT49-14	LEU-COMP-THERM-049 (14)	45.58	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC14
LCT49-15	LEU-COMP-THERM-049 (15)	45.63	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC15
LCT49-16	LEU-COMP-THERM-049 (16)	50.68	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC16
LCT49-17	LEU-COMP-THERM-049 (17)	50.68	5.00	UO2 POWDER	CUBOID	H2O	BARE	-	AL,POLY,SS304,RUBBER	MARAC17
LST01-01	LEU-SOL-THERM-001 (1)	453.90	5.00	UO2F2	CYLINDER	H2O	BARE	-	SS304	SHEBA2
LST03-01	LEU-SOL-THERM-003 (1)	770.31	10.07	UNH	SPHERE	H2O	BARE	-	SS	BRUNH01
LST03-02	LEU-SOL-THERM-003 (2)	877.60	10.07	UNH	SPHERE	H2O	BARE	-	SS	BRUNH02
LST03-03	LEU-SOL-THERM-003 (3)	897.01	10.07	UNH	SPHERE	H2O	BARE	-	SS	BRUNH03
LST03-04	LEU-SOL-THERM-003 (4)	913.25	10.07	UNH	SPHERE	H2O	BARE	-	SS	BRUNH04
LST03-05	LEU-SOL-THERM-003 (5)	1173.38	10.07	UNH	SPHERE	H2O	BARE	-	SS	BRUNH05
LST03-06	LEU-SOL-THERM-003 (6)	1213.10	10.07	UNH	SPHERE	H2O	BARE	-	SS	BRUNH06
LST03-07	LEU-SOL-THERM-003 (7)	1239.80	10.07	UNH	SPHERE	H2O	BARE	-	SS	BRUNH07
LST03-08	LEU-SOL-THERM-003 (8)	1411.64	10.07	UNH	SPHERE	H2O	BARE	-	SS	BRUNH08
LST03-09	LEU-SOL-THERM-003 (9)	1437.51	10.07	UNH	SPHERE	H2O	BARE	-	SS	BRUNH09
LST04-01	LEU-SOL-THERM-004 (1)	719.02	9.97	UNH	CYLINDER	H2O	H2O	-	SS304	STACY
P6205-01	PNL-6205 (214R)	92.88	4.31	UO2	S LATTICE	H2O	H2O	BORAL	AL, RUBBER, ACRYLIC	NT8-1
PB255-02	PB-255-728 (2)	163.70	2.35	UO2	S LATTICE	H2O	H2O	B	AL	RSIC-58
PB255-04	PB-255-728 (4)	329.53	2.35	UO2	S LATTICE	H2O	H2O	B	AL	RSIC-60
PDK05-01	PDK-VV-005 (1)	0.00	53.60	U-MET	CYLINDER	NONE	BARE	-	-	LANLC54
PDK06-01	PDK-VV-006 (1)	0.00	37.70	U-MET	CYLINDER	NONE	BARE	-	-	LANLC38
PDK07-01	PDK-VV-007 (1)	0.00	29.00	U-MET	CYLINDER	NONE	BARE	-	-	LANLC29
PDK08-01	PDK-VV-008 (1)	0.00	16.01	U-MET	CYLINDER	NONE	BARE	-	-	LANLC16
PDK09-01	PDK-VV-009 (1)	0.00	14.11	U-MET	CYLINDER	NONE	BARE	-	-	LANLC14
PDK10-01	PDK-VV-010 (1)	0.00	12.32	U-MET	CYLINDER	NONE	BARE	-	-	LANLC12

PDK11-01	PDK-VV-011 (1)	0.00	10.90	U-MET	CYLINDER	NONE	BARE	-	-	LANLC11
PDK15-01	PDK-VV-015 (1)	1269.36	4.89	U-MET	S LATTICE	UO2F2 SOLN	UO2F2 SOLN	-	AL, PLEXIGLAS	ORNL1242
PDK15-02	PDK-VV-015 (2)	1571.29	4.89	U-MET	S LATTICE	UO2F2 SOLN	UO2F2 SOLN	-	AL, PLEXIGLAS	ORNL1542
PDK15-03	PDK-VV-015 (3)	1560.69	4.89	U-MET	S LATTICE	UO2F2 SOLN	UO2F2 SOLN	-	AL, PLEXIGLAS	ORNL1742
PDK15-04	PDK-VV-015 (4)	1561.30	4.89	U-MET	S LATTICE	UO2F2 SOLN	UO2F2 SOLN	-	AL, PLEXIGLAS	ORNL1842
PDK15-09	PDK-VV-015 (9)	199.30	4.89	U3O8	CUBOID	STEREOTEX	H2O	-	-	ORNL2342
PDK15-10	PDK-VV-015 (10)	396.70	4.89	U3O8	CUBOID	STEREOTEX	H2O	-	-	ORNL2542
PDK15-11	PDK-VV-015 (11)	756.59	4.89	U3O8	CUBOID	STEREOTEX	H2O	-	-	ORNL2642
PDK15-13	PDK-VV-015 (13)	525.99	4.89	UO2F2	CYLINDER	H2O	BARE	-	SS304	ORNL3042
PDK15-14	PDK-VV-015 (14)	733.74	4.89	UO2F2	CYLINDER	H2O	BARE	-	SS304	ORNL3242
PDK15-15	PDK-VV-015 (15)	998.84	4.89	UO2F2	SPHERE	H2O	BARE	-	AL	ORNL3342
PDK15-16	PDK-VV-015 (16)	991.00	4.89	UO2F2	CYLINDER	H2O	PLEXIGLAS	-	AL	ORNL3442
PDK15-17	PDK-VV-015 (17)	525.99	4.89	UO2F2	CYLINDER	H2O	H2O	-	SS304	ORNL3542
PDK15-18	PDK-VV-015 (18)	733.74	4.89	UO2F2	CYLINDER	H2O	H2O	-	SS304	ORNL3742
PDK15-19	PDK-VV-015 (19)	1093.84	4.89	UO2F2	SPHERE	H2O	H2O	-	AL	ORNL3842
PDK15-20	PDK-VV-015 (20)	990.72	4.89	UO2F2	CYLINDER	H2O	H2O	-	SS304	ORNL3942
PDK15-23	PDK-VV-015 (23)	76.19	4.89	U-MET	S LATTICE	H2O	H2O	-	-	ORNL0242
PDK15-24	PDK-VV-015 (24)	231.34	4.89	U-MET	S LATTICE	H2O	H2O	-	-	ORNL0542
PDK15-25	PDK-VV-015 (25)	76.19	4.89	U-MET	S LATTICE	H2O	H2O/PLEXIGLAS	-	PB	ORNL0642
PDK15-27	PDK-VV-015 (27)	23.42	3.85	U-MET	S LATTICE	H2O	H2O	-	CS, SS304, WOOD	ORNL1442
PDK15-28	PDK-VV-015 (28)	41.19	3.85	U-MET	S LATTICE	H2O	H2O	-	CS, SS304, WOOD	ORNLA542
PDK15-29	PDK-VV-015 (29)	80.81	3.85	U-MET	S LATTICE	H2O	H2O	-	CS, SS304, WOOD	ORNL1642
PDK15-36	PDK-VV-015 (36)	99.02	5.74	UO2	S LATTICE	H2O	H2O	-	SS304	SAXTON56
PDK15-37	PDK-VV-015 (37)	259.53	5.74	UO2	S LATTICE	H2O	H2O	-	SS304	SAXTON79
PDK16-01	PDK-VV-016 (1)	496.00	4.98	UO2F2	CYLINDER	H2O	BARE	-	SS304	LEWIS01
PDK16-03	PDK-VV-016 (3)	645.76	4.89	UO2F2	CYLINDER	H2O	BARE	-	SS304	LEWIS03
PDK16-04	PDK-VV-016 (4)	733.74	4.89	UO2F2	CYLINDER	H2O	BARE	-	SS304	LEWIS04
PDK16-05	PDK-VV-016 (5)	244.60	4.89	U3O8	CUBOID	STEREOTEX	BARE	-	-	LEWIS05
PDK16-06	PDK-VV-016 (6)	395.00	4.89	U3O8	CUBOID	STEREOTEX	BARE	-	-	LEWIS06
PDK16-07	PDK-VV-016 (7)	503.50	4.89	U3O8	CUBOID	STEREOTEX	BARE	-	-	LEWIS07
PDK16-08	PDK-VV-016 (8)	756.99	4.89	U3O8	CUBOID	STEREOTEX	BARE	-	-	LEWIS08
PDK16-12	PDK-VV-016 (12)	158.62	4.89	U-MET	S LATTICE	H2O	H2O	-	-	LEWIS12
PDK16-13	PDK-VV-016 (13)	296.17	4.89	U-MET	S LATTICE	H2O	H2O	-	-	LEWIS13
PDK16-14	PDK-VV-016 (14)	158.62	4.89	U-MET	S LATTICE	H2O	H2O	-	-	LEWIS14

PDK16-15	PDK-VV-016 (15)	198.10	4.89	U-MET	S LATTICE	H2O	H2O	-	-	LEWIS15
PDK16-16	PDK-VV-016 (16)	62.52	4.89	U-MET	S LATTICE	H2O	H2O	-	-	LEWIS16
PDK17-01	PDK-VV-017 (CAB-01)	9.90	3.85	U-MET	S LATTICE	H2O	H2O	-	CS, SS304, WOOD	ORNL-B
PDK17-07	PDK-VV-017 (CAB-07)	6.54	3.85	U-MET	H LATTICE	H2O	H2O	-	CS, SS304, WOOD	ORNL-C
WAP931-1	WAPD-TM-931 (1)	278.66	1.29	UO2, U-MET	H LATTICE	H2O	H2O	-	AL	TRX-4
WAP931-2	WAPD-TM-931 (2)	429.55	1.29	U-MET	H LATTICE	H2O	H2O	-	AL	TRX-2
WAP931-3	WAPD-TM-931 (3)	251.10	1.29	U-MET	H LATTICE	H2O	H2O	-	AL	TRX-1
WAP931-4	WAPD-TM-931 (4)	256.82	1.29	UO2, U-MET	H LATTICE	H2O	H2O	-	AL	TRX-3
Y1858A02	Y-1858 (A2)	0.00	93.20	U-AL MET	CYLINDER	NONE	BARE	-	-	HH-A2
Y1858A03	Y-1858 (A3)	0.00	93.20	U-AL MET	CYLINDER	NONE	BARE	-	-	HH-A3
Y1858A06	Y-1858 (A6)	0.00	93.50	U-MET	HEMISPHERE	NONE	H2O	-	-	HH-A6
Y1858A07	Y-1858 (A7)	0.00	93.20	U-MET	CYLINDER	NONE	GRAPHITE	-	-	HH-A7
Y1858A08	Y-1858 (A8)	0.00	93.20	U-MET	CYLINDER	NONE	GRAPHITE	-	-	HH-A8
Y1858A09	Y-1858 (A9)	0.00	94.00	U-MET	CUBOID	NONE	NATURAL U	-	-	HH-A9
Y1858A10	Y-1858 (A10)	0.04	93.10	U-MET	SPHERE	NONE	OIL	-	-	HH-A10
Y1858A11	Y-1858 (A11)	0.04	93.10	U-MET	SPHERE	NONE	OIL	-	CS	HH-A11
Y1858A12	Y-1858 (A12)	0.04	93.10	U-MET	SPHERE	NONE	OIL	-	-	HH-A12
Y1858A13	Y-1858 (A13)	0.04	93.10	U-MET	SPHERE	NONE	OIL	-	CS	HH-A13
Y1858A14	Y-1858 (A14)	0.00	93.30	U-MET	CYLINDER	NONE	BARE	-	CU	HH-A14
Y1858A17	Y-1858 (A17)	490.00	4.98	UO2F2	SPHERE	H2O	BARE	-	SS	HH-A17
Y1858A18	Y-1858 (A18)	0.00	56.60	U-MET	CYLINDER	NONE	BARE	-	NATURAL U	HH-A18
Y1858A19	Y-1858 (A19)	0.00	75.10	U-MET	CYLINDER	NONE	BARE	-	NATURAL U	HH-A19
Y1858B01	Y-1858 (B1)	0.00	93.20	U-MET	CYLINDER	NONE	BARE	-	-	HH-B1
Y1858B02	Y-1858 (B2)	0.00	93.20	U-MET	CYLINDER	NONE	BARE	-	-	HH-B2
Y1858B03	Y-1858 (B3)	0.00	93.20	U-MET	GG*	NONE	BARE	-	-	HH-B3
Y1858B06	Y-1858 (B6)	0.00	93.20	U-MET	CYLINDER	NONE	BARE	-	SS	HH-B6
Y1858B07	Y-1858 (B7)	0.00	93.20	U-MET	CYLINDER	NONE	BARE	-	SS	HH-B7
Y1858B08	Y-1858 (B8)	0.00	93.20	U-MET	CYLINDER	NONE	BARE	-	-	HH-B8
Y1858B09	Y-1858 (B9)	0.00	93.20	U-MET	CYLINDER	NONE	PARAFFIN	-	-	HH-B9
Y1858B10	Y-1858 (B10)	0.00	93.20	U-MET	CYLINDER	PARAFFIN	PARAFFIN	-	-	HH-B10
Y1858B11	Y-1858 (B11)	2.33	93.20	U-MET	CYLINDER	PARAFFIN	PLEXIGLAS	-	-	HH-B11
Y1858B12	Y-1858 (B12)	5.77	93.20	U-MET	CYLINDER	PLEXIGLAS	PARAFFIN	-	-	HH-B12
Y1858B15	Y-1858 (B15)	45.18	93.20	UNH	CYLINDER	H2O	PLEXIGLAS	-	SS	HH-B15
Y1858B16	Y-1858 (B16)	0.00	93.20	U-MET	CYLINDER	GRAPHITE	POLY	-	CS	HH-B16

Y1948-01	Y-1948 (1)	420.00	1.40	UF-4	CUBOID	PARAFFIN	POLY	-	-	HH-1
Y1948-02	Y-1948 (2)	420.00	1.40	UF-4	CUBOID	PARAFFIN	POLY/STEEL	-	CS	HH-2
Y1948-03	Y-1948 (3)	420.00	1.40	UF-4	CUBOID	PARAFFIN	POLY/CONCRETE	-	SS	HH-3
Y1948-04	Y-1948 (4)	421.80	1.40	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-4
Y1948-05	Y-1948 (5)	421.80	1.40	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-5
Y1948-06	Y-1948 (6)	421.80	1.40	UF-4	CUBOID	PARAFFIN	BARE	-	-	HH-6
Y1948-07	Y-1948 (7)	425.00	1.40	UF-4	CUBOID	PARAFFIN	POLY	-	-	HH-7
Y1948-08	Y-1948 (8)	425.00	1.40	UF-4	CUBOID	PARAFFIN	POLY	-	-	HH-8
Y1948-09	Y-1948 (9)	500.00	1.40	UF-4	CUBOID	PARAFFIN	POLY	-	-	HH-9
Y1948-10	Y-1948 (10)	595.00	1.40	UF-4	CUBOID	PARAFFIN	POLY	-	-	HH-10
Y1948-33	Y-1948 (33)	488.00	4.98	UO2F2	CYLINDER	H2O	H2O	CD	CS, SS	HH-33
Y1948-34	Y-1948 (34)	488.00	4.98	UO2F2	CYLINDER	H2O	H2O	-	CS, SS	HH-34
Y1948-36	Y-1948 (36)	496.03	4.98	UO2F2	CYLINDER	H2O	BARE	-	SS	HH-36
Y1948-37	Y-1948 (37)	498.06	5.00	UO2F2	GG*	H2O	H2O	-	SS	HH-37
Y1948-38	Y-1948 (38)	511.65	5.00	UO2F2	GG*	H2O	H2O	-	AL	HH-38
Y1948-39	Y-1948 (39)	524.42	5.00	UO2F2	GG*	H2O	H2O	-	SS	HH-39
Y1948-40	Y-1948 (40)	572.90	5.00	UO2F2	GG*	H2O	H2O	-	AL	HH-40

7 Appendix B – Critical Benchmark Tabulated keff's

TABLE OF K-EFFECTIVE DATA (USER SKIP)									
NO	INPUT NAME	KEFF	SIGMA	HIST	SKIP	nå	DATE	ELAPSED	LOST
1	CR067401	1.02191	0.00072	1000000	0	-1	4/2/2004	4.18	1
2	CR067402	1.01976	0.00084	1000000	0	-3	4/2/2004	6.45	0
3	CR067403	1.01931	0.00093	1000000	0	-2	4/2/2004	2.82	0
4	CR067404	1.00951	0.00084	1000000	0	-1	4/2/2004	4.2	0
5	CR067405	1.00766	0.00083	1000000	0	-1	4/2/2004	6.42	0
6	CR067406	1.00609	0.00087	1000000	0	-2	4/2/2004	2.82	0
7	CR067407	1.00831	0.00079	1000000	0	-2	4/2/2004	4.53	0
8	CR067408	1.00311	0.00079	1000000	0	-2	4/2/2004	8.17	0
9	CR067409	1.00425	0.00075	1000000	0	-1	4/2/2004	7.33	0
10	CR067410	1.00124	0.00078	1000000	0	-2	4/2/2004	3.28	0
11	CR610242	0.97974	0.00045	1000000	0	-4	4/2/2004	9.68	2
12	CR610243	0.98108	0.00042	1000000	0	-2	4/2/2004	9.82	2
13	CR610244	0.98106	0.00042	1000000	0	-2	4/2/2004	9.83	2
14	CR636131	0.98129	0.00046	1000000	0	-4	4/2/2004	10.62	1
15	CR636132	0.98140	0.00045	1000000	0	-2	4/2/2004	10.67	1
16	CR636133	0.98255	0.00040	1000000	0	-3	4/2/2004	9.65	1
17	HMF01-01	1.01710	0.00059	1000000	0	-1	4/2/2004	0.3	0
18	HMF04-01	1.01445	0.00081	1000000	0	-2	4/2/2004	16.17	0
19	HMF23-06	1.01073	0.00080	1000000	0	-2	4/2/2004	8.87	16
20	HMF23-29	1.01360	0.00076	1000000	0	-2	4/2/2004	9.15	12
21	HST01-02	0.99530	0.00101	1000000	0	0	4/2/2004	1.4	0
22	HST07-04	1.01336	0.00096	1000000	0	0	4/2/2004	10.87	62
23	HST08-04	1.00875	0.00095	1000000	0	0	4/2/2004	18.08	25
24	HST13-01	0.99247	0.00056	1000000	0	0	4/2/2004	8.32	0
25	HST14-01	0.99016	0.00086	1000000	0	0	4/2/2004	6.37	0
26	HST14-02	1.00629	0.00076	1000000	0	0	4/2/2004	6.87	0
27	HST14-03	1.01498	0.00070	1000000	0	0	4/2/2004	6.37	0
28	HST15-01	0.99568	0.00096	1000000	0	0	4/2/2004	3.98	2
29	HST15-02	0.98801	0.00096	1000000	0	0	4/2/2004	5.87	0
30	HST15-03	1.00364	0.00072	1000000	0	0	4/2/2004	4.1	0
31	HST15-04	1.01161	0.00076	1000000	0	0	4/2/2004	5.73	0
32	HST15-05	1.00513	0.00065	1000000	0	0	4/2/2004	5.25	0
33	HST16-01	0.98911	0.00101	1000000	0	0	4/2/2004	5.08	0
34	HST16-02	1.00271	0.00077	1000000	0	0	4/2/2004	5.35	1
35	HST16-03	1.02120	0.00077	1000000	0	0	4/2/2004	4.93	2
36	HST17-01	0.98725	0.00097	1000000	0	0	4/2/2004	6.47	0
37	HST17-02	0.97592	0.00099	1000000	0	0	4/2/2004	3.53	1
38	HST17-03	0.97491	0.00105	1000000	0	0	4/2/2004	4.98	0
39	HST17-04	0.99427	0.00084	1000000	0	0	4/2/2004	7.4	0
40	HST17-05	1.00194	0.00076	1000000	0	0	4/2/2004	7.2	0
41	HST17-06	0.99788	0.00092	1000000	0	0	4/2/2004	3.18	2
42	HST17-07	1.00286	0.00077	1000000	0	0	4/2/2004	5.18	0
43	HST17-08	0.99870	0.00068	1000000	0	0	4/2/2004	2.88	4
44	HST18-01	0.98647	0.00098	1000000	0	0	4/2/2004	6.38	0
45	HST18-02	0.98460	0.00093	1000000	0	0	4/2/2004	3.37	0
46	HST18-03	0.98690	0.00103	1000000	0	0	4/2/2004	4.62	0
47	HST18-04	0.99474	0.00082	1000000	0	0	4/2/2004	7.57	0

48	HST18-05	0.99223	0.00086	1000000	0	0	4/2/2004	3.15	2
49	HST18-06	0.98943	0.00100	1000000	0	0	4/5/2004	4.78	1
50	HST18-07	1.00282	0.00071	1000000	0	0	4/2/2004	6.72	0
51	HST18-08	1.00738	0.00086	1000000	0	0	4/2/2004	2.8	1
52	HST18-09	1.00227	0.00075	1000000	0	0	4/2/2004	4.53	0
53	HST18-10	1.01831	0.00075	1000000	0	0	4/2/2004	2.48	2
54	HST18-11	1.02098	0.00074	1000000	0	0	4/2/2004	4.5	0
55	HST18-12	1.01250	0.00064	1000000	0	0	4/2/2004	4.1	1
56	HST19-01	0.99654	0.00102	1000000	0	0	4/2/2004	6.17	1
57	HST19-02	0.99811	0.00088	1000000	0	0	4/2/2004	7.05	0
58	HST19-03	0.99335	0.00078	1000000	0	0	4/2/2004	6.98	0
59	HST21-16	0.99026	0.00106	1000000	0	0	4/2/2004	8.6	52
60	HST21-22	1.00423	0.00089	1000000	0	0	4/2/2004	17.07	64
61	HST21-23	0.99399	0.00095	1000000	0	0	4/2/2004	9.62	31
62	HST21-26	0.99186	0.00112	1000000	0	0	4/2/2004	11.23	63
63	HST21-32	1.00064	0.00091	1000000	0	0	4/2/2004	11.12	72
64	HST40-11	1.00165	0.00090	1000000	0	0	4/2/2004	1.65	6
65	HST43-03	0.99608	0.00059	1000000	0	0	4/2/2004	7.83	0
66	IMF02-01	1.01717	0.00066	1000000	0	-8	4/2/2004	1.53	20
67	IMF07-01	1.00966	0.00054	1000000	0	-11	4/2/2004	2.42	84
68	IMF10-01	1.00800	0.00048	1000000	0	-14	4/2/2004	3.12	3670
69	LCT09-01	0.99135	0.00081	1000000	0	-1	4/5/2004	10.63	1
70	LCT09-06	0.99300	0.00078	1000000	0	-1	4/2/2004	9.73	0
71	LCT09-08	0.99134	0.00074	1000000	0	0	4/2/2004	9.75	1
72	LCT09-09	0.99248	0.00077	1000000	0	-1	4/2/2004	9.47	2
73	LCT09-14	0.98965	0.00071	1000000	0	0	4/2/2004	10.08	547
74	LCT09-15	0.99263	0.00072	1000000	0	-2	4/2/2004	9.93	442
75	LCT09-16	0.99191	0.00069	1000000	0	-2	4/2/2004	9.7	0
76	LCT09-17	0.99179	0.00077	1000000	0	0	4/2/2004	9.63	0
77	LCT09-18	0.98992	0.00076	1000000	0	0	4/2/2004	9.72	0
78	LCT09-19	0.99261	0.00084	1000000	0	-1	4/2/2004	9.63	2
79	LCT09-20	0.99241	0.00083	1000000	0	-1	4/2/2004	9.67	0
80	LCT09-21	0.99245	0.00078	1000000	0	-1	4/2/2004	9.62	0
81	LCT09-22	0.99089	0.00077	1000000	0	-1	4/2/2004	9.68	0
82	LCT09-23	0.99374	0.00079	1000000	0	-1	4/2/2004	9.58	1
83	LCT09-24	0.99054	0.00075	1000000	0	0	4/2/2004	10.43	0
84	LCT09-27	0.99158	0.00071	1000000	0	-1	4/2/2004	10.4	2
85	LCT10-08	0.99115	0.00069	1000000	0	-1	4/2/2004	8.47	354
86	LCT10-09	1.00174	0.00078	1000000	0	-1	4/2/2004	7.68	0
87	LCT10-14	1.00066	0.00074	1000000	0	0	4/2/2004	9	0
88	LCT16-21	0.99157	0.00066	1000000	0	-1	4/2/2004	10.73	3
89	LCT16-22	0.99292	0.00057	1000000	0	-3	4/2/2004	10.73	4
90	LCT16-23	0.99215	0.00059	1000000	0	-2	4/2/2004	10.67	3
91	LCT16-24	0.99291	0.00067	1000000	0	0	4/2/2004	10.73	3
92	LCT16-26	0.99247	0.00063	1000000	0	-2	4/2/2004	10.73	6
93	LCT16-31	0.99143	0.00063	1000000	0	-2	4/3/2004	11.28	7
94	LCT16-32	0.99164	0.00061	1000000	0	0	4/3/2004	11.3	6
95	LCT17-01	0.99875	0.00063	1000000	0	0	4/3/2004	10.68	6
96	LCT17-04	0.99154	0.00061	1000000	0	-3	4/3/2004	9.35	638
97	LCT17-10	0.99623	0.00062	1000000	0	-2	4/3/2004	9.45	7
98	LCT17-15	0.99659	0.00060	1000000	0	-1	4/3/2004	10.13	14
99	LCT18-09	0.99708	0.00082	1000000	0	-1	4/3/2004	19.9	18
100	LCT19-01	1.01024	0.00077	1000000	0	0	4/3/2004	28.62	12

101	LCT19-02	1.00297	0.00072	1000000	0	-1	4/3/2004	24.18	7
102	LCT19-03	0.99985	0.00056	1000000	0	-1	4/3/2004	19.63	7
103	LCT20-01	0.98927	0.00080	1000000	0	-1	4/3/2004	19.58	17
104	LCT20-02	0.99366	0.00069	1000000	0	-1	4/3/2004	18.67	5
105	LCT20-03	0.99612	0.00071	1000000	0	0	4/3/2004	18.72	4
106	LCT20-04	0.99622	0.00073	1000000	0	-2	4/3/2004	18.7	3
107	LCT20-05	0.99641	0.00079	1000000	0	0	4/3/2004	18.93	6
108	LCT20-06	0.99510	0.00080	1000000	0	-1	4/3/2004	19	3
109	LCT20-07	0.99649	0.00078	1000000	0	0	4/3/2004	21.13	3
110	LCT21-01	1.00338	0.00065	1000000	0	0	4/3/2004	18.28	6
111	LCT21-02	1.00455	0.00063	1000000	0	-1	4/3/2004	18.05	6
112	LCT21-03	1.00366	0.00074	1000000	0	-1	4/3/2004	17.9	3
113	LCT21-04	1.00616	0.00056	1000000	0	-2	4/3/2004	16.27	3
114	LCT21-05	1.00509	0.00065	1000000	0	0	4/3/2004	16.18	5
115	LCT21-06	1.00480	0.00053	1000000	0	-1	4/3/2004	16.08	2
116	LCT22-01	0.99713	0.00081	1000000	0	-1	4/3/2004	31.23	12
117	LCT22-02	0.99994	0.00080	1000000	0	-1	4/3/2004	26.4	5
118	LCT22-03	1.00160	0.00081	1000000	0	0	4/3/2004	22.7	3
119	LCT22-04	1.00119	0.00078	1000000	0	0	4/3/2004	21.12	0
120	LCT22-05	0.99729	0.00077	1000000	0	-1	4/3/2004	20.62	1
121	LCT22-06	0.99367	0.00062	1000000	0	0	4/3/2004	20.7	3
122	LCT22-07	0.99608	0.00058	1000000	0	-1	4/3/2004	20.82	1
123	LCT23-01	0.99049	0.00074	1000000	0	-1	4/3/2004	21.4	37
124	LCT23-02	0.99179	0.00080	1000000	0	0	4/3/2004	21.33	19
125	LCT23-03	0.99244	0.00074	1000000	0	0	4/3/2004	21.75	21
126	LCT23-04	0.99543	0.00073	1000000	0	-1	4/3/2004	21.62	4
127	LCT23-05	0.99576	0.00074	1000000	0	0	4/3/2004	22.22	10
128	LCT23-06	0.99600	0.00075	1000000	0	0	4/3/2004	22.53	6
129	LCT24-01	0.99635	0.00066	1000000	0	-3	4/3/2004	28.77	25
130	LCT24-02	0.99937	0.00077	1000000	0	1	4/3/2004	41.48	44
131	LCT25-01	0.98152	0.00078	1000000	0	-2	4/3/2004	33.32	12
132	LCT25-02	0.98801	0.00072	1000000	0	-1	4/3/2004	28.2	4
133	LCT25-03	0.99152	0.00068	1000000	0	0	4/3/2004	23.9	3
134	LCT25-04	0.99459	0.00063	1000000	0	0	4/3/2004	22.4	2
135	LCT26-01	0.99490	0.00080	1000000	0	-2	4/3/2004	21.3	13
136	LCT26-02	0.99391	0.00078	1000000	0	-2	4/3/2004	24.03	22
137	LCT26-03	0.99880	0.00078	1000000	0	-1	4/3/2004	27.8	30
138	LCT26-04	0.99573	0.00073	1000000	0	-3	4/3/2004	30.77	45
139	LCT26-05	0.99557	0.00080	1000000	0	-1	4/3/2004	250.98	27
140	LCT26-06	0.99596	0.00076	1000000	0	-1	4/4/2004	269.75	43
141	LCT33-01	0.99444	0.00063	1000000	0	0	4/4/2004	5.53	0
142	LCT33-05	0.99524	0.00059	1000000	0	0	4/4/2004	6.2	0
143	LCT33-09	0.99483	0.00061	1000000	0	-2	4/4/2004	6.62	0
144	LCT33-10	0.99257	0.00064	1000000	0	-1	4/4/2004	6.93	0
145	LCT33-13	0.99190	0.00059	1000000	0	0	4/4/2004	7.18	0
146	LCT33-14	0.98592	0.00044	1000000	0	0	4/4/2004	7.9	0
147	LCT33-17	1.00477	0.00067	1000000	0	0	4/4/2004	6.23	0
148	LCT33-18	1.00512	0.00073	1000000	0	0	4/4/2004	6.2	0
149	LCT33-19	1.00446	0.00073	1000000	0	-1	4/4/2004	6.18	0
150	LCT33-20	1.00462	0.00070	1000000	0	0	4/4/2004	6.17	0
151	LCT33-21	1.00502	0.00073	1000000	0	-1	4/4/2004	6.15	0
152	LCT33-22	1.00543	0.00067	1000000	0	0	4/4/2004	7.1	0
153	LCT33-23	0.99357	0.00066	1000000	0	-3	4/4/2004	2.67	0

154	LCT33-26	0.99613	0.00064	1000000	0	-2	4/4/2004	3.07	0
155	LCT33-42	0.99102	0.00056	1000000	0	-2	4/4/2004	4.6	0
156	LCT33-45	0.98490	0.00047	1000000	0	-1	4/4/2004	6.52	0
157	LCT33-47	1.00755	0.00072	1000000	0	-3	4/4/2004	2.23	0
158	LCT33-48	1.00845	0.00075	1000000	0	-1	4/4/2004	2.25	0
159	LCT33-49	1.00658	0.00073	1000000	0	-2	4/4/2004	2.22	0
160	LCT33-50	1.00845	0.00072	1000000	0	-1	4/4/2004	2.8	0
161	LCT33-51	1.00938	0.00078	1000000	0	0	4/4/2004	2.82	0
162	LCT33-52	1.00444	0.00075	1000000	0	-1	4/4/2004	2.78	0
163	LCT49-01	0.99607	0.00071	1000000	0	-2	4/4/2004	9.47	7
164	LCT49-02	0.99485	0.00070	1000000	0	-3	4/4/2004	9.45	17
165	LCT49-03	0.99684	0.00073	1000000	0	-1	4/4/2004	9.12	8
166	LCT49-04	0.99629	0.00069	1000000	0	-3	4/4/2004	8.92	14
167	LCT49-05	0.99541	0.00073	1000000	0	-2	4/5/2004	9.92	8
168	LCT49-06	0.99806	0.00069	1000000	0	-3	4/4/2004	9.05	8
169	LCT49-07	0.99463	0.00072	1000000	0	-3	4/4/2004	9.3	8
170	LCT49-08	0.99390	0.00075	1000000	0	-2	4/4/2004	8.9	4
171	LCT49-09	0.99446	0.00078	1000000	0	-1	4/4/2004	9.07	13
172	LCT49-10	0.99571	0.00074	1000000	0	-2	4/4/2004	9	9
173	LCT49-11	0.99544	0.00079	1000000	0	-3	4/4/2004	9.03	3
174	LCT49-12	0.99629	0.00078	1000000	0	-2	4/4/2004	8.65	8
175	LCT49-13	0.99750	0.00077	1000000	0	-3	4/4/2004	9.33	4
176	LCT49-14	0.99678	0.00076	1000000	0	-1	4/4/2004	9.15	4
177	LCT49-15	0.99814	0.00066	1000000	0	-2	4/4/2004	9.1	6
178	LCT49-16	0.99612	0.00073	1000000	0	-2	4/4/2004	9.38	0
179	LCT49-17	0.99594	0.00072	1000000	0	-3	4/4/2004	8.93	2
180	LST01-01	1.00565	0.00077	1000000	0	0	4/4/2004	3.75	0
181	LST03-01	0.99217	0.00069	1000000	0	0	4/4/2004	6.03	0
182	LST03-02	0.98975	0.00060	1000000	0	0	4/4/2004	6.7	0
183	LST03-03	0.99486	0.00059	1000000	0	-1	4/4/2004	5.68	0
184	LST03-04	0.98805	0.00065	1000000	0	0	4/4/2004	6.87	0
185	LST03-05	0.99128	0.00056	1000000	0	0	4/4/2004	8.55	0
186	LST03-06	0.99058	0.00048	1000000	0	0	4/4/2004	7.3	0
187	LST03-07	0.99025	0.00040	1000000	0	1	4/4/2004	8.92	0
188	LST03-08	0.99397	0.00041	1000000	0	-1	4/4/2004	10.03	0
189	LST03-09	0.99158	0.00040	1000000	0	0	4/4/2004	8.45	0
190	LST04-01	0.99503	0.00062	1000000	0	0	4/4/2004	8.25	140
191	P6205-01	1.01246	0.00079	1000000	0	-2	4/4/2004	14.57	53
192	PB255-02	0.99541	0.00059	1000000	0	-3	4/4/2004	7.52	0
193	PB255-04	0.98789	0.00052	1000000	0	-2	4/4/2004	6.55	0
194	PDK05-01	1.01509	0.00063	1000000	0	-6	4/4/2004	1.08	8
195	PDK06-01	1.00024	0.00060	1000000	0	-5	4/4/2004	1.18	8
196	PDK07-01	1.01171	0.00069	1000000	0	-5	4/4/2004	1.3	9
197	PDK08-01	1.02442	0.00062	1000000	0	-5	4/4/2004	2.57	19
198	PDK09-01	1.02218	0.00064	1000000	0	-4	4/4/2004	2.67	16
199	PDK10-01	1.01651	0.00055	1000000	0	-4	4/4/2004	3.33	30
200	PDK11-01	1.02156	0.00059	1000000	0	-4	4/4/2004	2.77	34
201	PDK15-01	0.98592	0.00065	1000000	0	-1	4/4/2004	7.05	273
202	PDK15-02	0.99131	0.00055	1000000	0	0	4/4/2004	8.22	161
203	PDK15-03	0.98978	0.00055	1000000	0	-2	4/4/2004	7.98	127
204	PDK15-04	0.98695	0.00058	1000000	0	-1	4/4/2004	8.08	97
205	PDK15-09	0.97584	0.00073	1000000	0	-1	4/4/2004	8.23	0
206	PDK15-10	0.99021	0.00071	1000000	0	0	4/4/2004	8.68	0

207	PDK15-11	0.99882	0.00064	1000000	0	-1	4/4/2004	9.42	0
208	PDK15-13	0.98761	0.00071	1000000	0	-1	4/4/2004	3.73	0
209	PDK15-14	0.98827	0.00064	1000000	0	0	4/4/2004	4.82	0
210	PDK15-15	0.98756	0.00060	1000000	0	1	4/4/2004	7.38	0
211	PDK15-16	0.99222	0.00060	1000000	0	0	4/4/2004	6.27	0
212	PDK15-17	0.99816	0.00067	1000000	0	0	4/4/2004	8.25	0
213	PDK15-18	0.99380	0.00062	1000000	0	0	4/4/2004	8.65	0
214	PDK15-19	0.99188	0.00055	1000000	0	0	4/4/2004	11.02	0
215	PDK15-20	0.99246	0.00057	1000000	0	0	4/4/2004	9.08	0
216	PDK15-23	0.99081	0.00084	1000000	0	-3	4/4/2004	7.55	1099
217	PDK15-24	0.98212	0.00082	1000000	0	-1	4/4/2004	7.77	505
218	PDK15-25	0.99922	0.00079	1000000	0	-3	4/4/2004	7.13	1401
219	PDK15-27	0.99278	0.00070	1000000	0	-5	4/4/2004	22.4	1717
220	PDK15-28	0.99011	0.00076	1000000	0	-5	4/4/2004	18.93	1191
221	PDK15-29	0.98427	0.00069	1000000	0	-5	4/4/2004	18.67	698
222	PDK15-36	0.99425	0.00079	1000000	0	0	4/4/2004	14.13	13
223	PDK15-37	0.99500	0.00072	1000000	0	0	4/4/2004	13.1	3
224	PDK16-01	0.99858	0.00075	1000000	0	0	4/4/2004	3.42	1
225	PDK16-03	0.98738	0.00074	1000000	0	-1	4/4/2004	4.35	0
226	PDK16-04	0.98808	0.00067	1000000	0	0	4/4/2004	4.83	0
227	PDK16-05	0.97931	0.00086	1000000	0	-1	4/4/2004	2.57	0
228	PDK16-06	0.99743	0.00083	1000000	0	-1	4/4/2004	3.17	0
229	PDK16-07	0.99113	0.00073	1000000	0	0	4/4/2004	3.72	0
230	PDK16-08	1.00020	0.00065	1000000	0	0	4/4/2004	5.08	0
231	PDK16-12	0.99255	0.00077	1000000	0	-2	4/4/2004	8.32	563
232	PDK16-13	0.98503	0.00075	1000000	0	0	4/4/2004	8.62	384
233	PDK16-14	0.99518	0.00083	1000000	0	-2	4/4/2004	8.32	604
234	PDK16-15	0.98719	0.00078	1000000	0	-2	4/4/2004	8.53	410
235	PDK16-16	0.99420	0.00085	1000000	0	-2	4/4/2004	7.98	841
236	PDK17-01	0.99715	0.00063	1000000	0	-9	4/4/2004	11.77	2250
237	PDK17-07	0.98418	0.00064	1000000	0	-8	4/4/2004	10.82	2914
238	WAP931-1	0.99566	0.00043	1000000	0	-3	4/4/2004	279.48	114
239	WAP931-2	0.99168	0.00052	1000000	0	-4	4/4/2004	10	1557
240	WAP931-3	0.99184	0.00055	1000000	0	-5	4/4/2004	10.42	2307
241	WAP931-4	0.99563	0.00053	1000000	0	-3	4/4/2004	246.9	538
242	Y1858A02	1.01558	0.00060	1000000	0	-4	4/4/2004	0.33	0
243	Y1858A03	1.01408	0.00057	1000000	0	-4	4/4/2004	0.35	0
244	Y1858A06	1.01178	0.00085	1000000	0	-2	4/4/2004	10.48	29
245	Y1858A07	1.01326	0.00092	1000000	0	-1	4/4/2004	1.67	1
246	Y1858A08	1.01275	0.00075	1000000	0	-3	4/4/2004	0.65	1
247	Y1858A09	1.01282	0.00080	1000000	0	6	4/4/2004	2.32	85
248	Y1858A10	1.00932	0.00079	1000000	0	0	4/4/2004	11.62	0
249	Y1858A11	1.00787	0.00083	1000000	0	-2	4/4/2004	11.9	0
250	Y1858A12	1.01138	0.00083	1000000	0	-1	4/4/2004	11.9	5
251	Y1858A13	1.00501	0.00083	1000000	0	-2	4/4/2004	12.13	2
252	Y1858A14	1.03555	0.00063	1000000	0	-2	4/4/2004	0.42	166
253	Y1858A17	0.99594	0.00081	1000000	0	-1	4/4/2004	3.27	0
254	Y1858A18	1.00980	0.00061	1000000	0	-5	4/4/2004	0.5	2
255	Y1858A19	1.02096	0.00064	1000000	0	-5	4/4/2004	0.57	1
256	Y1858B01	1.01265	0.00067	1000000	0	-2	4/4/2004	1.08	0
257	Y1858B02	1.01743	0.00064	1000000	0	-3	4/4/2004	0.33	0
258	Y1858B03	0.99536	0.00063	1000000	0	-3	4/4/2004	1.77	0
259	Y1858B06	1.00278	0.00059	1000000	0	-2	4/4/2004	2.92	0

260	Y1858B07	1.01111	0.00063	1000000	0	-3	4/4/2004	1.75	0
261	Y1858B08	1.01288	0.00063	1000000	0	-5	4/4/2004	0.5	0
262	Y1858B09	1.00498	0.00076	1000000	0	-1	4/5/2004	11.68	0
263	Y1858B10	1.00510	0.00080	1000000	0	-1	4/5/2004	11.68	0
264	Y1858B11	1.01527	0.00071	1000000	0	-1	4/5/2004	0.95	0
265	Y1858B12	1.01086	0.00075	1000000	0	-2	4/5/2004	12.23	0
266	Y1858B15	1.03017	0.00094	1000000	0	0	4/5/2004	6.22	0
267	Y1858B16	1.01955	0.00083	1000000	0	-2	7/30/2004	27.35	0
268	Y1948-01	0.99016	0.00047	1000000	0	-1	4/5/2004	5.2	0
269	Y1948-02	0.99151	0.00050	1000000	0	-2	4/5/2004	5.3	0
270	Y1948-03	0.99220	0.00048	1000000	0	-1	4/5/2004	5.3	0
271	Y1948-04	0.98900	0.00055	1000000	0	-3	4/5/2004	3.67	0
272	Y1948-05	0.98972	0.00051	1000000	0	-2	4/5/2004	3.68	0
273	Y1948-06	0.98865	0.00053	1000000	0	-4	4/5/2004	3.65	0
274	Y1948-07	0.99233	0.00052	1000000	0	-2	7/30/2004	11.8	0
275	Y1948-08	0.99236	0.00054	1000000	0	-3	7/30/2004	11.68	0
276	Y1948-09	0.98604	0.00045	1000000	0	0	4/5/2004	5.73	0
277	Y1948-10	0.98433	0.00047	1000000	0	-1	4/5/2004	5.97	0
278	Y1948-33	0.99375	0.00073	1000000	0	0	4/5/2004	5.68	1
279	Y1948-34	0.99657	0.00072	1000000	0	-1	4/5/2004	6.78	1
280	Y1948-36	0.99019	0.00076	1000000	0	0	4/5/2004	3.37	0
281	Y1948-37	0.99694	0.00070	1000000	0	0	4/5/2004	59.25	0
282	Y1948-38	0.99788	0.00074	1000000	0	0	4/5/2004	31.97	0
283	Y1948-39	0.99075	0.00071	1000000	0	0	4/5/2004	61.13	0
284	Y1948-40	0.99673	0.00067	1000000	0	0	4/5/2004	32.37	0

ATTACHMENT 5

This Attachment contains GNF-A Proprietary Information and is being withheld.

ATTACHMENT 6

These are replacement / new pages to the existing consolidated application. They are identified on the footer showing the date of the change and the revision number. The location of each change is shown with an asterisk in the right hand margin of the page.

The following is an explanation of what changed on the existing pages.

1) Page 5-A3 – Corrected the carbon and oxygen values. See NRC RAI 6-6 question on Attachment 3, page 9 of 12. Page 5-A4 did not change, but is provided on the back side of page 5-A3.

2) Page 7-J(a)1 – New page added

3) Page 8-J(a)1 – New page added

4) Index, Page iii, Revision 2, – Added wording "through 7-2" and "through 8-2"

5) Page 7-1 and 8-1 did not change, but are provided on the front side of each back-to-back sheet. Page 7-2 of Section 7.0 and page 8-2 of Section 8.0 – Added Appendix J(a) and the details of that added Appendix.

Please remove the existing pages and replace them with those provided in this Attachment.

Table A-1

NUMBER DENSITIES USED DURING MERIT CALCULATIONS

Fuel – 3.2% U-235 Enrichment, $\rho(UO_2) = 10.41$ gm/cc

N (U-235) = 0.00075258 (atoms/cm – barn)
N (U-238) = 0.022478
N (O) = 0.04646099
N (Zr) = 0.038373 (smeared on gap region)

Inner Container – S/S 304

N (Fe) = 0.05879965
N (Ni) = 0.000815469
N (Cr) = 0.01630939
N (Mn) = 0.00171677
N (Si) = 0.00085839

Polyethylene Inserts – Assuming Density = 0.965 gm/cc

N (H) = 0.082938
N (C) = 0.041469

Water

N (H) = 0.06688
N (O) = 0.03344

Honeycomb - $\rho = 4.92$ lb/ft^3 (range 4.9-5.1 lb/ft^3)*
Assuming* 33% ($C_6H_5OH\text{-}CH_2O$)
63.65% ($C_6H_{10}O_5$)x
2.68% lignins ($C_{10}H_{15}O_3$)x

N (H) = 0.0030131
N (C) = 0.0020929
N (O) = 0.00122197

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*Data obtained from Mr. J. Pollick, Vertical Honeycomb Co., Englewood, Colorado

Table A-1 (Continued)

Ethafoam (expanded polyethylene)
Assuming* 2.2 lb/ft^3 = 0.0352 gm/cc

N (H) = 0.003030
N (C) = 0.001515

Wood – Assuming density = 0.5 gm/cc (soft wood)**
7% H_2O
65% cellulose$(C_6H_{10}O_5)x$
28% lignins $(C_{10}H_{15}O_3)x$

N (H) = 0.021334
N (C) = 0.011858
N (O) = 0.0085933

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*Data obtained from Hibco Plastics Co., Yadkinville, N. C.

**Based on data obtained during telecon with Weyerhauser Co., Plymouth, N. C., with staff member

SECTION 7.0

APPENDIX J(a)

Non-proprietary version of the criticality safety analysis for use with the GNF2 Fuel Design in 10x10 design assemblies dated November 2004

and

the GEMER Monte Carlo Validation Report: RA-3 Analysis with GNF2 Fuel dated November 2004. This document does not contain proprietary information.

This submittal was made 12/03/04.

SECTION 8.0

APPENDIX J(a)

Proprietary version of the criticality safety analysis for use with the GNF2 Fuel Design in 10x10 design assemblies. This submittal was made 12/03/04.

Page(s)

6.0 OPERATING PROCEDURES, ACCEPTANCE TESTS, AND MAINTENANCE PROGRAM 6-1

6.1 Operating Procedures - Fuel Assemblies 6-1 through 6-3

6.2 Operating Procedures - Loose Rods in Channel or Pipe 6-3 through 6-5

6.3 Acceptance Tests 6-5 through 6-7

6.4 Maintenance Program 6-7 through 6-10

7.0 NON-PROPRIETARY VERSION OF THE CRITICALITY SAFETY INFORMATION 7-1 through 7-2 * *

Appendices A through L

8.0 PROPRIETARY VERSION OF THE CRITICALITY SAFETY INFORMATION 8-1 through 8-2 * *

Appendices A through L

7.0 NON-PROPRIETARY VERSION OF THE CRITICALITY SAFETY INFORMATION

This section contains non-proprietary versions of the criticality safety information for the contents allowed in the certificate of compliance.

Contents from the March 15, 1982, submittal were page and drawing revisions to the March 1, 1982, application and are included in Sections 1.0, 2.0, 6.0, and the drawings of this application.

Appendix A: Non-proprietary version of the analysis for the 8x8 fuel design containing maximum enrichments of up to 5% U^{235} and taking into account the effects of pellet cladding dimensions and nuclear poison specifications. The original submittal was made April 29, 1986.

Appendix B: Non-proprietary version of the July 22, 1988, submittal to cut out a small section of ethafoam in the RA inner container.

Appendix C: Non-proprietary version of the 9x9 fuel design, one assembly, per RA container. The original submittal was made July 12, 1989.

Appendix D: Non-proprietary version for the 8x8 fuel design showing safety with various gad rod locations. The original submittal was made August 24, 1990, and included reference to the April 29, 1986, submittal.

Appendix E: Non-proprietary version for a specific 9x9 fuel assembly design specification. The original submittals were made April 16, April 17, and May 7, 1991.

Appendix F: Non-proprietary version for a specific 9x9 fuel assembly design specification. The original submittals were made August 22 and October 29, 1991.

Appendix G: Non-proprietary version for using cluster separators in 9x9 design fuel assemblies. The submittal was made 3/18/93.

Appendix H: Non-proprietary criticality safety analysis for using cluster separators in 8x8 design fuel assemblies. The submittal was made 6/27/95.

Appendix I: Non-proprietary criticality safety analysis for using cluster separators in 9x9 design fuel assemblies. The submittal was made 6/27/95.

Appendix J: Non-proprietary criticality safety analysis for using cluster separators in 10x10 design fuel assemblies. The submittal was made 6/27/95.

Appendix J(a): Non-proprietary versions of the *
criticality safety analysis and the GEMER Monte Carlo *
Validation Report for use with the GNF2 Fuel Design *
in 10x10 design assemblies. This submittal was made *
12/03/04.

Appendix K: Non-proprietary version of the NRC’s request for additional information dated 10/19/95 and GE’s responses dated 11/1/95 and 11/3/95.

Appendix L: Non-proprietary version of the criticality safety analysis for the shipment of loose rods in the RA packaging. The submittals were made 6/5/98, 7/1/98 and 7/21/98.

8.0 PROPRIETARY VERSION OF THE CRITICALITY SAFETY INFORMATION

This section contains **proprietary** versions of the criticality safety information for the contents allowed in the certificate of compliance.

Appendix A: Proprietary version of the analysis of the 8x8 fuel design containing maximum enrichments of up to 5% U^{235} and taking into account the effects of pellet and cladding dimensions and nuclear poison specifications. The original submittal was made April 29, 1986.

Appendix B: There is no proprietary information contained in the July 22, 1988, submittal. The submittal allows for cutting out a small section of ethafoam in the inner RA container. This note is intended to maintain Appendices sequence correlation between Sections 7.0 and 8.0 of this application.

Appendix C: There is no proprietary information contained in the July 12, 1989, submittal for the 9x9 fuel design, one assembly per RA container. This note is intended to maintain Appendices correlation between Sections 7.0 and 8.0 of this application.

Appendix D: Proprietary version for the 8x8 fuel design showing safety with various gad rod locations. The original submittal was made August 24, 1990, and included reference to the April 29, 1986, submittal.

Appendix E: Proprietary version for a specific 9x9 fuel assembly design specification. The original submittals were made April 16, 17, and May 7, 1991.

Appendix F: Proprietary version for a specific 9x9 fuel assembly design specification. The original submittals were made August 22 and October 29, 1991.

Appendix G: Proprietary version for using cluster separators in 9x9 design fuel assemblies. The submittal was made 3/18/93.

Appendix H: Proprietary criticality safety analysis for using cluster separators in 8x8 design fuel assemblies. The submittal was made 6/27/95.

Appendix I: Proprietary criticality safety analysis for using cluster separators in 9x9 design fuel assemblies. The submittal was made 6/27/95.

Appendix J: Proprietary criticality safety analysis for using cluster separators in 10x10 design fuel assemblies. The submittal was made 6/27/95.

Appendix J(a): Proprietary version of the criticality safety analysis for use with the GNF2 Fuel Design in 10x10 design assemblies. This submittal was made 12/03/04. * * * *

Appendix K: Proprietary version of the NRC’s request for additional information dated 10/19/95, and GE’s responses dated 11/1/95 and 11/3/95.

Appendix L: Proprietary version of the criticality safety analysis for the shipment of loose rods in the RA packaging. The submittals were made 6/5/98, 7/1/98 and 7/21/98.