## 6.0 OPERATING PROCEDURES, ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

### 6.1 Operating Procedures

The following describes procedures for loading the fuel assemblies into the RA packaging.

6.1.1 Verification is performed to assure that the fuel assemblies have been completed satisfactorily with all acceptance criteria.

6.1.2 Inspect the fuel assemblies to assure they are visually clean (i.e., free of oil, rust, foreign particles), comply with assembly requirements and that the polyethylene sheath is open at both ends and does not exceed the length of the assembly.

6.1.3 Prior to placing fuel assemblies into the RA inner, visually inspect RA inner for overall physical condition including:

- Handles and brackets
- Exterior welds
- Foam padding
- Gasket
- Cleanliness

6.1.4 Raise the RA inner to the vertical position.

6.1.5 Place fuel assemblies into RA inner and secure with hold down bars (lower tie plate of assembly fits into a fixture within the RA inner to assure positioning).

6.1.6 Lower RA inner to the horizontal position and remove the hold down bars.

6.1.7 Inspect loaded RA inner prior to putting on lid to assure the polyethylene sheath does not extend beyond the ends of the assembly and the ends of the sheath are left open.

6.1.8 Verify that the correct assemblies have been loaded into the RA inner.

6.1.9 Bolt lid and end cap onto RA inner.

6.1.10 Apply tampersafe seals to RA inner.

6.1.11 Place RA inner into RA outer (with a crane) in the horizontal position.

6.1.12 Inspect loaded RA outer prior to putting on lid to assure:

- RA outer has been refurbished, verified and released
- Tampersafe seals on RA inner are not broken
- The RA inner is resting properly in the RA outer
- Cleanliness

- Packing material is in place
- No damage to RA inner container.

6.1.14 Bolt lid onto RA outer.

6.1.15 Apply tampersafe seals.

6.1.16 Band RA outer.

6.1.17 Inspect loaded RA outer for proper closure and tampersafe seals.

6.1.18 Survey and release loaded RA outer for compliance to DOT shipping regulations.

## 6.2 Acceptance Tests

### 6.2.1 Quality Assurance Program

Construction and use of the RA series transportation packages is accomplished in conformance with the General Electric Quality Assurance Program "NEDO-11209-04A" or the latest program as approved by the NRC. Currently the General Electric QA Program is approved by the NRC's Quality Assurance Program Approval for Radioactive Material Packages, approval number 0254, Docket 71-0254.

6.2.2 Inspection Prior to First Use

6.2.2.1 The following represents the steps that are performed when purchasing new RA inner containers from a vendor or having a vendor perform refurbishment:

| Typical Characteristics to be Inspected | Typical Method of Inspection |
|---|---|
| 1) Source inspection at vendor's facility | 1) GE-Quality representative |
| 2) Verification of container measurements | 2) Based on dimensions on approved licensing drawing |
| 3) Appearance integrity (i.e., painted surface, markings legibility and location) | 3) Visual per drawing and inspection instructions |
| 4) Weld integrity and weld dimensions | 4) Visual per drawing/ review welders qualifications |
| 5) Cleanliness, finished appearance | 5) Visual |
| 6) Gasket | 6) Per drawing/ certification review/sample inspection |
| 7) Pressure relief valve | 7) Review certification for proper type. If installed at GE-Wilmington, see maintenance Section 6.3 |
| 8) Certification of conformance | 8) Review for completeness |

Failures are rejected and dispositioned (i.e., reworked) based upon the discrepancy.

6.2.2.2 The followiong represents the steps that are performed when purchasing new RA outer containers from a vendor or having a vendor perform refurbishment:

| Typical Characteristics to be Inspected | Typical Method of Inspection |
|---|---|
| 1) Source inspection (1st article) | 1) GE-Quality representative |
| 2) Verification of container characteristics (e.g., materials, dimensions, bolt holes, nail patterns, Ethafoam and honeycomb) | 2) Based on notes and dimensions on approved licensing drawing |
| 3) Appearance integrity, (e.g. fit and finish, painted surfaces, finished appearance) | 3) Visual per drawing and inspection instructions |
| 4) Certification of conformance and dimensional data sheets | 4) Visual for completeness |

Failures are rejected and dispositioned (e.g., reworked) based upon the discrepancy.

6.3 Maintenance Program

6.3.1 The metal RA inner container - All RA inners are inspected and/or refurbished (at the GE-Wilmington facility) prior to packaging for shipment as follows:

6.3.1.1 Container Exterior (RA inner)

(1) No holes on surface.

(2) Dents not exceeding 1/2 inch in depth over a one square foot area allowable.

(3) Lifting handles on lid are securely fitted in brackets and brackets are welded per drawing. No cracks on weld.

(4) Body and lid lugs securely welded as per drawing. No cracks on weld.

(5) Lifting handles are securely in brackets and brackets are welded per drawing. No cracks on weld.

(6) No cracks on weld seams.

(7) Gasket must adhere to lid and end cap and have a clean sealing surface in good physical condition. Gasket is visually inspected and replaced if damaged.

(8) Pressure relief valve in place and in good working order.

6.3.1.2 Container Interior (RA inner)

(1) Ethafoam lining visually clean, dry, and adherent to the container. Up to 2% of the total volume of the ethafoam may be removed for packing purposes.

(2) "Y" support blocks in place.

(3) Body and cover are visually clean and free of loose debris.

6.3.2 The RA Wooden Outer Container - All RA outers are inspected and/or refurbished (at the GE-Wilmington facility) prior to packing for shipment as follows:

(1) Interior and exterior surfaces and bracing in good visual condition.

(2) Wooden skids properly located and firmly attached to container base.

(3) Bolts in good condition.

(4) Ethafoam material properly positioned, in good condition, clean, dry, and adhering properly.

(5) Interior must be clean and dry.

(6) Honeycomb that is deteriorated, cracking, or flaking material is replaced if the damaged (or missing) areas exceed 1% of the individual pieces cubic volume or the total for the container exceeds 10%.

In addition, honeycomb located in the ends of the box is replaced if after inspection (and removal if necessary) it is not within 1 inch of normal width or does not extend to at least the height of the top of the steel plate attached to the 1/2 inch plywood. The top portion of the end material is inspected and replaced as required.

The following exceptions do not count toward the 1% inspection criteria because they are viewed to be insignificant to the total performance of the container.

(a) Small areas of individual pieces where corners are rounded to approximately a radius of 3 inches.

(b) Minor crevices approximately 1/2 inch wide between butt joints of cushioning material, when due to small irregularities in edges of pieces of minor deviations in alignment during application of adhesive.

(c) In some, but not all boxes, there are four small areas of cushioning (approximately 8 inches x 8 inches) which have been removed to allow the engaging of lifting hooks with the body handles without damaging adjacent cushioning material. This is necessary because some handles vary slightly in location.

## 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 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.

## SECTION 7.0

## 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.

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**ATTACHMENT 3**

| CRITICALITY SAFETY ANALYSIS |
|---|

# DEMONSTRATION OF CONDITIONS FOR CLASS I SHIPMENT OF GADOLINIUM POISONED FUEL BUNDLES IN THE RA SHIPPING PACKAGE


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- MARCH 27, 1986 -

NOTE:
THROUGHOUT THE TEXT,
PROPRIETARY INFORMATION HAS BEEN DELETED
AS INDICATED IN THE RIGHT MARGIN

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## 1.0 SUMMARY

Based on previous criticality safety analyses, the RA container is licensed as a Fissile Class I shipping container for GE 7 x 7 and 8 x 8 fuel assemblies which have bundle average enrichments of up to 3.2%. This report describes a criticality safety analysis which has been performed for 8 x 8 fuel assemblies having maximum enrichments greater than 3.2%.

In this analysis, the RA container has been demonstrated to comply with the criticality safety requirements for Fissile Class I shipping containers for shipments of GE 8 x 8 fuel assemblies which satisfy either Condition (1) or (2) for shipment of fuel assemblies as listed below:

(1) Maximum enrichments up to 5%

(a) The maximum enrichment in the bundle does not exceed 5% weight percent.

(b) The bundle contains at least gadolinium rods †
each with a minimum of weight percent $Gd_2O_3$. None †
of the gadolinium rods may be located in the
of locations or in the †
locations. Furthermore, at least †
must be located in of and and in †
of and . may not †

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be considered to satisfy the requirement for both a row and a column.

(2) <u>Maximum enrichments up to 4.025%</u>

(a) The maximum enrichment in the bundle does not exceed 4.025 weight percent.

(b) The bundle contains at least   gadolinium rods each †
with a minimum of   weight percent $Gd_2O_3$. †
Restrictions on the location of these rods are the same as listed in Condition (1)(b) above.

Presence of the Gad rods and minimum gadolinium content in the Gad rods will be ensured by the NRC approved quality assurance program in effect for all fabricated fuel assemblies.

This analysis has been performed with the GEMER Monte Carlo Code which is a successor of the MERIT Monte Carlo code used in the previous RA container analysis. GEMER uses the same treatment of cross-sections as MERIT but differs in that its geometry handling capabilities are more like those of the KENO IV Monte Carlo code. Use of GEMER has allowed explicit representation of each rod in the 8 x 8 bundle lattice and has permitted modeling of both the infinite array of undamaged (outer) containers and the 13 x 20 array of damaged (inner) containers.

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The RA container model used in this analysis is similar to that used in the previous analysis but differs in the following ways.

(1) The bottom angle iron support brackets are modeled as two inches wide rather than four inches wide sections.

(2) The fuel rods are modeled as       inches in diameter †
rather than       inches. †

(3) The top angle iron support brackets have been included (again as two inches wide sections).

(4) The theoretical density of $UO_2$ (10.96 grams per cc) has been used in calculating fuel atomic densities rather than 95% of the theoretical value.

(5) The half density ethafoam in the inner container has not been included in the analysis of the normal case infinite array of outer containers.

Except for item (3), these differences are all conservative relative to the prior analysis. Inclusion of the top angle iron support brackets constitutes a refinement of the model more representative of the RA containers actual configuration but is one not implemented in the prior analysis because of time and code limitations.

## 2.0 INTRODUCTION

GEMER and MERIT have been extensively benchmarked against other calculational techniques and against critical experiments representative of GE reactor fuel assemblies. For the present analysis, GEMER results have also been compared against results from the prior analysis for fuel assemblies with 3.2% bundle average enrichments (with no Gad rods) as well as to KENO IV results using the SCALE system for selected limiting cases in the current analysis.

## 2.1 Historical Perspective

At the present time, the RA container is authorized for shipment of GE 7 x 7 and 8 x 8 fuel assemblies (Certificate of Compliance 4896, Revision 17, 12/19/84). This authorization has been limited to shipment of fuel assemblies with bundle average enrichments of not greater than 3.2 percent (without taking credit for bundle Gad rod content). The purpose of this analysis is to extend the use of the container to GE 8 x 8 fuel assemblies having bundle enrichments of up to 5.0%, by explicitly taking into account the effect of gadolinium poisons.

## 2.2 Previously Demonstrated Requirements & Objective of The Present Analysis

Requirements for a Fissile Class I package as stated in 10 CFR 71.57 as follows:

"A Fissile Class I package must be so designed and constructed and its contents so limited that:

(a) Any number of undamaged packages would be subcritical in any arrangement and with optimum interspersed hydrogeneous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case the greater amount may be assumed for this determination; and

(b) Two hundred fifty (250) packages if each package were subjected to the tests specified in section 71.73 (Hypothetical Accident Conditions), would be subcritical if stacked together in any arrangement, closely reflected on all sides of the stack by water, and with optimum interspersed hydrogenous moderation."

In the previous analysis it was demonstrated that the minimum packaging model of the RA container met the listed requirements for a Class I container for shipments of the GE 7 x 7 and 8 x 8 fuel bundle designs with bundle average enrichments up to 3.2 percent. The MERIT and KENO Monte Carlo codes were used in that analysis. Both the normal and accident conditions were analyzed. The accident conditions analyzed included arrays of damaged inner containers both with interspersed moderation in the interior (including in the bundle) and with regions of full density water between the units.

The objective of the present work is to extend the earlier analysis to show that the RA container satisfies the Fissile Class I requirements for fuel assemblies with higher enrichments by taking into account the effect of gadolinium in rods in the fuel assemblies. This analysis has been done using the GEMER code (which is an extension of MERIT) together with the geometry models and considerations reported in the previous analysis.

2.3 Damaged Versus Undamaged Containers

When the RA container was subjected to the tests prescribed in 10 CFR 71.73, the effect on the RA container was to remove wood and cushioning material from the outer and inner containers and to damage the inner container gasket material. A slight distortion of the inner container also occurred but it did not increase the reactivity of a close-packed array. Therefore in analysis of accident cases, the damaged container has been represented by the inner container with the assumption that the container is not sealed and that interspersed water may be present in the interior. It was shown in the previous analysis that the array of damaged inner containers is more reactive when the inner containers are filled with optimum interspersed moderation than when the array is moderated by layers of full density water outside of the inner containers. The current analysis has therefore used the internal interspersed moderation case to demonstrate sub-criticality of the 250 unit accident case. (As in the prior analysis, the accident case has actually been analyzed as a 13 x 20 = 260 unit array in order to conservatively represent array geometry effects.)

## 3.0 ANALYTICAL METHODS

### 3.1 The GEMER Code

GEMER is an acronym for Geometry Enhanced MERIT. The MERIT code is a derivative of the Battelle Northwest BMC code and is characterized by its explicit treatment of resolved resonances in material cross-section sets. The MERIT treatment uses cross-sections processed from the ENDF/B-IV library. These cross-sections are prepared in the 190 energy group format and those in the resonance energy range have the form of resonance parameters. Thermal scattering of hydrogen in water, paraffin, etc., is represented by the S ($\alpha$, $\beta$) data in the ENDF/B library. The types of reactions considered in the Monte Carlo calculation are the fission reaction and elastic, inelastic and (n, 2n) collisions. Absorption is implicitly treated by reducing the neutron weight through determining the non-absorption probability on each collision.

The geometry treatment in GEMER is the same as that in KENO-IV and the models used in this analysis consist of a combination of the specialized (regular) and generalized geometries.

In the specialized (regular) geometry treatment, a spatial description is generated by defining boxes each of which contains an increment of the desired system. Within each box the description consists of a nested series of shapes such as CYLINDERs, SPHEREs, and CUBOIDs. Arrays of the boxes can be put together to describe the entire system and surrounded by reflecting materials as required.

In the generalized geometry treatment, a system is represented by writing the equations of the surfaces involved and then specifying where the various media lie relative to these surfaces. A region defined in specialized geometry may be combined with regions defined in specialized geometry to describe an entire system. In the current analysis the generalized geometry feature was used primarily to describe the fuel assembly (i.e., inner basket, rods, plastic separators and interspersed water in the fuel assembly) and the specialized geometry was used to describe the other regions of the shipping container.

## 3.2 The SCALE System

SCALE is an acronym derived from the name Standardized Computer Analysis for Licensing Evaluation. SCALE was developed by the Computer Sciences Division at the Oak Ridge National Laboratory under contract from the Nuclear Regulatory Commission. SCALE consists of a combination of the Monte Carlo code KENO with a series of codes designed to process cross-sections. For the present analysis, cross sections from the 27 broad group version of the Criticality Safety Reference Library were resonance-treated with the NITAWL code and used in the SCALE REV.-2 version of KENO-IV.

## 4.0 MODELING

Representative inputs for the GEMER and KENO/SCALE computer calculations are included in Attachment 4 and include the relevant mixture specifications for the fuel and Gad and materials of construction. The following is a general description of the system and the assumptions upon which these computer inputs were based.

## 4.1 General Description

The RA container has been described in detail in the General Electric RA Package Application dated March 1, 1982, and updated March 15, 1982.

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The RA series package consists of a wooden outer container and a carbon steel inner container separated by cushioning materials. The inner metal container is constructed of minimum 16-gauge carbon steel sheathing and is approximately 11 inches by 18 inches by 179 inches long. There is an inner basket consisting of two metal channels formed of carbon steel which has 3/4 inch perforations on 1 3/4 inch centers. The inner basket is held in place within the outer walls by six 3 x 3 inch angle iron supports 1/8 inch thick. The container outer walls and the inner basket walls provide a 2 inch annulus around the fuel area.

Closure of the inner container is accomplished by bolts, latches and other equivalent means. Rubber gaskets are provided on closing surfaces. A pressure relief valve is provided on the inner container and is set to pass up to 2 cfm air automatically for a 0.5 psi pressure differential.

The outer container is a rectangular box with maximum dimensions of 33 inches high, 32 inches wide and 207 inches long, fabricated of 1/2 inch plywood sheets. Phenolic resin impregnated honeycomb 8 1/2 to 9 inches thick lines the box at the ends, and one 3 inch layer lines the top, bottom and sides. Ethafoam cushioning pads three or four inches thick are provided at top and bottom and 1/2 inch pads at the sides of the inner container.

Two BWR fuel assemblies are normally placed in each inner container. During the preparation of the fuel assembly for loading into the inner container, plastic separators are placed in each fuel assembly to protect against damage from vibration during transportation.

## 4.2 Modeling of the Inner Container

For the present analysis, the inner container has been modeled as shown in Figure 1. Modeling of the inner container is conservative, i.e., the model is more reactive than the actual assembly. The metal in the shell, the inner basket, and basket supports has been explicitly modeled. As in the prior analysis, the perforated inner basket has been approximated by using of 85% of full density carbon steel. The cushioning material between the outer shell and the inner basket has not been included.

## 4.3 Modeling of the Outer Container

The outer container modeled is shown in Figure 2. The ethafoam, honeycomb, and the wood of the outer container have been explictly modeled in the worst case minimum package configuration described in the prior analysis. This is conservative since arrays of the outer container are over moderated by the cushioning materials.

FIGURE 1

RA INNER CONTAINER GEOMETRY MODEL

FIGURE WITHHELD UNDER 10 CFR 2.390

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FIGURE 2

RA OUTER CONTAINER GEOMETRY MODEL

FIGURE WITHHELD UNDER 10 CFR 2.390

## 4.4 Modeling of the Fuel Assembly

The fuel assemblies have been modeled in generalized geometry. This has consisted of writing equations for each of the surfaces involved and then defining where each material lies relative to these surfaces. As in the prior analysis, all materials in the fuel assembly have been described conservatively. The following assumptions/ parameters have been used in this description:

(1) The diameter of the fuel pellets has been assumed to be equal to the inside diameter of the cladding. (This is different from the treatment in the prior analysis in which the pellet OD was set at inches and the Zirc cladding was "smeared" over the region between the pellet and the Zirc cladding OD.) †

(2) A cladding thickness of inches and a cladding OD of inches have been used. † †

(3) A fuel length of 174 inches has been assumed in all analyses.

(4) When calculating the atomic densities for uranium materials, the theoretical density of the pellet (i.e., 10.96 grams per cc rather than the previously used .95 x 10.96) has been assumed.

(5) When calculating the atomic densities of the $Gd_2O_3$ in the fuel rods, the minimum specification density for the $Gd_2O_3$ has been assumed. The theoretical density of a % $UO_2$, % $Gd_2O_3$ mixture is grams per cc. The fraction of this density used in the calculation of gadolinium atomic density was . (That is, the $Gd_2O_3$ density has been calculated to be x x gms/cc.) Table 1 lists the number densities of the materials for the % and % $Gd_2O_3$ mixtures. †

(6) The displacement of uranium (i.e., $UO_2$) by the $Gd_2O_3$ material was neglected.

(7) The gadolinium pins have been taken to be either % or % by weight $Gd_2O_3$ for the two Gad rod cases considered in this analysis. †

(8) The plastic separators between fuel rods have been explictly modeled in all calculations. This explicit modeling has been used for conservatism but comparisons show that the separators make little difference in calculated neutron multiplication factors - at least at the point of maximum $k_{eff}$s.

## 4.5 Restraints on Location of Gadolinium Rods

In the modeling of fuel assemblies, the following restraints are placed on gadolinium rod locations.

# TABLE 1

## GADOLINIUM ROD ATOMIC DENSITIES

| Nuclide | 4.025% En U<br>% $Gd_2O_3$ | 5.0% En U<br>% $Gd_2O_3$ | † |
|---|---|---|---|
| $U^{235}$ | 9.964140E-04 | 1.237776E-03 | |
| $U^{238}$ | 2.345910E-02 | 2.322069E-02 | |
| Gadolinium | | | † |
| Oxygen | | | † |

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(1) The poisoning effect of a gadolinium rod may not be considered if the rod is located in the ring of † assembly positions or in the assembly † positions.

(2) of and must contain † gadolinium rod. †

(3) rod may not satisfy condition 2 for † . †

## 5.0 DESCRIPTION OF ANALYSES

### 5.1 Systems Analyzed

The arrangement of the Gad rods analyzed in fuel assemblies evaluated in the present analysis is shown in Figure 3. Two cases have been considered. The first is that for fuel assemblies with at least Gad rods. An example is the Gad A † arrangement which has Gad rods each with % $Gd_2O_3$ and † which is considered to be a representative bundle design. Its impact on the RA container has been analyzed at both 4.025% and 5.0% ($U^{235}$) enrichments. Gad B, C and E represent configurations of Gad rods which, while not as realistic † from a core design point of view, are conservative bounds for the geometry constraints described in Section 4.5. The impact of these two bundle configurations on the RA container

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FIGURE 3

GADOLINIUM LOCATIONS CONSIDERED

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has been analyzed at 5.0% ($U^{235}$ enrichment). For comparison, the 5.0% enrichment Gad A and Gad C outer container cases have also been calculated with KENO/SCALE.

The second case is one which has Gad rods with each Gad rod †
containing % $Gd_2O_3$. Figure 3, Section (d), represents a †
conservative arrangement of such rods in a system which conforms to the geometry constraints described in Section 4.5. This case represents a minimum Gad rod in fuel assemblies having bundle average enrichments greater than 3.2% and has been analyzed for a uranium enrichment of 4.025%.

5.2 Results

Tables 2 and 3 show the results of these calculations. For comparison, results have also been included for the 3.2% bundle average enrichment/no Gad case (the currently licensed configuration ) which has also been performed with GEMER and the models described in this report. (Table 4 shows the results for the 3.2% bundle average enrichment cases reported in the prior analysis.) The KENO/SCALE results for infinite arrays of undamaged containers are:

## TABLE 2

GEMER RESULTS FOR INFINITE ARRAYS OF UNDAMAGED CONTAINERS
WITH THE MINIMUM PACKAGING MODEL

| Fuel Assembly Model (Figure 5.0) | Maximum Bundle Enrichment (%) | Minimum $Gd_2O_3$ Content in Gad Rods | GEMER $K_\infty \pm \sigma$ | |
|---|---|---|---|---|
| No Gad | 3.2 | --- | 0.958 ± 0.003 | |
| Gad A | 4.025 | | | † |
| Gad A | 5.0 | | | † |
| Gad B | 5.0 | | 0.958 ± 0.003 | † |
| Gad C | 5.0 | | | † |
| Gad D | 4.025 | | 0.937 ± 0.003 | † |
| Gad E | 5.0 | | | † |

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TABLE 3
GEMER RESULTS
FOR 13 x 20 ARRAYS OF DAMAGED INNER CONTAINERS
WITH VARYING AMOUNTS OF WATER
INTERSPERSED IN THE CONTAINERS*

| Interspersed Water in Container (gms/cc) | Keff ± σ | | | |
|---|---|---|---|---|
| | No Gad 3.2% Enr | Gad A 4.025% Enr | GAD A 5.0% Enr | |
| 0.00 | | | | |
| 0.025 | | | | † |
| 0.050 | | | | † |
| 0.075 | | | | † |
| 0.100 | | | | † |
| 0.200 | | | | † |
| 0.400 | | | | † |
| 0.800 | | | | † |
| 1.000 | | | | † |
| | | | | † |
| | GAD B 5.0% Enr | GAD E 5.0% Enr | GAD D 4.025% Enr | |
| 0.00 | | | | |
| 0.025 | | | | † |
| 0.050 | | | | † |
| 0.075 | | | | † |
| 0.100 | 0.944 ± 0.004 | | 0.932 ± 0.004 | † |
| 0.200 | | | | † |
| 0.400 | | | | † |
| 0.800 | | | | † |
| 1.000 | | | | † |

*$Gd_2O_3$ Content

Gad A, B, C, & E = weight percent †
Gad D = weight percent †

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## TABLE 4

### KENO IV RESULTS
### FOR 3.2% BUNDLE AVERAGE MERIT ENRICHMENT
### - NO GAD CONTENT
### (PRIOR ANALYSIS)

A. Infinite Array of Undamaged Outer Containers*, Minimum Packaging Model

| Code | K∞ ± σ | |
|---|---|---|
| KENO IV | | † |
| MERIT | | † |

B. 13 x 20 Arrays of Damaged Inner Containers with Varying Amounts of Water Inspersed in the Containers.

| Interspersed Water In Container | KENO Keff ± σ | |
|---|---|---|
| 0.0 | | † |
| 0.025 | | † |
| 0.05 | | † |
| 0.075 | | † |
| 0.10 | | † |
| 0.15 | | † |
| 0.20 | | † |
| 0.40 | | † |
| 0.60 | | † |
| 0.80 | | † |
| 1.00 | | † |

* No Plastic Separators

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| Fuel Assembly Model | Maximum Bundle Enrichment, % | KENO/SCALE $K_\infty \pm \sigma$ |
|---|---|---|
| A | 5.0 | 0.954 ± 0.003 |
| E | 5.0 | 0.945 ± 0.003 |

## 5.3 Discussion of Results

(1) Configurations of Gad rods with % $Gd_2O_3$. †

From the results in Tables 2 and 3, it can be seen that the widely dispersed Gad arrangement tends to maximize † the effect of the gadolinium poison while the more closely packed Gad B arrangement tends to minimize the poison effect. The Gad B configuration is therefore the worst case for arrangements of Gad rods with a minimum † $Gd_2O_3$ content of % which satisfy the conditions that: †

(a) Gad rods which occur in the rod positions † or in the rod positions may not be † counted as part of the . †

(b) of and must contain † Gad rod. †

(c) may not fulfill the conditions of item † (b) above for . †

The Gad B configuration results in a K∞ ± σ of 0.958 ± 0.003 for the infinite array of undamaged RA containers and a maximum Keff ± σ of 0.944 ± 0.004 for 13 x 20 arrays of damaged containers and therefore satisfies the requirements of 10 CFR 71.57.

(2) Configurations of Gad Rods with % $Gd_2O_3$ †

As shown in Tables 2 and 3, infinite arrays of undamaged and 13 x 20 arrays of damaged RA containers with Gad D fuel assemblies are less reactive than the corresponding arrays of Gad B or No Gad assemblies. Therefore, this arrangement also satisfies the requirements of 10 CFR 71.57.

(3) Comparison With Other Methods

Comparing the results from Table 2 with the results listed in Section 5.2 shows agreement between GEMER and KENO/SCALE to within %. †

From Tables 2, 3 and 4, it can also be seen that GEMER with the RA container models used in this analysis is conservative relative to the prior analysis. For example, current GEMER results for the most reactive 13 x 20 array of damaged inner containers with 3.2% Bundle Average Enrichment Fuel assemblies (with no Gad

rods) is as compared to KENO results of †
. †

## 6.0 CONCLUSIONS

This analysis has demonstrated that the RA container complies with the requirements of 10 CFR 71.57 for Fissile Class I shipping containers for shipment of the following two types of fuel assemblies:

(1) Maximum enrichment not greater than 5.0 weight percent provided that:

(a) The assembly has at least rods each of which †
contain not less than % by weight of $Gd_2O_3$. †

(b) Gadolinium rods which occur in the †
assembly positions or in the assembly †
positions are not counted as part of the required . †

(c) of and must contain †
gadolinium rod. gadolinium rod †
may not be counted as fulfilling this requirement for †
. †

(2) Maximum enrichment not greater than 4.025 weight percent provided that:

GENERAL ELECTRIC

Mr. Charles E. MacDonald
April 29, 1986
Attachment 3 - Page 26

(a) The bundle has at least rods each of which †
contains not less than % by weight $Gd_2O_3$. †

(b) The location of the gadolinium rods satisfies the conditions of (1)(b) and (1)(c) above.

## SECTION 7.0

## APPENDIX B

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

# ATTACHMENT 1

## Background

NRC Certificate of Compliance USA/4986/AF authorizes the RA-2 and RA-3 packaging to be used to ship fuel assemblies and unassembled fuel rods. The packagings are rectangular containers consisting of an outer box made of wood and an inner box made of metal. Cushioning is provided between the inner and outer container as a lining in the outer wooden container. The inner metal container is lined with an ethafoam cushioning the entire length of each of the two inner channels. Each of these channels is designed to house one fuel assembly.

## Request

General Electric Company hereby requests permission to have the option of reducing the ethafoam thickness in the lower eight inches of the RA-2 and RA-3 metal inner container from 3/4 inches to 5/8 inches. This change involves a total of four locations per container, one on each wall side, as identified on drawings 769E231, Revision 4, and 769E232, Revision 4, in drawing location D-3.

Presently the fuel assembly fits snugly into the channel cavity. The purpose of this request is to allow space for a protective strap to be applied to the lower end of the fuel assembly on an as-needed basis.

## Justification of Request

The requested modification has no effect on the criticality analysis submitted on April 29, 1986 for the following reasons:

1. In the normal condition (infinite array) calculation, the arrays of RA containers are over-moderated by the cushioning material between the inner and outer containers. In these calculations the ethafoam for which the modification is requested was conservatively omitted from the analysis.

2. In the accident condition calculation, the region occupied by the ethafoam for which the modification is requested was conservatively assumed to be occupied by water of optimum concentration.

The analysis as performed is therefore a conservative representation of the RA container and is not affected by the proposed reduction in the thickness of the ethafoam.

Also, the removal of the ethafoam represents less than 1/2% of the total ethafoam in the inner container and does not impact the mechanical performance of the container.

Mr. Charles E. MacDonald
July 22, 1988

## ATTACHMENT 2

RA-2 and RA-3 inner container licensing drawings:

769 E 231, Revision 4 (RA-3)

and

769 E 232, Revision 4 (RA-2)

FIGURE WITHHELD UNDER 10 CFR 2.390

END CAP

SEE SECTIONAL VIEW H/J - 13

| | | | |
|---|---|---|---|
| 3 | PECN 630<br>PECN 631 2-25-82 | 0 | FMA-065 |
| | | 1 | |
| | | | PECN 611 |
| 4 | PECN 710 | 2 | |
| | | | PECN 623 |

NED

SAN JOSE

769E231

FIGURE WITHHELD UNDER 10 CFR 2.390

**END CAP**

SECTIONAL VIEW
J-12/13

IMPORTANT TO SAFETY

| | | |
|---|---|---|
| 0 FMA-065 | | 02/25/1 |
| 1 | | |
| PECN 612 | | |
| 2 | | |
| PECN 623 | | |
| 3 | | |
| PECN 630 | | |
| PECN 631 | | |
| 4 PECN 710 | | |

R. PROLLA 3-29-78

NED

SAN JOSE

769E232

SECTION 7.0

APPENDIX C

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

# DEMONSTRATION THAT FOR CERTAIN DEFINED CONDITIONS THE EXISTING RA CONTAINER MEETS FISSILE CLASS I REQUIREMENTS FOR GE 9 x 9 FUEL ASSEMBLIES

Analysis F. G. Welfare (7/5/89)
F. G. Welfare

Verification
J. T. Taylor

July 5, 1989

## SUMMARY

The RA container is presently licensed as a fissile Class I container for the shipping of GE 7 x 7 and 8 x 8 fuel assemblies of up to five percent enrichment subject to the condition that some gadolinium poison is required in assemblies for which the average enrichment is greater than 3.2 percent.

In this analysis it is demonstrated that the RA container may also be licensed as a Class I container for 9 x 9 fuel assemblies of up to 4.0 % nominal enrichment without requiring the presence of gadolinium provided that only one assembly is shipped per container. The following conditions were considered in this analysis:

1. Clad and other assembly hardware were not included. This demonstration is therefore not dependent upon the amount of clad or other structural materials in the assembly.

2. The effect of omitted fuel rods was considered. Up to 14 fuel rods were omitted in a dispersed arrangement and up to 8 fuel rods were omitted in a clustered arrangement and showed a decreasing neutron multiplication as an increased number of rods were omitted. Fuel rods may therefore be omitted with no effect on the validity of this demonstration.

These analyses were performed with the GEMER Monte Carlo code. This is the same code used in the analyses for the submittal of April 29, 1986 in which the present limits were established. The neutronics of this code were derived from an earlier Monte Carlo code called MERIT and the geometry routines of this code closely resemble those of the Monte Carlo code KENO IV. Extensive benchmarking has been done on the MERIT code, on the KENO IV code, and on the GEMER code. The capabilities of GEMER are clearly understood.

The models of the RA container used in this demonstration are shown in Figures 1 and 2. These models are identical to those used in the prior submittal except for the following:

1. Only one (9 x 9) fuel assembly is present in each container.

2. The gadolinium content of the assembly is not considered.

3. The structure is conservatively modified by omitting the support bracket from above the empty position in the assembly.

( C C

FIGURE I RA OUTER CONTAINER GEOMETRY MODEL

rRCUM \1-(n

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 2 RA INNER CONTAINER GEOMETRY MODEL

FIGURE WITHHELD UNDER 10 CFR 2.390

4. The clad material is omitted from the assembly.

5. The plastic separators within the assembly are conservatively assumed to fill the regions between rows of fuel rods.

6. The end regions of the containers are treated more accurately in the present demonstration.

## INTRODUCTION

### Historical Perspective

At the present time the RA container is authorized for shipment of GE 7 x 7 and 8 x 8 fuel assemblies of up to 3.2 percent average enrichment without considering the gadolinium content of the assemblies. In addition the RA container is authorized for shipment of GE 8 x 8 assemblies with up to 5 percent enrichment subject to the presence of a minimum gadolinium content. The purpose of this analysis is to extend the authorized use of the container to allow shipping of GE 9 x 9 fuel assemblies with up to a nominal 4 percent enrichment without considering the effect of the gadolinium and with a limit of one fuel assembly per container.

### Fissile Class I Package Requirements

Requirements for a Fissile Class I package as presented in 10CFR71.57 are as follows:

> A Fissile Class I package must be so designed and constructed and its contents so limited that:
>
> (a) Any number of undamaged packages would be subcritical in any arrangement and with optimum interspersed hydrogeneous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case the greater amount may be assumed for this determination; and
>
> (b) Two-hundred fifty (250) packages, if each package were subjected to the tests specified in section 71.73 (Hypothetical Accident Conditions), would be subcritical if stacked together in any arrangement, closely reflected on all sides of the stack by water, and with optimum interspersed hydrogenous moderation.

### Damaged versus Undamaged Containers

When the RA container was subjected to the tests prescribed in 10CFR71.73, the significant effect was to remove wood and cushioning material from the outer and inner container and to damage the gasket material of the inner container. Therefore, the accident condition container has been represented by an inner container with the assumption that the container is not sealed and is subject to interspersed moderation. Prior analyses have shown that an array of such containers in contact with interspersed moderation is more reactive than when the containers are separated by layers of full density water. Therefore, the in-contact array was used in this analysis. A 13 x 20 array was used to conservatively represent the required 250 damaged units.

ANALYTICAL METHOD

The code used in this work is GEMER which is an acronym for Geometry Enhanced MERIT. The MERIT code is characterized by its explicit treatment of resolved resonances in material cross-section sets. The MERIT cross-sections are prepared from ENDF/B-IV data in a 190 energy group format and in the resonance energy range have the form of resonance parameters. Thermal scattering of hydrogen in water, paraffin, etc., is represented by the S $(\alpha,\beta)$ data in the ENDF/B library. The types of reactions considered in the Monte Carlo calculation are the fission reaction and elastic, inelastic and (n,2n) collions. Absorption is implicitly treated by reducing the neutron weight through determining the non-absortion probability on each collision.

In the version of GEMER used, the geometry treatment is the same as that in KENO-IV and the models used in this analysis consist of a combination of the specialized (regular) and generalized geometries. In the specialized (regular) geometry treatment, a spatial description is generated by defining boxes each of which contains an increment of the desired system. Within each box, the description consists of a nested series of shapes such as CYLINDERS, SPHERES, AND CUBOIDS. Arrays of the boxes can be put together to describe the entire system and surounded by reflecting materials as required.

In the generalized gemetry treatment, a system is represented by writing the equations of the surfaces involved and then specifying where the various media lie relative to these surfaces. A region defined in generalized geometry may be combined with regions defined in specialized geometry to describe an entire system. In the present analysis, the generalized geometry treatment was used primarily to describe the components of the fuel assembly and nearby portions of the container. Specialized geometry was used to describe the other regions of the shipping container.

The biases used in this analysis have been determined through comparison of calculated results with critical experiments and have been conservatively applied. For moderations of interest in this analysis, the bias increases with increasing moderation. The water to fuel ratios used in calculating the bias were calculated for the actual spacings involved assuming the regions between fuel pins to be filled with full density water. Since most calculations were done at reduced water density, this results in an over estimation of the bias. In all bias calculations, the average water to fuel ratio of the entire fuel assembly was used.

## MODELING

### General Description

The RA container has been described in detail in the General Electric RA Package Application dated March 1, 1982, as supplemented. A summary of this description is given here. The RA series package consists of a wooden outer containeer and a carbon steel inner container separated by cushioning materials. The inner metal container is constructed of minimum 16-gauge carbon steel sheathing and is approximately 11.5 inches by 18 inches by 179 inches long. There is an inner basket consisting of two metal channels formed of carbon steel which has 3/4 inch perforations on 1 3/4 inch centers. The inner basket is held in place within the outer walls by six 3x3 inch angle iron supports 1/8 inch thick. The container outer walls and the inner basket walls provide a 2 inch annulus around the fuel area. Closure of the inner container is accomplished by bolts, latches and other equivalent means. Rubber gaskets are provided on closing surfaces.

The outer container is a rectangular wooden box with maximum dimensions of 33 inches high, 32 inches wide and 207 inches long, fabricated of 1/2 inch plywood sheets cleated with 2 x 4 inch studs, mounted on 2 x 10 inch planks and mounted on 4 x 4 inch skids. Phenolic resin impregnated honeycomb 8 1/2 to 9 inches thick lines the box at the ends, and one 3 inch layer lines the top, bottom, and sides. Ethafoam cushioning pads, three or four inches thick, are provided at top and bottom and 1/2 inch pads at the sides of the inner container. Each container can hold a maximum of two fuel assemblies.

### Modeling of the Inner Container

For the present analysis, the inner container has been modeled as shown in Figure 1. Modeling of the inner container is conservative, i.e. the model is more reactive than the actual assembly. The metal in the shell and the inner basket has been modeled explicitly. Five of the six basket supports have been modeled explicitly and one has been conservatively omitted. As in the prior analyses the perforated inner basket has been approximated by using 85 % of full density carbon steel. The cushioning material inside the inner container has not been included. The results include a demonstration that this is conservative.

### Modeling of the Outer Container

The outer container is modeled as shown in Figure 2. The ethafoam, honeycomb, and the wood of the outer container have been modeled explicitly in the minimum package configuration which has been shown to have the highest multiplication. It will be shown in the results that this is conservative and that arrays of the outer container are over moderated by the cushioning materials.

## Modeling of the Fuel Assembly

The fuel assemblies have been modeled in generalized geometry. This consists of writing equations for each of the surfaces involved and then defining were each material lies relative to these surfaces. The following assumptions/parameters have been used as part of the conservative model generated:

a. The clad and other structural materials have been omitted.

b. The fuel has been represented as rods of theoretical density UO2 (10.96 grams/cc) of 4.025 percent enrichment with the nominal specified diameter of .376 inches and with a length of 174 inches. Gadolinium was not included.

c. Plastic separators are assumed to completely fill the volume between rows of fuel rods. In the usual case these separators are thin plastic with ribs which fill the space between rods. Therefore, the present assumption conservatively represents the amount of plastic present.

# DESCRIPTION OF ANALYSES AND RESULTS

## Normal Condition Arrays

The first set of analyses demonstrate that an infinite array of outer containers is subcritical. This was done by describing the container as shown in Figure 2 and using a reflecting boundary condition on all surfaces. Three types of calculations were performed . The first depicted the normal condition as shown in Figure 2. The packing material between the inner and outer containers was present but no packing material was present in the inner container. The second type of calculation added increasing amounts of moisture inside of the inner container. This was done to verify that the packing material between the inner and outer containers over moderates the array. The third type of calculation added thin regions of water between outer containers to verify that the highest multiplication situation had been calculated. These results are shown in Table 1.

Table 1.

Infinite Normal Condition Arrays

| Case # | Internal Water Density gm/cc | Water Between Containers Inches | Avg K-eff | Sigma | Bias | K-eff + 3 Sigma - Bias |
|---|---|---|---|---|---|---|
| 1 | 0.00 | | 0.8039 | 0.0035 | -.00081 | 0.8152 |
| 2 | 0.01 | | 0.7841 | 0.0035 | -.00081 | 0.7954 |
| 3 | 0.03 | | 0.7292 | 0.0046 | -.00081 | 0.7314 |
| 4 | 0.06 | | 0.6838 | 0.0047 | -.00081 | 0.6987 |
| 5 | 0.10 | | 0.6368 | 0.0036 | -.00081 | 0.6484 |
| 6 | 0.14 | | 0.5998 | 0.0038 | -.00081 | 0.6120 |
| 7 | 0.0 | 0.25 | 0.7217 | 0.0035 | -.00081 | 0.7330 |
| 8 | 0.0 | 0.50 | 0.6596 | 0.0032 | -.00081 | 0.6700 |
| 9 | 0.0 | 1.00 | 0.5515 | 0.0036 | -.00081 | 0.5631 |

The first of these cases demonstrates that an infinite array of the outer containers as modeled is indeed subcritical by a large amount. Cases 2 through 6 show that addition of water to the inner container causes the multiplication to decrease. This demonstrates that the array is over moderated by the packing material between the inner and outer containers. It is therefore conservative to omit the packing material from the inner container in the normal condition array. Cases 7, 8, and 9 demonstrate that the array cannot be made more reactive by the addition of full density water between containers. Taken collectively, the cases in Table 1 demonstrate that the normal condition array satisfies the Code of Federal Regulations requirements for a Class 1 shipping container when restricted as described.

Accident Condition Arrays

The effect of the prescribed tests was the burning away of wood and packing material and the damaging of the gasket on the inner container. Therefore, the accident condition array was assumed to be arrays of innner containers in contact but with the internal packing material destroyed and the gasket so damaged that the container is subject to internal moderation. A 13 x 20 unit array was used to conservatively represent the required 250 containers. The dimensions of the inner container are such that a 13 x 20 array is approximately cubic. The array was water reflected as prescribed by the regulations.

Three types of calculations were performed. The first of these was calculation of the multiplication of the array as a function of the interspersed moderation. Moderations from 1 to 100 percent of full density water were considered. Since the clad and the volume between the clad and the fuel were omitted, the water density within the assembly was adjusted so that the actual amount of water present within the fuel assembly was the same for a given interspersed water density as would have been the case had the clad been present. The results of these calculations, as shown in

Table 2

DAMAGED CONTAINER ARRAYS

| Case # | Water Density (gm/cc) | Missing Rod Pattern | K-eff | Sigma | Bias | K-eff + 3 Sigma - Bias |
|---|---|---|---|---|---|---|
| 1 | 0.01 | --- | 0.8181 | .0035 | -.00081 | 0.8294 |
| 2 | 0.03 | --- | 0.8635 | .0040 | -.00081 | 0.8763 |
| 3 | 0.06 | --- | 0.8583 | .0038 | -.00081 | 0.8705 |
| 4 | 0.10 | --- | 0.8020 | .0042 | -.00081 | 0.8154 |
| 5 | 0.14 | --- | 0.7403 | .0041 | -.00081 | 0.7534 |
| 6 | 0.18 | --- | 0.7082 | .0039 | -.00081 | 0.7207 |
| 7 | 0.30 | --- | 0.6262 | .0046 | -.00081 | 0.6408 |
| 8 | 0.50 | --- | 0.5992 | .0053 | -.00081 | 0.6159 |
| 9 | 0.70 | --- | 0.6181 | .0037 | -.00081 | 0.6300 |
| 10 | 1.00 | --- | 0.6812 | .0050 | -.00081 | 0.6970 |
| 11 | 0.03 | 1 | 0.8574 | .0042 | -.0013 | 0.8713 |
| 12 | 0.03 | 2 | 0.8577 | .0044 | -.0015 | 0.8724 |
| 13 | 0.03 | 3 | 0.8523 | .0041 | -.0022 | 0.8668 |
| 14 | 0.03 | 4 | 0.8424 | .0044 | -.0034 | 0.8590 |
| 15 | 0.03 | 5 | 0.8601 | .0044 | -.0013 | 0.8746 |
| 16 | 0.03 | 6 | 0.8548 | .0046 | -.0015 | 0.8701 |
| 17 | 0.03 | 7 | 0.8417 | .0036 | -.0022 | 0.8547 |

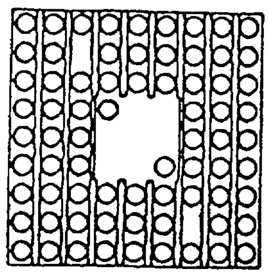
Missing rod patterns are shown in Figure 3.

The cases in Table 2 were run under the assumption that the containers were so stacked that the fuel assemblies were arranged in vertical columns. Cases two and three were rerun with the alternate arrangement shown in Figure 4 but with all other conditions (reflection and etc.) unchanged. Under this arrangement the K-eff + 3 sigma - bias values were 0.8804 for case 2 and 0.8797 for case 3. The system would therefore be safe under this alternate stacking arrangement.

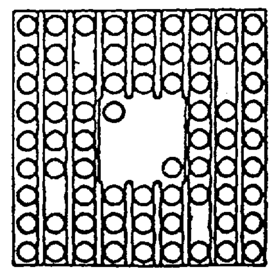
FIGURE 3

OMITTED ROD PATTERNS

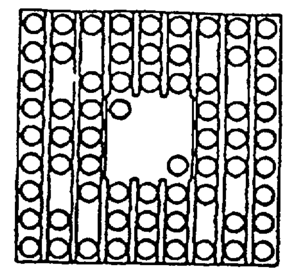
(SEE TABLE 2)



#1



#2



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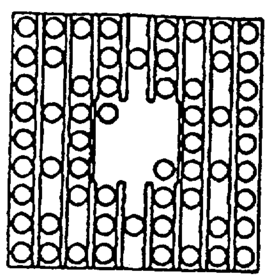

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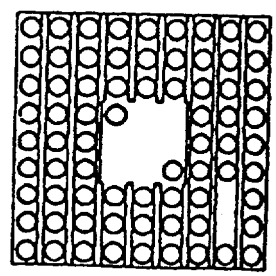

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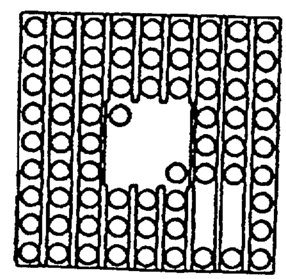

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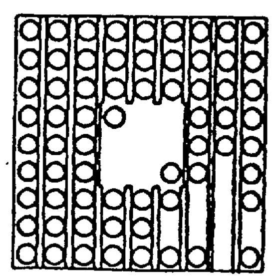


#7

FIGURE 4

ALTERNATE ARRANGEMENT

OF DAMAGED CONTAINER ARRAY

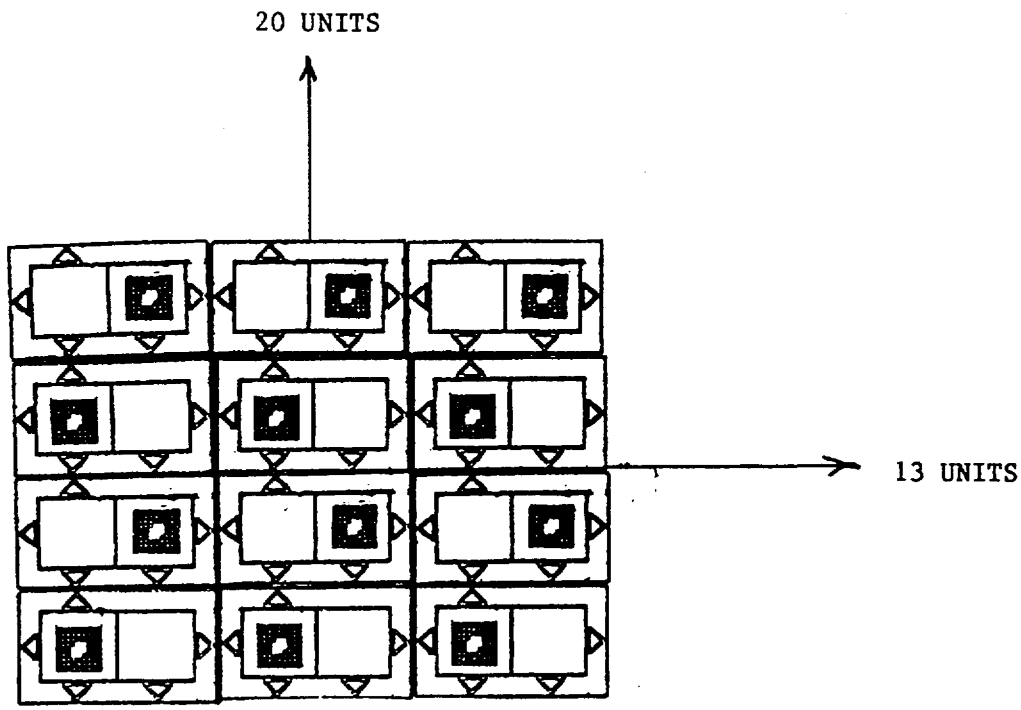


Table 2, demonstrate that the maximum multiplication obtained is well below the critical value.

The other types of calculations performed involved omitting some fuel rods and replacing them with interspersed moderation. These calculations, as summerized in Table 2, demonstrate that omitting fuel rods lowers the multiplication of the system. Fuel rods were omitted in a dispersed arrangement and in a clustered arrangement. The specific rods omitted are shown in Figure 3. Note that for the normal condition assembly, the seven rods near the center are omitted. Where reference is made to omitted rods, this means in addition to the seven rods which are normally omitted. These calculations show that the accident condition array satisfies the Code of Federal Regulation requirements for a Class I container when restricted as described.

SECTION 7.0

APPENDIX D

Non-proprietary version of 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.

# REQUEST FOR A MODIFICATION IN REQUIREMENTS FOR GADOLINIUM ROD LOCATIONS IN ASSEMBLIES SHIPPED IN THE RA CONTAINER

## BACKGROUND

The existing USNRC Certificate of Compliance No. 4986 for the shipping of GE 8x8 fuel assembly designs in the RA container includes restrictions which will not permit the shipping of one specifically desired fuel assembly design. This is true even though the desired design has a much lower neutron multiplication than the designs which are presently acceptable. In this document, the desired design is evaluated as required by the Code of Federal Regulations under the conditions which have been shown to be limiting.

The existing certificate of compliance permits, by reference to the April 29, 1986 submittal, the shipping of GE 8 X 8 fuel assemblies of up to a maximum enrichment of 4.025 weight percent provided each assembly contains at least gadolinium rods of at least weight percent gadolinia, but restraints on the location of these gadolinium rods must be satisfied. These restraints require that at least be located in . These restraints further require that may not satisfy the requirements for both a row and a column.

Figure I of this submittal shows the gadolinium rod locations in the design for which shipping approval is requested. Other assembly characteristics (e.g. fuel and cladding) are the same as those described in the April 29, 1986 submittal. This design contains gadolinium rods of at least weight percent gadolinia, but it does not contain in or as required by the existing certificate of compliance. In the following, this design is shown to both meet the multiplication requirements of the Code Of Federal Regulations and to have substantially lower multiplication than those designs already approved.

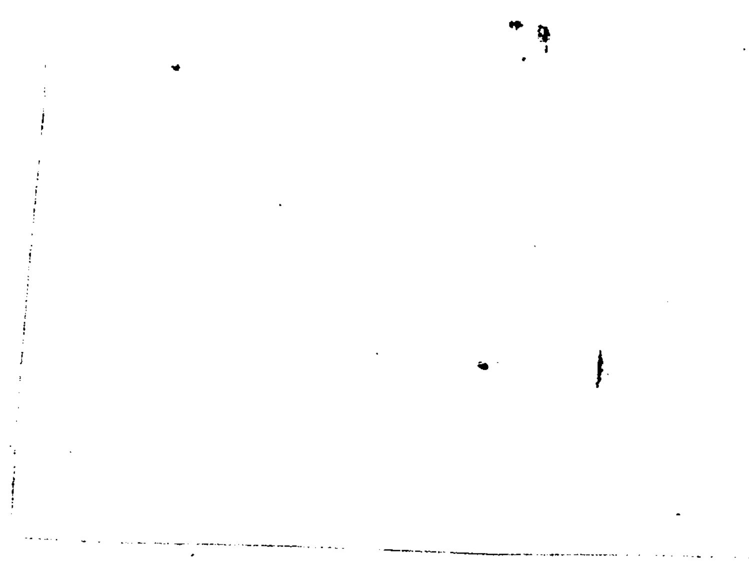
## CALCULATIONAL TECHNIQUE

The GEMER Monte Carlo code as used in the original April 29, 1986 submittal was used in this work. GEMER is a Monte Carlo code combining a detailed resonnance treatment and a 190 group cross section library with the KENO geometry system. This code has been extensively benchmarked and its accuracy is understood for systems resembling those used in this work.

FIGURE 1

ASSEMBLY DESIGN FOR WHICH

SHIPPING APPROVAL IS REQUESTED



## CALCULATIONS PERFORMED AND RESULTS OBTAINED

### Normal Conditions

Entry 6 from Table 2 in the submittal of April 29, 1986 shows that an infinite array of normal condition containers has a limiting multiplication of with a standard deviation of . In generating this entry each assembly was assumed to be of 4.025 percent enrichment and to contain rods of percent gadolinium with the location restraints as described above. In the present analysis this calculation was repeated with the same enrichment and the same ( weight percent) gadolinia content but with the gadolinium rod locations as shown in Figure 1. The resulting multiplication was with a standard deviation of . This demonstrates the acceptability of the desired assembly design under normal conditions. Input for this normal condition calculation is provided as Attachment 1.

### Accident Conditions

Table 1 below shows the limiting multiplication accident condition cases for 4.025 percent enrichment from the submittal of April 29, 1986. These cases are for a water reflected approximately cubic array containing 260 (required number is 250) accident condition containers. As described in previous submittals the prescribed accidents result in the wooden outer container being burned away so that only the metal inner container remains. The accidents further result in destroying of the gasket material so that internal moderation must be considered. In these cases, each assembly contained gadolinium rods of percent gadolina content located as described above.

Table 1 below also shows the multiplications obtained for identical calculations but with gadolinium rod locations as shown in Figure 1. These results clearly show that the assembly design for which approval is requested results in multiplications which are acceptable under the Code of Federal Regulations and which are less than previously approved designs. Input for the accident condition calculation at an interspersed water density of 0.10 is provided as Attachment 2.

TABLE 1.
ACCIDENT CONDITION MULTIPLICATIONS

| Interspersed Water (gm/cc) | Previous limiting Multiplications For 4.025 % Enrichment | Gadolinium As Located In Figure 1 |
|---|---|---|
| 0.05 | | |
| 0.10 | | |
| 0.20 | | |

CONCLUSIONS

THE GE 8 X 8 fuel assembly design as shown in Figure 1 may be shipped in the RA container in accord with the provisions of the Code of Federal Regulations provided:

1. The maximum enrichment of the assembly does not exceed 4.025 weight percent.

2. The assembly contains gadolinium rods located as shown in Figure 1.

3. Each gadolinium rod contains not less than percent Gd2O3 by weight.

Analysis by

Fred G. Welfare (8/17/90)

Fred G. Welfare
Principle Engineer
Nuclear Safety Engineering

Verification by

John T. Taylor 8/17/90

John T. Taylor
Principle Engineer
Nuclear Safety Engineering

# ATTACHMENT 1

## INPUT - NORMAL CONDITION CALCULATION

**ALL INFORMATION IN ATTACHMENT 1**

**IS PROPRIETARY AND HAS BEEN OMITTED** * *

ATTACHMENT 2

INPUT - ACCIDENT CONDITION ANALYSIS

(0.10 interspersed moderation)

**ALL INFORMATION IN ATTACHMENT 2** *

**IS PROPRIETARY AND HAS BEEN OMITTED** *

## SECTION 7.0

## 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.

## ATTACHMENT III

## RA CONTAINER CALCULATIONS SPECIFICALLY FOR THE GE-11 DESIGN ASSEMBLY SHIPMENTS SCHEDULED TO BEGIN JUNE 1991

**SUMMARY**

A series of criticality safety calculations has been completed dealing specifically with the GE-11 design fuel assembly shipments scheduled to begin June 1991. This series demonstrates very conservatively that the scheduled shipment satisfies the requirements for Class I use of the RA container.

**MODELING**

Accident condition and normal condition models have been developed. Computer listings of these models are included as Enclosures 1 & 2. The assumptions used in these models are as follows:

1. All fuel assembly and container specifications (except as described below) are identical to those described in the previous generic submittal dated November 28, 1990.

2. The highest lattice average enrichment occurring in either of the two types scheduled for shipments to begin June 1991 is percent. This has been represented throughout the active length of the assembly as . * *

3. The gadolinium is represented by rods containing a nominal weight percent $Gd_2O_3$ throughout their entire length. The gadolinium content is not considered for those rods types . In addition, four of the gadolinium rods will contain percent $Gd_2O_3$ in the actual assembly, however, these have been conservatively reduced to percent for modeling purposes. * * * * * * *

4. The locations of the gadolinium rods are as shown in Figure 1. . A computer drawing of a portion of the accident condition array is shown in Figure 2. * *

**FIGURE 1**

X = Gadolinia rod location

**FIGURE 2**

**A PORTION OF THE ACCIDENT CONDITION ARRAY**

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5. As a measure to expedite the present considerations, *
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. We do not believe this assumption is necessary for the general analysis. *

6. The atomic densities used (atoms per barn centimeter), calculated as described in the original report, are shown in Table 1.

<u>**CALCULATIONS PERFORMED AND RESULTS OBTAINED**</u>

<u>Normal Condition Arrays (Infinite Arrays of Normal Condition Containers)</u>

The results obtained for normal condition arrays are shown in Table 2. Case NJ91-11-1 is for a normal condition array which, *
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This result shows the assemblies to be highly poisoned and to meet the multiplication requirements very conservatively.

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. However, the system still very conservatively meets the multiplication requirements. *

Cases NJ91-11-2C, NJ91-11-2A, and NJ91-11-2B treat the question of *
. With the *
*
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. The multiplication goes with the *
addition of this internal moderation demonstrating that, *
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. The precise assumptions made in modeling the ethafoam region cannot therefore result in an unsafe system. *

**TABLE 1**

**ATOMIC DENSITIES
(ATOMS/BARN CM)**

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**TABLE 2**

**NORMAL CONDITIONS ARRAYS**

| CASE | ETHAFOAM DENSITY | MODERATION IN ASSEMBLY AND INNER CONTAINER | KEFF | SIGMA | |
|---|---|---|---|---|---|
| NJ91-11-1 | | | | | * |
| NJ91-11-2 | | | | | * |
| NJ91-11-2C | | | | | * |
| NJ91-11-2A | | | | | * |
| NJ91-11-2B | | | | | * |

Accident Conditions Arrays (20 x 13 Array of Inner Containers)

Table 3 shows the results of calculations for accident condition arrays. Except as described above in "modeling", *
*
. These results show the system to be highly poisoned and to have multiplications which very conservatively satisfy the requirements for CLASS I shipment in the RA container. *

**CONCLUSIONS**

The calculations run, conservatively represent the GE-11 fuel assemblies to be shipped beginning in June, 1991. These calculations show that these fuel assemblies very conservatively comply with the multiplication requirements for shipment as CLASS I in the RA container. The previous demonstration showed that arrays of normal condition containers are over-moderated. These results show that arrays of normal condition containers are over-moderated even when zero density is assumed for the ethafoam.

**TABLE 3**

**ACCIDENT CONDITION ARRAYS**

| CASE | MODERATION IN ASSEMBLY AND INNER CONTAINER | KEFF | SIGMA | |
|---|---|---|---|---|
| AJ91-11-1 | | | | * |
| AJ91-11-1 | | | | * |
| AJ91-11-1 | | | | * |
| AJ91-11-1 | | | | |
| AJ91-11-1 | | | | * |
| AJ91-11-1 | | | | * |

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**ENCLOSURE 2**

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## ATTACHMENT 3

During the week of June 24, 1991, GE-Wilmington is scheduled to begin shipping new design GE-11, 9x9 fuel assemblies in the RA series shipping containers.

The following describes assumptions made at GE in developing a model which will conservatively represent the GE-11 type fuel assemblies to be shipped beginning in June of 1991.

1. The highest lattice average enrichment occurring in either of the two assembly types is represented as in the †
model throughout the active length of the assembly. Also, the highest pellet enrichment within these assemblies is a nominal
. †

2. The gadolinium is represented by rods containing a nominal †
percent $Gd_2O_3$ (see †
matrix on page 2). The gadolinium content is not considered for those rod types which †
. In addition, four of the †
gadolinium rods will contain $Gd_2O_3$ in the actual assembly, †
however, these have been conservatively reduced to for †
modeling purposes.

3. The locations of the rods as shown in †
the matrix on page 2 are those specified from the specific designs to be shipped beginning June 24, 1991.

4. As a measure to expedite the present considerations, the gadolinia content has been assumed to be 75% of the specified nominal. We do not believe this assumption is necessary for the general analysis.

5. The atomic densities (atoms per barn centimeter) being used, calculated as described in the original report, are as follows:

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**ATTACHMENT III**

**RA CONTAINER CALCULATIONS SPECIFICALLY FOR THE GE-11 DESIGN ASSEMBLY SHIPMENTS SCHEDULED TO BEGIN JUNE 1991**

## SUMMARY

A series of criticality safety calculations has been completed dealing specifically with the GE-11 design fuel assembly shipments scheduled to begin June 1991. This series demonstrates very conservatively that the scheduled shipment satisfies the requirements for Class I use of the RA container.

## MODELING

Accident condition and normal condition models have been developed. Computer listings of these models are included as Enclosures 1 & 2. The assumptions used in these models are as follows:

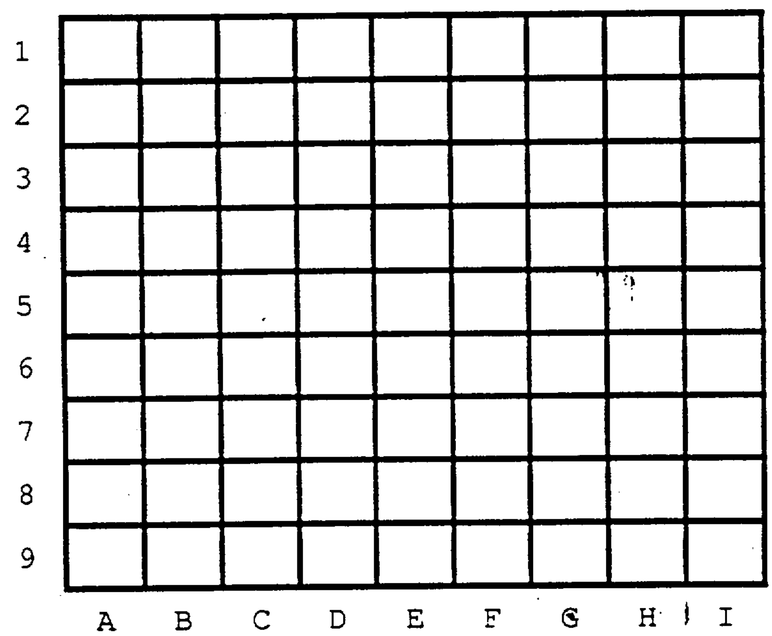
1. All fuel assembly and container specifications (except as described below) are identical to those described in the previous generic submittal dated November 28, 1990.

2. The lattice average enrichment was conservatively represented as a maximum 4.00% in the model throughout the active length of the assembly.

3. The gadolinium is represented by rods containing a nominal * weight percent $Gd_2O_3$ throughout their entire length. The * gadolinium content is not considered for those rods types * * . In addition, four of the gadolinium * rods will contain percent $Gd_2O_3$ in the actual assembly, * however, these have been conservatively reduced to percent * for modeling purposes.

4. The locations of the gadolinium rods are as shown in Figure 1. * . A computer * drawing of a portion of the accident condition array is shown in Figure 2.

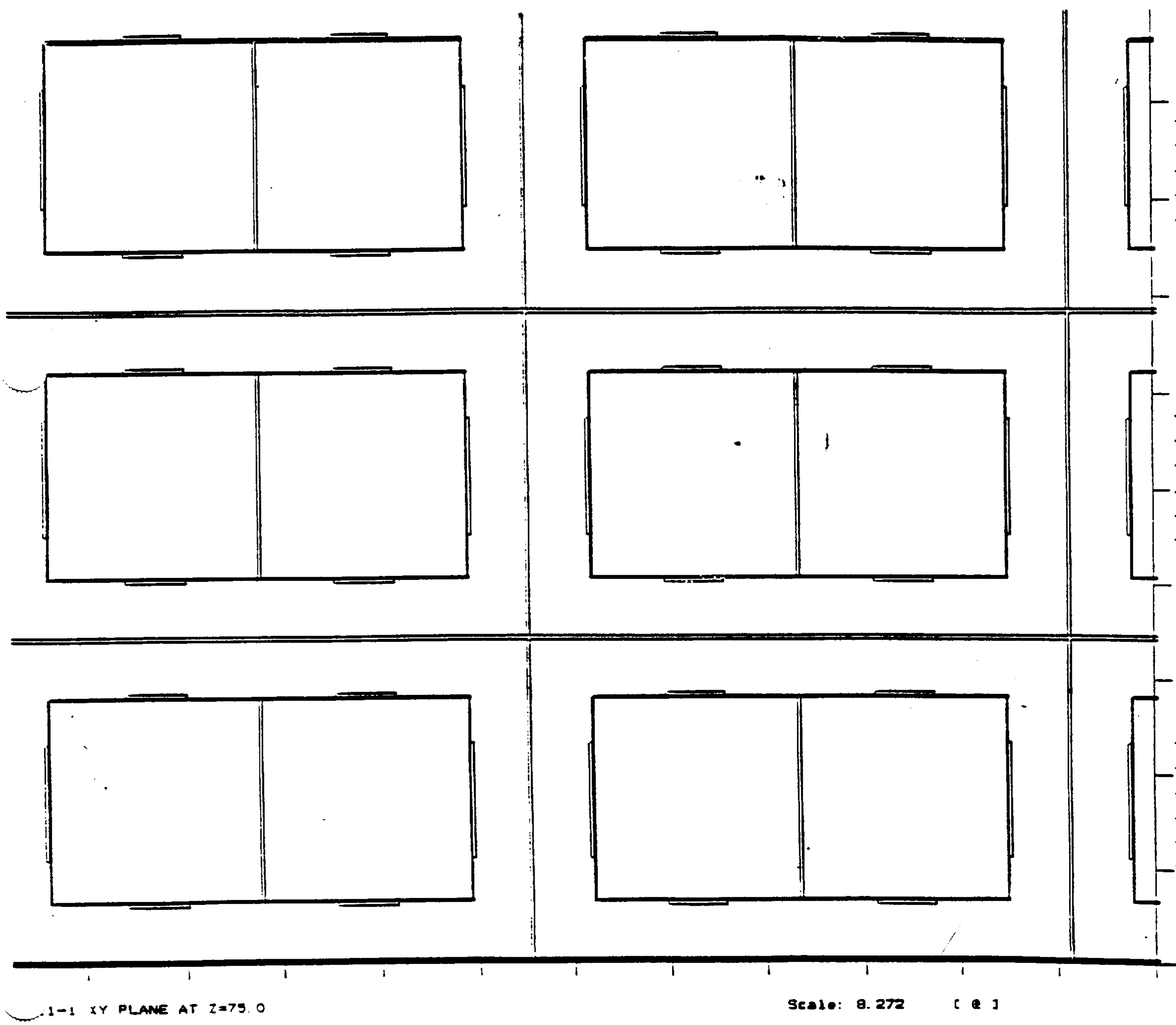
**FIGURE 1**




X = Gadolinia rod location

FIGURE 2

A PORTION OF THE ACCIDENT CONDITION ARRAY



5. As a measure to expedite the present considerations, the gadolinia content has been assumed to be 75 percent of the specified nominal. We do not believe this assumption is necessary for the general analysis.

6. The atomic densities used (atoms per barn centimeter), calculated as described in the original report, are shown in Table 1.

## CALCULATIONS PERFORMED AND RESULTS OBTAINED

### Normal Condition Arrays (Infinite Arrays of Normal Condition Containers)

The results obtained for normal condition arrays are shown in Table 2. Case NJ91-11-1 is for a normal condition array which, except for the changes described above, is identical to the normal condition calculations submitted with the generic application. This result shows the assemblies to be highly poisoned and to meet the multiplication requirements very conservatively.

Case NJ91-11-2 is identical to NJ91-11-1 except that the atomic densities in the ethafoam region surrounding the inner container have been made effectively zero. This was done in answer to NRC question number 8, in NRC letter dated 3/18/91) concerning the treatment of this region. Note that, as expected, removing this material from the over-moderated system caused a rise in the multiplication. However, the system still very conservatively meets the multiplication requirements.

Cases NJ91-11-2C, NJ91-11-2A, and NJ91-11-2B treat the question of whether or not an array of inner containers remains over-moderated with the ethafoam at effectively zero density. With the effectively zero density ethafoam, these cases progressively add 1, 2, and 5 percent moderation to the fuel assembly and the inside of the inner container. The multiplication goes down with the addition of this internal moderation demonstrating that, even with the ethafoam effectively at zero, the system is over-moderated. Therefore, additional moderation does not have to be considered in the normal condition array. The precise assumptions made in modeling the ethafoam region cannot therefore result in an unsafe system.

**TABLE 1**

**ATOMIC DENSITIES**
**(ATOMS/BARN CM)**

Pure $UO_2$

| | |
|---|---|
| U25 | 9.3025-04 |
| U28 | 2.2044-02 |
| O | 4.5949-02 |

$UO_2$ + $Gd_2O_3$ *

| | |
|---|---|
| U25 | 9.3025-04 |
| U28 | 2.2044-02 |
| Gd | * |
| O | * |

**TABLE 2**

**NORMAL CONDITIONS ARRAYS**

| CASE | ETHAFOAM DENSITY | MODERATION IN ASSEMBLY AND INNER CONTAINER | KEFF | SIGMA |
|---|---|---|---|---|
| NJ91-11-1 | Full | 0.0 | .7653 | .0025 |
| NJ91-11-2 | ~ 0.0 | 0.0 | .7835 | .0028 |
| NJ91-11-2C | ~ 0.0 | 0.01 | .7689 | .0026 |
| NJ91-11-2A | ~ 0.0 | 0.02 | .7518 | .0025 |
| NJ91-11-2B | ~ 0.0 | 0.05 | .7228 | .0026 |

Accident Conditions Arrays (20 x 13 Array of Inner Containers)

Table 3 shows the results of calculations for accident condition arrays. Except as described above in "modeling", these calculations are identical to those included in the original generic submittal. These results show the system to be highly poisoned and to have multiplications which very conservatively satisfy the requirements for CLASS I shipment in the RA container.

**CONCLUSIONS**

The calculations run, conservatively represent the GE-11 fuel assemblies to be shipped beginning in June 1991. These calculations show that these fuel assemblies very conservatively comply with the multiplication requirements for shipment as CLASS I in the RA container. The previous demonstration showed that arrays of normal condition containers are over-moderated. These results show that arrays of normal condition containers are over-moderated even when zero density is assumed for the ethafoam.

**TABLE 3**

**ACCIDENT CONDITION ARRAYS**

| CASE | MODERATION IN ASSEMBLY AND INNER CONTAINER | KEFF | SIGMA |
|---|---|---|---|
| AJ91-11-1-.05 | 0.05 | .7814 | .0044 |
| AJ91-11-1-.075 | 0.075 | .8002 | .0044 |
| AJ91-11-1 | 0.10 | .8039 | .0028 |
| AJ91-11-1-.125 | 0.125 | .8032 | .0032 |
| AJ91-11-1-.15 | 0.15 | .7861 | .0028 |

# ENCLOSURE 1

User ID:            Request 540 [illegible]  *

Project ID: DEFAULT

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W   W      W W   W WW        WW   WW         WW     W   WW  W
W   W      W W   W  W         W    W          W     W   W W W
WWWWW      W  WWWW  W  WWWWW  W    W  WWWWW   W     W   W W W
W   W W W  W     W  W         W    W          W     W   W W W
W   W W W  W    W   W         W    W          W     W   W  WW
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[DESPOOL Rev. 21.0.6 Copyright (c) 1989, Prime Computer, Inc.]

Using Despooler Environment: PRO
Print Request Attributes: PRO
Spool options:
Total size: 4 records

Pathname: <D61460>        >RAQUESTIONS2>AJ91-11-1IN  *
File last modified: 91-03-30.11:36:04.Sat

Spooled: 91-04-12.11:35:48.Fri
Started: 91-04-12.11:36:28.Fri

ENCLOSURE 1
(CONTINUED)

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RA-INN,        ,376 ,  4.025,WTOFO.000,G,000,   0,I,GC


RA-INN,        ,376 ,  4.025,WTOFO.000,G,000,   0,I,GC
    150   /* # BATCHES
    400   /* # NEUTRONS PER BATCH
      3   /* # 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)


          2   293 0 0 CARBON STEEL
         12   3.921000E-03
         26   8.349100E-02


          2   293 0 0 FULL DENSITY WATER
          1   6.674300E-02
         16   3.337200E-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
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**ENCLOSURE 1**
**(CONTINUED)**

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RA-INN,        ,376 ,  4.025,WTOFO.000,G.000,   O,I,GC

        0  /* "NTYPST"
        1  /* "NEMBRG"
        0  /* "NGMCHK"
    BOX TYPE
    CYLINDER                                        *
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ENCLOSURE 1
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# ENCLOSURE 2

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W W W W W      W   W          W    W          W     W  W W W
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Using Despooler Environment: PRO
Print Request Attributes: PRO
Spool options:
Total size: 4 records

Pathname: <D61460>          >RAQUESTIONS2>NJ91-11-1IN *
File last modified: 91-03-27.08:53:16.Wed

Spooled: 91-04-12.11:35:24.Fri
Started: 91-04-12.11:35:44.Fri

**ENCLOSURE 2**
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RA-OUT,       ,376 ,  5.000,WTOFO.000,G,000,   0,I,GC           *
   150   /* # BATCHES                                            *
   400   /* # NEUTRONS PER BATCH                                 *
     3   /* # 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)         *
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      2   293 0 0 CARBON STEEL
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     26   8.349100E-02
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                                                                 *
     2   293 0 0 FULL DENSITY WATER
     1   6.674300E-02
    16   3.337200E-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
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**ENCLOSURE 2**
**(CONTINUED)**

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RA-OUT,        ,376 ,  5.000,WTOFO.000,G,000,   0,I,GC

     0  /* "NTYPST"
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     0  /* "NGMCHK"
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 BOX TYPE                                           *
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**ENCLOSURE 2**
**(CONTINUED)**

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RA-OUT,        ,376 ,  5.000,WTOFO.000,G,000,   0,I,GC

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COMPLEX
COMPLEX
```

ENCLOSURE 2
(CONTINUED)

```
RA-OUT,        ,376 ,  5.000,WTOFO.000,G,000,   0,I,GÇ
                                                                  *
                                                                  *
COMPLEX                                                           *
COMPLEX                                                           *
COMPLEX                                                           *
COMPLEX                                                           *
COMPLEX                                                           *
COMPLEX                                                           *
COMPLEX                                                           *
COMPLEX                                                           *
COMPLEX                                                           *
COMPLEX                                                           *
COMPLEX                                                           *
END GEOM                                                          *
*END GEMER*                                                       *
```

SECTION 7.0

APPENDIX F

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

**ATTACHMENT 3**

# RA CONTAINER CALCULATIONS SPECIFICALLY FOR THE GE-11 DESIGN ASSEMBLY SHIPMENTS SCHEDULED TO BEGIN JANUARY 1992

## SUMMARY

A series of criticality safety calculations has been completed dealing specifically with the GE-11 9x9 design fuel assembly shipments scheduled to begin the first week of January, 1992. This series demonstrates very conservatively that the scheduled shipment satisfies the requirements for Class I use of the RA container.

## MODELING

The GE-11 9x9 fuel design which is to be shipped beginning in January of 1992 is very similar to the design previously approved for shipment beginning in June of 1991. The primary differences are that both the enrichment and the number of gadolinium rods have been reduced. The model generated for the proposed shipment conservatively assumes the previous maximum lattice average enrichment (4.0%). The number of gadolinium rods is reduced to nine, and these rods are located as specified in the new design.

Accident condition and normal condition models have been developed. Computer listings of these models are included as Enclosures 1 & 2. The assumptions used in these models are as follows:

1. All fuel assembly and container specifications (except as described below) are identical to those described in the previous generic submittal dated November 28, 1990, and in the specific submittal dated May 7, 1991.

2. The lattice average enrichment was conservatively represented as a maximum 4.00% in the model throughout the active length of the assembly. The actual highest lattice average enrichment is      percent. The highest nominal enrichment *
within this assembly design is      percent. *

3. The gadolinium is represented by rods containing a nominal weight percent $Gd_2O_3$ throughout their entire length. *

4. The locations of the gadolinium rods are as shown in Figure 1. A computer drawing of a portion of the accident condition array is shown in Figure 2.

5. As a measure to expedite the present considerations, the gadolinia content has been assumed to be 75 percent of the specified nominal. We believe this assumption to be excessively conservative.

6. The atomic densities used (atoms per barn centimeter), calculated as described in the original report, are shown in Table 1.

**CALCULATIONS PERFORMED AND RESULTS OBTAINED**

Normal Condition Arrays (Infinite Arrays of Normal Condition Containers)

The results obtained for normal condition arrays are shown in Table 2. Case NJ91-11-1L is for a normal condition array which, except for the changes described above, is identical to the normal condition calculations submitted with the generic application. This result shows the assemblies to be highly poisoned and to meet the multiplication requirements very conservatively.

Case NJ91-11-2L is identical to NJ91-11-1L except that the atomic densities in the ethafoam region surrounding the inner container have been made effectively zero. This was done in answer to NRC question number 8, in NRC letter dated 3/18/91, concerning the treatment of this region. Note that, as expected, removing this material from the over-moderated system caused a rise in the multiplication. However, the system still very conservatively meets the multiplication requirements.

Cases NJ91-11-2L-.01, NJ91-11-2L-.02, and NJ91-11-2L-.05 treat the question of whether or not an array of inner containers remains over-moderated with the ethafoam at effectively zero density. With the effectively zero density ethafoam, these cases progressively add 1, 2, and 5 percent moderation to the fuel assembly and the inside of the inner container. The

**FIGURE 1**

| | A | B | C | D | E | F | G | H | I | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | * |
| 2 | | | | | | | | | | * |
| 3 | | | | | | | | | | * |
| 4 | | | | | | | | | | * |
| 5 | | | | | | | | | | * |
| 6 | | | | | | | | | | * |
| 7 | | | | | | | | | | * |
| 8 | | | | | | | | | | * |
| 9 | | | | | | | | | | * |

X = Gadolinia rod location

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**FIGURE 2**

**A PORTION OF THE ACCIDENT CONDITION ARRAY**

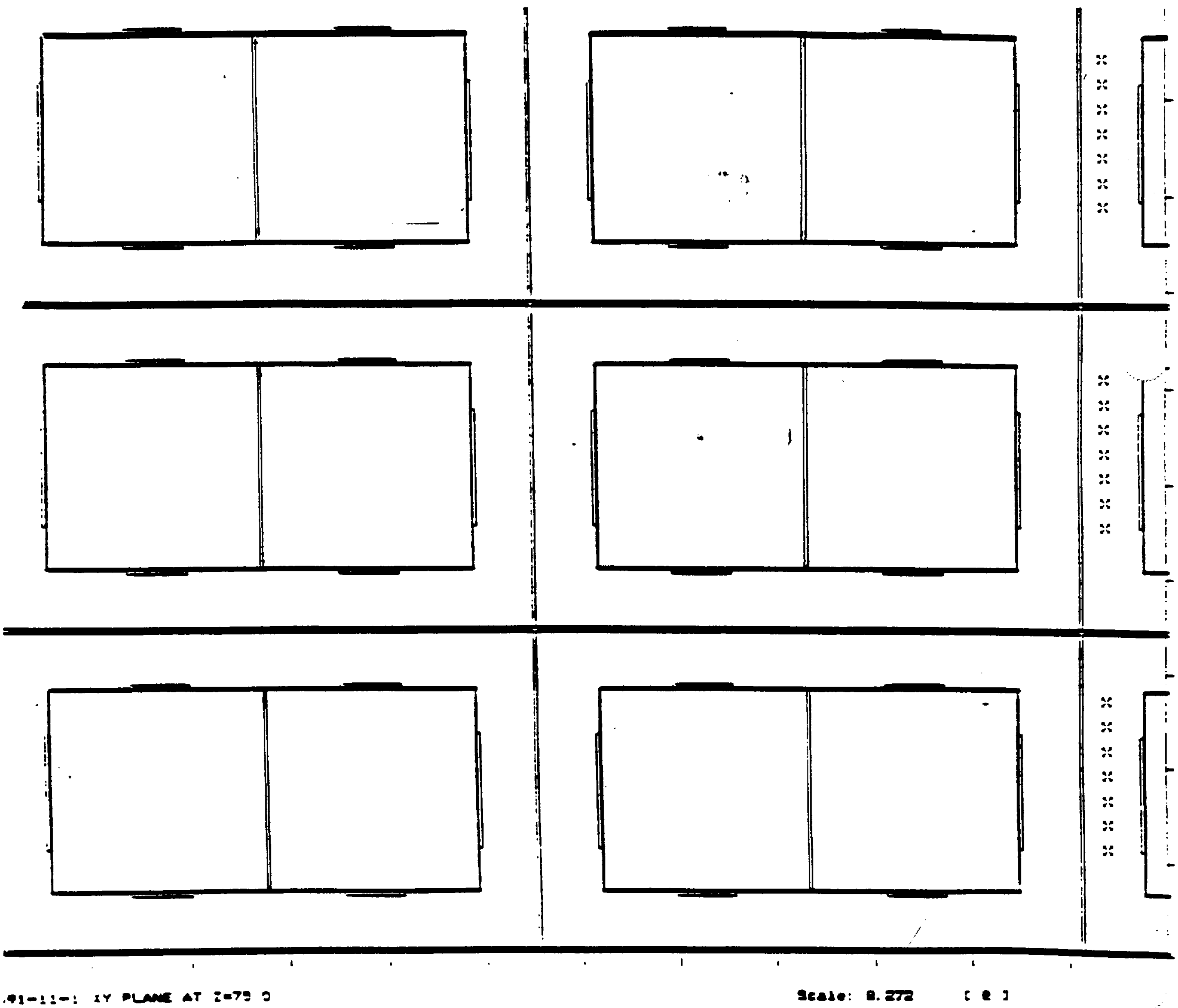

**TABLE 1**

**ATOMIC DENSITIES**
**(ATOMS/BARN CM)**

Pure $UO_2$

| | |
|---|---|
| U25 | 9.3025-04 |
| U28 | 2.2044-02 |
| O | 4.5949-02 |

$UO_2$ + $Gd_2O_3$ *

| | | |
|---|---|---|
| U25 | 9.3025-04 | |
| U28 | 2.2044-02 | |
| Gd | | * |
| O | | * |

**TABLE 2**

**NORMAL CONDITIONS ARRAYS**

| CASE | ETHAFOAM DENSITY | MODERATION IN ASSEMBLY AND INNER CONTAINER | KEFF | SIGMA |
|---|---|---|---|---|
| NJ91-11-1L | Full | 0.0 | .7902 | .0026 |
| NJ91-11-2L | ~ 0.0 | 0.0 | .8082 | .0025 |
| NJ91-11-2L-.01 | ~ 0.0 | 0.01 | .7936 | .0030 |
| NJ91-11-2L-.02 | ~ 0.0 | 0.02 | .7821 | .0027 |
| NJ91-11-2L-.05 | ~ 0.0 | 0.05 | .7493 | .0030 |

multiplication goes down with the addition of this internal moderation demonstrating that, even with the ethafoam effectively at zero, the system is over-moderated. Therefore, additional moderation does not have to be considered in the normal condition array. The precise assumptions made in modeling the ethafoam region cannot therefore result in an unsafe system.

Accident Conditions Arrays (20 x 13 Array of Inner Containers)

Table 3 shows the results of calculations for accident condition arrays. Except as described above in "modeling", these calculations are identical to those included in the original generic submittal and in the specific submittal of May 7, 1991. These results show the system to be highly poisoned and to have multiplications which very conservatively satisfy the requirements for CLASS I shipment in the RA container.

**CONCLUSIONS**

The calculations conservatively represent the GE-11 fuel assemblies to be shipped starting the week of January 1, 1992. Very conservative assumptions have been made in modeling both the enrichment and the gadolinium content. These calculations show that these fuel assemblies very conservatively comply with the multiplication requirements for shipment as CLASS I in the RA container. Previous demonstrations have shown that arrays of normal condition containers are over-moderated even if the ethafoam is omitted. This demonstration has been repeated for the proposed January 1992 shipment again verifying that interspersed moderation does not need to be considered in the normal condition.

**TABLE 3**

**ACCIDENT CONDITION ARRAYS**

| CASE | MODERATION IN ASSEMBLY AND INNER CONTAINER | KEFF | SIGMA |
|---|---|---|---|
| AJ91-11-1L-.025 | 0.025 | .7553 | .0024 |
| AJ91-11-1L-.05 | 0.05 | .8105 | .0029 |
| AJ91-11-1L-.075 | 0.075 | .8328 | .0029 |
| AJ91-11-1L | 0.10 | .8333 | .0023 |
| AJ91-11-1L-.125 | 0.125 | .8329 | .0028 |
| AJ91-11-1L-.15 | 0.15 | .8282 | .0032 |

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Attachment 3
Page 9 of 17

**ENCLOSURE 1**

```
User ID: WELFAR       Request 316 from node SYSC

Project ID: DEFAULT

:FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
:FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF

W    W WWWWW W      WWWWW  WWW   WWWW
W    W W     W      W     W   W  W   W
W W  W W     W      W     W   W  W   W
W W  W WWWW  W      WWWW  WWWWW  WWWW
W W  W W     W      W     W   W  W W
WW WW W     W      W     W   W  W  W
W    W WWWWW WWWWW W     W   W  W   W

 WWW     WWW  WWW    W        W   W         W   W        WWW  W   W
W   W      W W   W  WW       WW  WW        WW   W         W   WW  W
W   W      W W   W   W        W   W         W   W         W   W W W
WWWWW      W  WWWW   W  WWWWW W   W  WWWWW  W   W         W   W W W
W   W  W   W     W   W        W   W         W   W         W   W W W
W   W  W   W    W    W        W   W         W   W         W   W  WW
W   W   WWW   WWW   WWW      WWW WWW       WWW  WWWWW    WWW  W   W

:FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
:FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF

[DESPOOL Rev. 21.0.6 Copyright (c) 1989, Prime Computer, Inc.]

Using Despooler Environment: PRO
Print Request Attributes: PRO
Spool options:
Total size: 4 records

Pathname: <D61460>WELFAR1>          >AJ91-11-1LIN
File last modified: 91-07-29.15:28:00.Mon

Spooled: 91-08-21.09:23:48.Wed
Started: 91-08-21.09:34:56.Wed
```

**ENCLOSURE 1**
**(CONTINUED)**

```
RA-INN,        ,376 ,  4.025,WTOFO.000,G,000,   O,I,GC


RA-INN,        ,376 ,  4.025,WTOFO.000,G,000,   O,I,GC
   200  /* # BATCHES
   400  /* # NEUTRONS PER BATCH
    10  /* # 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)
```

```
    2  293 0 0 CARBON STEEL
   12  3.921000E-03
   26  8.349100E-02
```

```
    2  293 0 0 FULL DENSITY WATER
    1  6.674300E-02
   16  3.337200E-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
```

# ENCLOSURE 1
# (CONTINUED)

```
RA-INN,      ,376 ,  4.025,WTOFO.000,G,000,   0,I,GC


     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"
BOX TYPE
CYLINDER
CYLINDER
CYLINDER
CUBOID
BOX TYPE
CUBOID
CUBOID
CUBOID
BOX TYPE
CUBOID
CUBOID
CUBOID
CUBOID
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```

**ENCLOSURE 1**
**(CONTINUED)**

```
RA-INN,        ,376 ,  4.025,WTOFO.000,G,000,   O,I,GC


BOX TYPE
CUBOID
BOX TYPE
CUBOID
BOX TYPE
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BOX TYPE
CUBOID
CORE BDY
CUBOID

BEGIN COMPLEX
COMPLEX
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COMPLEX
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COMPLEX
COMPLEX
COMPLEX
COMPLEX
COMPLEX
COMPLEX
END GEOM
*END GEMER*
```

Mr. C. E. MacDonald
August 22, 1991
Attachment 3
Page 13 of 17

**ENCLOSURE 2**

```
User ID: WELFAR       Request 317 from node SYSC

Project ID: DEFAULT

:GGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG(
:GGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG(

W   W WWWWW W     WWWWW  WWW  WWWW
W   W W     W     W     W   W W   W
W W W W     W     W     W   W W   W
W W W WWWW  W     WWWW  WWWWW WWWW
W W W W     W     W     W   W W W
WW WW W     W     W     W   W W  W
W   W WWWWW WWWWW W     W   W W   W


W   W  WWW  WWW   W          W    W          W   W    WWW  W   W
WW  W    W W   W WW         WW   WW         WW   W     W   WW  W
W W W    W W   W  W          W    W          W   W     W   W W W
W W W    W  WWWW  W  WWWWW   W    W  WWWWW   W   W     W   W W W
W W W W  W     W  W          W    W          W   W     W   W W W
W  WW W  W    W   W          W    W          W   W     W   W  WW
W   W  WW   WWW  WWW        WWW  WWW        WWW  WWWWW WWW W   W

:GGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG(
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[DESPOOL Rev. 21.0.6 Copyright (c) 1989, Prime Computer, Inc.]

Using Despooler Environment: PRO
Print Request Attributes: PRO
Spool options:
Total size: 4 records

Pathname: <D61460>WELFAR1>          >NJ91-11-1LIN
File last modified: 91-08-09.09:38:40.Fri

Spooled: 91-08-21.09:24:16.Wed
Started: 91-08-21.09:35:40.Wed
```

**ENCLOSURE 2
(CONTINUED)**

```
RA-OUT,       ,376 ,  5.000,WTOFO.000,G,000,    0,I,GC


RA-OUT,       ,376 ,  5.000,WTOFO.000,G,000,    0,I,GC
   200  /* # BATCHES
   400  /* # NEUTRONS PER BATCH
     3  /* # 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)
```

```
  2  293 0 0 CARBON STEEL
 12  3.921000E-03
 26  8.349100E-02
```

```
  2  293 0 0 FULL DENSITY WATER
  1  6.674300E-02
 16  3.337200E-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
```

**ENCLOSURE 2**
**(CONTINUED)**

```
RA-OUT,        ,376 ,  5.000,WTOFO.000,G,000,   O,I,GC

     0  /* "NTYPST"
     1  /* "NEMBRG"
     0  /* "NGMCHK"

BOX TYPE
CYLINDER
CYLINDER
CYLINDER
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BOX TYPE
CYLINDER
CYLINDER
CYLINDER
CYLINDER
BOX TYPE
CYLINDER
```

ENCLOSURE 2
(CONTINUED)

RA-OUT, ,376 , 5.000,WTOFO.000,G,000, 0,I,GC

CYLINDER
CYLINDER
BOX TYPE
CUBOID
BOX TYPE
CUBOID
BOX TYPE
CUBOID
BOX TYPE
CUBOID
BOX TYPE
CYLINDER
CYLINDER
CYLINDER
CUBOID
BOX TYPE
CUBOID
BOX TYPE
CUBOID
BOX TYPE
CUBOID
BOX TYPE
CUBOID
BOX TYPE
CUBOID
BOX TYPE
CUBOID
BOX TYPE
CUBOID
CORE BDY
CUBOID
CUBOID

BEGIN COMPLEX
COMPLEX
COMPLEX
COMPLEX
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COMPLEX
COMPLEX
COMPLEX
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COMPLEX

**ENCLOSURE 2**
**(CONTINUED)**

```
RA-OUT,        ,376 ,  5.000,WTOFO.000,G,000,   O,I,GC
                                                              ::
COMPLEX                                                       ::
COMPLEX                                                       ::
COMPLEX                                                       ::
COMPLEX                                                       ::
COMPLEX                                                       ::
COMPLEX                                                       ::
COMPLEX                                                       ::
COMPLEX                                                       ::
END GEOM                                                      ::
*END GEMER*                                                   ::
```

**ATTACHMENT 4**

Non-Proprietary version of NRC Questions and GE Answers concerning the 8/22/91 application.

The proprietary information has been deleted and is so indicated with an asterisk (*) in the right-hand column.

The following are questions asked by the NRC regarding the NF&CM 8/22/91 application and our coresponding responses.

**NRC Question #1:**

1) What is the length of a full length fuel rod?

**GE Response:**

inches *

**NRC Question #2:**

2) What is the length of the fuel within a full length rod?

**GE Response:**

inches *

**NRC Question #3:**

3) How many part length rods are in each assembly?

**GE Response:**

*

**NRC Question #4:**

4) What is the length of a part length rod?

**GE Response:**

inches *

**NRC Question #5:**

5) What is the length of the fuel within a part length rod?

**GE Response:**

inches *

**NRC Question #6:**

6) What are the positions within the assembly of the part length rods? (i.e., axial location, grid)

**GE Response:**

As indicated in the matrix below, the part length rods are in locations . All part length rods are *
* 
*

| | A | B | C | D | E | F | G | H | I | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | * |
| 2 | | | | | | | | | | * |
| 3 | | | | | | | | | | * |
| 4 | | | | | | | | | | * |
| 5 | | | | | | | | | | * |
| 6 | | | | | | | | | | * |
| 7 | | | | | | | | | | * |
| 8 | | | | | | | | | | * |
| 9 | | | | | | | | | | * |

**NRC Question #7:**

7) How much water is in the grid position above the fuel rods that are part length rods?

**GE Response:**

All of the volume that would have been occupied by the fuel rod is evaluated as occupied by interspersed moderation.

SECTION 7.0

APPENDIX G

Non-proprietary version of the "Criticality Safety Analysis for the RA-3 shipping container with generic 9x9 fuel assemblies with cluster separators. The original submittal was made March 18, 1993.

**ATTACHMENT 3**

**NON-PROPRIETARY VERSION OF THE "CRITICALITY SAFETY ANALYSIS FOR THE RA-3 SHIPPING CONTAINER WITH GENERIC 9x9 FUEL ASSEMBLIES WITH CLUSTER SEPARATORS", DATED 2/1/93.**

# Criticality Safety Analysis for the RA–3 Shipping Container with Generic 9 X 9 Fuel Assemblies with Cluster Separators

**February 1, 1993**

# Criticality Safety Analysis for the RA–3 Shipping Container with Generic 9 X 9 Fuel Assemblies with Cluster Separators

## 1.0 Summary

This report summarizes a criticality safety analysis applicable to General Electric Nuclear Energy's RA–3 nuclear fuel shipping container. The criticality analysis presented in this report is based on the corresponding analysis for the RA–3 container with generic 9 X 9 fuel assemblies (no cluster separators). The results demonstrate that the RA–3 shipping container meets the requirements for a Fissile Class I package with the generic 9 X 9 fuel assemblies defined in Section 1.3.

## 1.1 Background

For more than 20 years, the RA series shipping containers have been used by General Electric Nuclear Energy (GENE) to ship BWR fuel elements to domestic and international customers. The RA series containers consist of rectangular steel inner containers transported in wooden outer overpacks. The wooden overpack containers are designed with ethafoam and honeycomb cushioning between the metal inner container and the inside walls of the outer. The inner metal container has two internal ethafoam–cushioned channel sections each of which can hold a single fuel assembly.

The original designed RA–1 inner container was modified in the 1970's to accommodate a longer fuel assembly. This was accomplished by adding a larger end cap to the body of the inner. The new design was designated as the RA–2. Subsequently, and as a result of consideration for fabrication and handling, the longer bodied RA–3 (with a shorter end cap) was introduced. Corresponding changes in the outer wooden container were also made to accommodate the new inner designs.

The RA series shipping containers are currently licensed as Fissile Class I shipping packages for the transport of 7 x 7, 8 x 8, 9 x 9, and specific 10 x 10 BWR fuel assemblies. The RA–3 shipping container is also currently licensed as a Type–A package in accordance with the Regulations for the Safe Transport of Radioactive Materials, 1985 edition (Supplement 1990) of the International Atomic Energy Agency (IAEA) for generic 9 x 9 BWR fuel assemblies.

In all previous analyses, consideration has been given to the plastic separators which are inserted in between rods to prevent unwanted motion and vibration during transport of the assembly. These separators are inserted individually along the length of the assembly. The cluster separator is a means by which these individual separators are connected to one another so that they may be easily extracted from the assembly. This is accomplished by adding a separator holder around the periphery of the assembly which is connected to the separators themselves. This separator holder results in the addition of a moderating material tightly fitted around each assembly.

## 1.2 Analysis Scope

The analysis presented in this report is the criticality safety demonstration for the RA–3 shipping container with generic 9 x 9 BWR fuel assemblies when packed with cluster separators. This analysis will be based on the most reactive configurations of the prior analysis. Since only small changes in effective multiplication are shown, only two configurations will be analyzed.

## 1.3 Generic 9 X 9 Fuel Assemblies*

In the analysis of the RA–3 container described in this report, it is demonstrated that the container meets the requirements for a Fissile Class I package with generic BWR 9 X 9 fuel assemblies. Generic 9 X 9 fuel assemblies are defined by enrichment and Gd rod content and the following rules:

1. Gd rods meeting the minimum requirements for each category must be distributed symmetrically about the major diagonal of the assembly.
2. A Gd rod located on either of the major or minor diagonals is considered to be a half rod in each of the adjacent quadrantsdefined by the diagonals.
3. Gd rods that meet the requirements for a given U–235 enrichment also meet the requirements for all lower enrichments.
4. The maximum pellet enrichment in any lattice must not exceed 5.0 percent.

With these rules, generic 9 X 9 fuel assemblies considered in this analysis are required to meet the requirements of at least one of the following categories:

A.1 <u>Lattices with a Maximum Pellet U–235 Enrichment No Greater Than 3.0 Percent</u>

1. No requirement is placed on Gadolinia content.

A.2 <u>Lattices with an Average U–235 Enrichment No Greater Than 3.3 Percent</u>

1. Each fuel assembly must contain at least two Gd rods of at least a nominal 2 weight percent Gadolinia content.

B. <u>Lattices with an Average U–235 Enrichment No Greater Than 4.025 Percent</u>

1. Each fuel assembly must contain at least six Gd rods of at least a nominal 2 weight percent Gadolinia content.
2. Each quadrant of the fuel assembly (as defined by the major and minor diagonals) must contain at least one of the six Gd rods.
3. At least two of the six Gd rods must be located in the two outermost rings of rod positions.

C. <u>Lattices with an Average U–235 Enrichment No Greater Than 4.6 Percent</u>

Such fuel assemblies must meet the requirements of at least one of the three following groups:

Group I

1. Each fuel assembly must contain at least eight Gd rods of at least a nominal 3 weight percent Gadolinia content.

* Definitions of key terms are given in Section 2.2

2. Each quadrant of the fuel assembly (as defined by the major and minor diagonals) must contain at least two of the eight Gd rods.

3. At least four of the eight Gd rods must be located in the two outermost rings of rod positions.

Group II

1. Each fuel assembly must contain at least ten Gd rods of at least a nominal 2 weight percent Gadolinia content.

2. Each quadrant of the fuel assembly (as defined by the major and minor diagonals) must contain at least two of the ten Gd rods.

3. At least two of the ten Gd rods must be located in the two outermost rings of rod positions.

Group III

1. Each fuel assembly must contain at least eleven Gd rods of at least a nominal 2 weight percent Gadolinia content.

2. Each quadrant of the fuel assembly (as defined by the major and minor diagonals) must contain at least two of the eleven Gd rods.

## 2.0 Introduction

### 2.1 Historical Perspective

In previous analyses, the RA container has been shown to meet the requirements for Fissile Class I shipping containers for BWR fuel assemblies subject to constraints on specific characteristics. These include:

1. 7 x 7 and 8 x 8 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. 8 x 8 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. 9 x 9 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. 9 x 9 fuel assemblies shipped two assembly per container 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.

5. 10 x 10 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.

The purpose of the present analysis is to demonstrate that the RA–3 shipping container meets the criticality safety requirements for Fissile Class I shipping packages for 9 x 9 fuel assemblies with cluster separators (or equivalent tight–fitting reflector/moderator around the assembly). As in Cases 2 and 4 above, this analysis has taken into account the presence of Gd rods. This has been done using the generic 9 x 9 fuel assembly definitions in Section 1.3 which has previously been devised with the intent to maximize application to real fuel assemblies. The analysis is performed with the most reactive assembly configurations (consisting of Gd rod location, concentration and number of Gd rods) for the top and bottom enrichment bands from Case 4 above [see Reference 3]. Monte Carlo methods, to be described later, are used to provide the basis of comparison for assemblies with and without cluster separators.

## 2.2 Definitions

The following definitions are used throughout this report.

1. <u>Fuel Assembly</u> – A complete fuel unit consisting of a basic 10 x 10 fuel rod structure. Rods around the center of the assembly are replaced by essentially identical water rods. Several shorter rods may be included in the assembly. These are called "partial length" rods.

2. <u>Gadolinia</u> – The compound $Gd_2O_3$. The Gadolinium content in Gd rods is usually expressed in weight percent Gadolinia.

3. <u>Gd Rod</u> – A fuel rod containing $UO_2$ and Gadolinia over its full active fuel length. Partial length rods do not qualify as Gd rods at this time, but this has not been a requirement for this analysis.

4. <u>Lattice</u> – 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 the maximum enrichment.

5. Major Diagonal – The diagonal of the 9 x 9 fuel assembly which passes between the water rods.

6. Minor Diagonal – The diagonal of the 9 x 9 fuel assembly which passes through the centers of the water rods.

7. Subcritical – Have a neutron multiplication factor ($k_{eff}$ or $k_\infty$) 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 (i.e. result in calculated multiplications less than 1.00).

8. Cluster separator – 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 separators and separator holders and to other hydrogenous materials placed around the assembly up to the equivalent water layer specified.

## 2.3 Analytical Technique

In this analysis, neutron multiplication factors ($k_\infty$'s or $k_{eff}$'s) have been calculated with the GEMER.4 Monte Carlo code. GEMER.4 is an enhanced combination of the geometry modeling capabilities of the well known KENO Monte Carlo code and the sophisticated cross section handling and neutron tracking of GENE's MERIT Monte Carlo code. A more detailed description of GEMER.4 is given in Section 3.

## 2.4 Fissile Class I Shipping Container Requirements

The criticality safety requirements for a Fissile Class I shipping container are as follows:

"A Fissile Class I package must be so designed and constructed and its contents so limited that:

(a) Any number of undamaged packages would be subcritical in any arrangement and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case the greater amount may be assumed for this determination; and

(b) Two hundred fifty (250) packages, if each package were subjected to ...Hypothetical Accident Conditions ... would be subcritical if stacked together in any arrangement, closely reflected on all sides of the stack by water, and with optimum interspersed hydrogenous moderation." (Ref. 1)

It is in addition required that a single Fissile Class I container be subcritical with optimum hydrogenous moderation and when closely reflected on all sides by water.

The Hypothetical Accident Conditions referred to in 2.4(b) are:

1. a 30 foot (9.15 m) free drop test
2. a 1 meter free drop and puncture test
3. a thermal exposure or fire test in which the container is exposed to 800 °C for at least 30 minutes, and
4. an immersion test equivalent to at least 50 feet (15.25 m) of water for at least 8 hours.

## 2.5 Analytical Procedure

Compliance with the Fissile Class I requirements described in Section 2.4 will be demonstrated in the following manner:

1. An array of 260 (13 x 20 x 1) accident condition containers will be demonstrated to be subcritical (in Section 5.1) in the following steps:

   d. The accident condition container will be defined based on prior Hypothetical Accident Condition tests of real containers as consisting only of the inner metal container with all cushioning and burnable components removed with the exception of the separators and separator holders. The absence of the sealing gasket between the lid and body of the inner container means that water in–leakage must be considered.

   e. Limiting locations for the Gd rods are established, including the effects of uranium enrichment and the number and Gadolinia concentration of the Gd rods, by the prior analysis for generic 9 x 9 assemblies [Reference 3]. These limiting Gd rod locations are the most reactive configurations from that report (i.e. have the highest $k_{eff}$s) and are also more reactive than actual Gd rod locations in real fuel assemblies.

   c. The interspersed water is varied from 0 to 15% of full density water to find the optimum moderation multiplication value for the fuel assembly of Section 2.5.1.b. Calculations are performed for assemblies with and without cluster separators. The comparison between these results will then be between consistent models. It will be shown that no statistical difference exists between the reactivity of a 9 x 9 fuel assembly with cluster separators and those without for the as–designed separator holders.

2. An single container will be demonstrated to be subcritical (in Section 5.2) by equivalence to the previous analysis. No additional calulations are required.

2. An infinite array of undamaged RA–3 containers will be shown to be subcritical (in Section 5.3) in the following steps:

   a. The limiting configurations used in the analysis described in Section 2.5.1.b will be used in the model for the undamaged container arrays.

   b. A comparison between the calculations with and without the cluster separator will be made. Since the array of undamaged containers has already been shown to be overmoderated, these calculations will be performed only at zero interunit water.

   c. It will then be demonstrated that an infinite close packed array of the undamaged containers is subcritical and the difference between the fuel assemblies with and without the cluster separators is small.

## 3.0 Analytical Method – The GEMER.4 Code

This section briefly describes the analytical method used for the calculations. More detailed information is available on the GEMER.4 code in References 2 and 4.

### 3.1 Cross sections

As noted in Section 2.3, GEMER.4[Reference 2] is a combination of the KENO and MERIT Monte Carlo codes. MERIT is a derivative of the Battelle Northwest BMC code, and is characterized by its explicit treatment of resolved resonances in material cross–section sets. The MERIT treatment uses cross–sections processed from the ENDF/B–IV library. These cross–sections are prepared in a 190 broad group format and the groups in the resonance energy range have the form of Breit–Wigner resonance parameters. These parameters are used in explicit sampling to determine the value of the cross–section at the neutron's energy. Since resonances are considered explicitly, flux weighting of cross–sections is unnecessary and only one cross section set is required per isotope (and per temperature). Thermal scattering of hydrogen in water, paraffin, etc., is represented by the $S(\alpha,\beta)$ kernels in the ENDF/B library. The types of reactions considered in the Monte Carlo calculations are fission, elastic scattering, inelastic scattering, and (n, 2n) collisions. Absorption is implicitly treated by reducing the neutron weight through determining the non–absorption probability at each collision.

### 3.2 Geometry Treatment

The geometry treatment in GEMER.4 includes the regular and generalized geometry options from the KENO–IV code and an enhanced complex embedded option which permits grouping of regular geometry regions inside of other such regions. In the regular geometry treatment, a geometric configuration is generated by defining boxes which when stacked together in one, two, or three dimensional arrays make up the total model. Within each box, individual regions and their corresponding materials (limited to one material per region) are defined using nested simple geometry forms such as CYLINDERs, SPHEREs, and CUBOIDs. Within each box, each region must completely enclose all previously defined regions except that successive regions may share common boundaries. The GEMER.4 geometry package permits arrays of boxes to themselves be enclosed by the simple geometry forms so that modeling a close water reflector can be achieved by using a simple water filled CUBOID to surround the array.

In the generalized geometry treatment, geometric modeling is achieved using the equations for quadratic surfaces and by specifying the various materials that lie in the regions bounded by the surfaces. This option allows a description of very complicated geometry models, but it becomes cumbersome and computationally inefficient when large numbers of surfaces (such as would be required for a lattice of fuel rods) are necessary. Generalized geometry boxes can, however, be stacked in (three dimensional) arrays with regular boxes.

In the complex embedded geometry treatment, arrays of regular geometry boxes may be placed inside of one or more other boxes. For example, if Box Type 1 describes a fuel rod, Box Type 2 a Gd rod, Box Type 3 a water rod, and Box Type 4 the region bounding an entire fuel assembly, then Box Types 1, 2, and 3 may be embedded in Box Type 4 to give the complete description of the assembly. Box Type 4 may then itself be assembled into an array which can then be surrounded by regions representing packaging or water reflection.

The three geometry options described above may be used in any combination to generate a geometry model. In the present analysis, the regular geometry option has been used to describe the outer regions of the shipping container, and the complex embedded option has been used to describe the fuel assemblies and their immediately adjacent regions. A $J = 0$ reflected boundary condition was used to analyze infinite arrays of undamaged containers, while the geometry models of individual (inner container) and finite arrays of damaged containers were stacked using the box array option.

### 3.3 Validation and Computational Bias

The GEMER.4 code has been validated by comparison against more than one hundred critical experiments. These critical experiments have included a significant number involving comparable lattices of light water reactor type low enriched fuel rods. From this validation, GEMER.4's bias has been conservatively estimated to be –0.003 for the range of materials, water–to–fuel ratios, and $k_{eff}$s and $k_\infty$'s applicable to this analysis. The minus sign in this value indicates that the neutron multiplication factors are underpredicted. Justification of this bias is given in Attachment 9 of Reference 4.

This bias is a result of three primary factors. The first is the random statistical uncertainties in the Monte Carlo calculations of the benchmarks themselves. Typical random errors ($\sigma$) for these calculations are in the range of 0.001 to 0.005 and consequently the average of N such values has an uncertainty on the order of ($\sigma/\sqrt{N}$) 0.0005 to 0.002.

The second significant component of the bias is in the uncertainty of the cross section sets. As noted above, GEMER.4 uses a single unique cross section set for each isotope and hence the benchmark calculations also serve to benchmark the cross section sets. This uncertainty in the cross section data is probably the largest contributor to the bias.

The third identifiable contributor to the bias is the cumulative effect of other code and modeling limitations. these include uncertainties due to programming approximations, the broad energy group cross section structure (as opposed to the cross section data set itself), and inherent limitations of the Monte Carlo method itself. The contribution to the bias of these types of errors is the smallest of the three types, especially since these errors are normally small and many of them will average out as the diversity and number of benchmark critical experiments increases.

## 4.0 Modelling

### 4.1 General Description

The RA–3 inner and outer container is shown in drawings 769E231 and 769E229 in Appendix A. It consists of a wooden outer overpack and a steel inner container cushioned with ethafoam and honeycomb. The inner metal container is constructed of mild steel with a minimum 16–gauge outer shell and structural and reinforcing components as shown. Inside the inner container, there is an inner basket formed of two perforated metal channels. The inner basket is held in place by the six 3 inch by 3 inch by 1/8 inch (7.62 cm by 7.62 cm by 0.3175 cm) thick angled supports welded to the inner wall of the outer shell. Within the inner basket, fuel assemblies rest on additional ethafoam cushioning. At the upper end of the inner container a removable end cap is attached by bolts which screw into threaded bolt holes welded onto the main body. A pressure relief valve is installed on the inner container which is designed to pass up to 2 cfm (56.6 l/m) of air if the pressure differential between the inside and outside of the container exceeds 0.5 psi (3450 Pa).

The outer container is a rectangular wooden box 33 inches high by 32 inches wide by 207 inches (83.82 cm by 81.28 cm by 525.78 cm) long. It is fabricated of 2 inch by 4 inch (5.08 cm by 10.16 cm) wooden studs, wood planks, and plywood and is lined with 8.5 to 9.0 inch (21.59 cm to 22.86 cm) thick phenolic resin impregnated honeycomb and 3 to 4 inch (7.62 to 10.16 cm) thick ethafoam pads. Cutouts are made in the ethafoam and honeycomb to accommodate the handles and lifting lugs on the inner container. Subject to meeting the minimum package requirements, the ethafoam and honeycomb cushioning are otherwise arranged in the outer container to minimize vibrational effects on the fuel assemblies being transported in the inner container.

During the packaging and handling of the RA–3 container, one or more BWR fuel assemblies are placed in the chambers in the inner container. (If only one fuel assembly is packed, the other chamber is usually filled with a dummy bundle to provide balanced loading.)

Prior to being placed in the inner container for shipment, each fuel assembly is first prepared by installing plastic separators between rows and columns of the fuel rods and by enclosing the entire fuel assembly in a thin plastic sheath. Where the cluster separators are used, the separator holder is modeled as a uniform thickness which is the average thickness of a cross–sectional cut through the holder. The maximum (including manufacturing tolerances) average thickness of the holder is 0.133 inches (0.338 cm). Both separators and holders are spaced periodically down the length of the assembly.

### 4.2 Modeling of the Inner Container

For the present analysis, the RA–3 container has been explicitly modeled by the model which is shown in Figure 4.1. The metal in the shell, the inner basket, and the angled basket supports are all

Dimensions in inches

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 4.1 RA-3 INNER CONTAINER GEOMETRY MODEL included. As in previous RA container analyses, the perforated inner basket is included by modelling it as metal with a reduced density (85% of the normal steel density). The ethafoam cushioning between the fuel assembly and the inner basket as well as the plastic sheathing around the fuel assemblies are not included. Eliminating this internal moderating material is conservative for the following reasons:

1. Arrays of undamaged containers are over–moderated by the cushioning material and wood in the outer container. (This was demonstrated in Reference 3.) Therefore, the omission of moderating materials will result in increasing the calculated $k_{eff}$s.

2. For accident condition arrays, the fire test (which is part of the Hypothetical Accident Conditions) completely burns away all internal flammable materials (except plastic separators and holders). Even were this not the case, the accident arrays are analyzed with interspersed moderation within the inner container which is varied to determine the optimum amount. The presence of additional ethafoam or the plastic sheaths around the assemblies will therefore not result in greater $k_{eff}$s but will only cause a slight change in the optimum interspersed moderator density.

This is consistent with the previous analysis.

## 4.3 Modeling of the Outer Container

The outer container is modeled as shown in Figure 4.2. This model is also conservative since it does not include all of the moderating cushioning materials that are actually present in the package. Note in particular that portions of the regions between the inner and outer containers are empty (i.e. void) in the model. The model corresponds in this regard to what is known as the "Minimum Packaging Model". The Minimum Packaging Model also includes a 50% reduced material density of the ethafoam to permit some flexibility in the arrangement of the cushioning. This is consistent with the previous analysis.

## 4.4 Modelling of the Fuel Assembly

Fuel assemblies have been modeled in complex embedded geometry. The model consists of constructing a box corresponding to each type of unit in the fuel assembly and embedding these units in another box with the same dimensions as the fuel assembly. The prior analysis [Reference 3] serves as the basis for selecting the Gadolinia/enrichment configuration to be examined. The most reactive configuration in the top enrichment band is the 4.6% average lattice enrichment, 10 Gd rod at 2% concentration, configuration 10–2B (Model name from prior analysis: AZX4–Q). The most reactive configuration in the bottom enrichment band is the 3.0% average lattice enrichment with no Gd rods. The following assumptions and parameters, consistent with the prior analysis, have been used in this scheme:

1. The diameter of the fuel region within the fuel rods has been assumed to equal the nominal inside diameter of the Zirc cladding. For determination of the fuel atomic densities, the fuel pellets have conservatively been assumed to have a density of 0.98 times the maximum theoretical value of 10.96 g/cm$^3$, which is greater than typical

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 4.2 RA-3 OUTER CONTAINER GEOMETRY MODEL density factors for real $UO_2$ pellets. The resulting density is then averaged over the inside of the cladding.

2. The thickness of the clad was the minimum allowed by tolerances.

3. An active fuel length of 150 inches (381 cm) was assumed for the full length $UO_2$ and Gd rods.

4. The plastic inserts described in Section 4.1 were conservatively modeled as cylindrical shells surrounding each individual fuel rod such that the amount of plastic was greater than that actually present. The plastic shells extended over the full length of the fuel rods.

5. For calculation of the Gadolinium atomic densities, the minimum acceptable $UO_2$ density (0.965 times the theoretical) was assumed for the fuel pellets. The Gadolinium density was then calculated as the specified percentage of the $UO_2$ density. The specified minimum weight percent of Gadolinia (determined as Weight Percent Gadolinia – 7.5% of the nominal gadolinia concentration) was used. For example, for 2 weight percent Gd, 1.85 percent was actually used. The displacement of $UO_2$ by Gadolinia was neglected. The averaged (or "smeared") fuel atomic densities used in this analysis are listed in Table 4.1 and 4.2.

6. The fuel pellet diameter, cladding thickness and rod pitch were modeled as given in Section 6.1 which describes the specific fuel characteristics and requirements for this analysis. All structural components in the fuel assembly except for the cladding were conservatively ignored.

7. The lattice average enrichment is used for all fuel rods. (This assumption is justified in Attachment 8 of Reference 4).

8. The plastic separators and separator holders are modelled as being distributed along the entire length of the assembly. This results in a modelled $H_2O$ equivalent averaged over the assembly of 0.1 g/cc $H_2O$ for the separators between the rods and 0.13 g/cc $H_2O$ equivalent for the holder immediately surrounding the periphery of the assembly. In fact, the holders and separators comprise approximately half of the modeled hydrogen content when averaged over the entire assembly.

**TABLE 4.1**
**ATOMIC DENSITIES FOR 4.6% ENRICHED $UO_2$**

| Nuclide | Pure $UO_2$ Atoms/Barn–Cm | $UO_2$ + 1.85% Gd. Atoms/Barn–Cm |
|---|---|---|
| $U_{235}$ | 1.06980E–03 | 1.06980E–03 |
| $U_{238}$ | 2.19060E–02 | 2.19060E–02 |
| Gd | — | 6.18770E–04 |
| O | 4.59520E–02 | 4.68810E–02 |

**TABLE 4.2**
**ATOMIC DENSITIES FOR 3.0% ENRICHED $UO_2$**

| Nuclide | Pure $UO_2$ Atoms/Barn–Cm |
|---|---|
| $U_{235}$ | 6.97700E–04 |
| $U_{238}$ | 2.227400E–02 |
| O | 4.59440E–02 |

## 5.0 Description of Analysis Results

The criticality safety criteria for shipping containers meeting the requirements for Fissile Class I containers is summarized from Section 2.4 as

1. An individual undamaged container must be subcritical when optimally moderated and fully reflected by water.
2. An infinite array of undamaged containers must be subcritical with optimum interspersed moderation between containers.
3. An array of 250 containers each subject to the Hypothetical Accident Conditions must be subcritical when closely reflected by water and when arranged in the most reactive configuration.

## 5.1 Accident Condition Arrays

In order to meet the criticality safety requirements for Fissile Class I shipping containers at least 250 "damaged" containers must be subcritical when arranged in the most reactive array and when closely reflected on all sides by water. A "damaged" container is one which has been subjected to the Hypothetical Accident Conditions described in Section 2.4.

For the RA series containers, the Hypothetical Accident Conditions resulted in the wooden outer container and all of the internal ethafoam, honeycomb, rubber, and plastic being burned away. With the rubber sealing gasket in the inner container gone, in–leakage of water during the immersion test is considered. With the destruction of all of the burnable materials, arrays of damaged containers are no longer over–moderated and the addition of interspersed water may cause the array $k_{eff}$s to increase. Other than the destruction of the burnable materials, the Hypothetical Accident Condition tests did not result in any changes in the fuel assemblies or the inner container significant to criticality safety analyses. (Minor changes in geometry due to the drop test and the fire test actually made it more difficult rather than easier to achieve the close–packed accident arrays that are assumed in criticality safety analyses. There was, of course, no loss of neutron absorbing materials in the inner metal container or in the Gd rods.) However, for the purpose of this analysis, the cluster separator is assumed to remain intact, forming a closely fitting hydrogenated reflector around the periphery of each assembly.

The results of the prior analysis from Reference 3 are repeated in Table 5.1. These results are for the accident condition container arrays for the Gd rod configuration 10–2B and the no Gd case. These configurations are summarized in Section 1.3 of Reference 3. The table shows accident array neutron multiplication values for the assembly (with no cluster separators) as a function of varying interspersed moderator density. These assemblies are full length (i.e., no partial length rods) and have a uniform lattice enrichment at the upper end of the enrichment band for which the analysis applies. The optimum moderation for this configuration occurs at an interspersed water density of 10% of full density. The highest neutron multiplication factor for each of the two cases is indicated in boldface in Table 5.1.

**TABLE 5.1**
**Accident Condition Array**
**ORIGINAL ANALYSIS WITH NO CLUSTER SEPARATORS**
(From Reference 3: Criticality Safety Analysis for the RA–3 Shipping Container with Generic 9 x 9 Fuel Assemblies", April 16, 1992)

| Lattice Enrichment | Gad Configuration | Interspersed Water | Keff | Sigma |
|---|---|---|---|---|
| 4.6 | 10G2.0 (10–2B) | 0.050 | 0.8751 | 0.0040 |
| 4.6 | 10G2.0 (10–2B) | 0.075 | 0.9084 | 0.0043 |
| 4.6 | 10G2.0 (10–2B) | 0.100 | **0.9099** | **0.0039** |
| 4.6 | 10G2.0 (10–2B) | 0.125 | 0.8975 | 0.0038 |
| 4.6 | 10G2.0 (10–2B) | 0.150 | 0.8980 | 0.0040 |
| 3.0 | none | 0.050 | 0.8826 | 0.0040 |
| 3.0 | none | 0.075 | 0.9126 | 0.0046 |
| 3.0 | none | 0.100 | 0.9171 | 0.0041 |
| 3.0 | none | 0.125 | 0.9189 | 0.0038 |
| 3.0 | none | 0.150 | **0.9184** | **0.0047** |

To add the cluster separator holder into the model, the model had to be altered in several places from the previous analysis. Therefore, as a check of the new model, the previous calculations of assemblies with no separator holders were performed with the new model with interspersed water instead of polyethylene in the separator holder regions. Additionally, more histories were run to improve convergence. This is expected since relatively thin regions of high density moderator result in worse statistics for the same number of histories. The results of the analysis with the new model are shown in Table 5.2. Neutron multiplication factors are shown as a function of interspersed moderator density for both the no gadolinia case (at a maximum enrichment of 3.0%) and for the most reactive gadolinia configuration, 10–2B (at a maximum lattice average enrichment of 4.6%). A comparison of the two sets of results to the corresponding results in Table 5.1 shows a slight increase due to the model change and additional number of neutron histories. These changes are slightly outside of the quoted statistics. However, all results are still well subcritical.

**TABLE 5.2**
**Accident Condition Array**
**NEW MODEL ANALYSIS WITH NO CLUSTER SEPARATORS**

| Lattice Enrichment | Gad Configuration | Interspersed Water | Keff | Sigma |
|---|---|---|---|---|
| 4.6 | 10G2.0 (10–2B) | 0.050 | 0.88048 | 0.00159 |
| 4.6 | 10G2.0 (10–2B) | 0.075 | 0.90895 | 0.00188 |
| 4.6 | 10G2.0 (10–2B) | 0.100 | **0.91866** | **0.00174** |
| 4.6 | 10G2.0 (10–2B) | 0.125 | 0.91049 | 0.00163 |
| 4.6 | 10G2.0 (10–2B) | 0.150 | 0.89798 | 0.00164 |
| 3.0 | none | 0.050 | 0.89154 | 0.00174 |
| 3.0 | none | 0.075 | 0.91953 | 0.00196 |
| 3.0 | none | 0.100 | **0.92344** | **0.00203** |
| 3.0 | none | 0.125 | 0.92265 | 0.00208 |
| 3.0 | none | 0.150 | 0.90981 | 0.00185 |

The model uses high density polyethylene for the holder. The actual material is low density polyethylene, but the differences are small and use of the higher hydrogen content material is conservative for this analysis. The results are shown in Table 5.3. Comparison to the results in Table 5.2 (without separator holders) shows an increase of only 0.0067 in $k_{eff}$ for the case of low enrichment (3.0%) and an increaseof 0.001 for the higher enrichment case. Although this is marginally statistically significant, the increase in neutron multiplication is very small and results in accident condition arrays which are still well subcritical. The results do, however, show that the optimum interspersed water has shifted from 10% with no holders to 7.5% with the holders. This is an expected result since it appears that the optimum amount of total hydrogen does not change, but its distribution between interspersed water and solid plastic changes the quoted value for optimum interspersed water.

**TABLE 5.3**
**Accident Condition Array**
**MODEL WITH CLUSTER SEPARATORS**

| Lattice Enrichment | Gad Configuration | Interspersed Water | Keff | Sigma |
|---|---|---|---|---|
| 4.6 | 10G2.0 (10–2B) | 0.000 | 0.88105 | 0.00180 |
| 4.6 | 10G2.0 (10–2B) | 0.025 | 0.90747 | 0.00191 |
| 4.6 | 10G2.0 (10–2B) | 0.050 | **0.91971** | **0.00173** |
| 4.6 | 10G2.0 (10–2B) | 0.075 | 0.91729 | 0.00183 |
| 4.6 | 10G2.0 (10–2B) | 0.100 | 0.90906 | 0.00204 |
| 4.6 | 10G2.0 (10–2B) | 0.125 | 0.89596 | 0.00194 |
| 4.6 | 10G2.0 (10–2B) | 0.150 | 0.87458 | 0.00184 |
| 3.0 | none | 0.050 | 0.92639 | 0.00186 |
| 3.0 | none | 0.075 | **0.93012** | **0.00192** |
| 3.0 | none | 0.100 | 0.91860 | 0.00186 |
| 3.0 | none | 0.125 | 0.90504 | 0.00219 |
| 3.0 | none | 0.150 | 0.88860 | 0.00188 |

Although the modeled cluster separator results in statistically no change, it is further shown that additional thickness of material does further shift the interspersed water optimum towards zero and very slowly increases $k_{eff}$. Such results are shown in Table 5.4. This table shows the effect of increasing the effective thickness of material at constant interspersed water density. The water density shown in Table 5.4 is 5% of full water density. The results of this analysis indicate a slight statistical increase in $k_{eff}$ as a result of the polyethylene becoming a better reflector as the thickness is increased, but remains subcritical even up to effective thicknesses of 0.150".

**TABLE 5.4**
**SENSITIVITY OF REACTIVITY WITH CLUSTER THICKNESS**
**AT CONSTANT INTERSPERSED WATER DENSITY**

| Lattice Enrichment | Gad Configuration | Holder Thickness (in) | Interspersed Water | Keff | Sigma |
|---|---|---|---|---|---|
| 4.6 | 10G2.0 (10–2B) | 0.000 | 0.050 | 0.88048 | 0.00159 |
| 4.6 | 10G2.0 (10–2B) | 0.066 | 0.050 | 0.90883 | 0.00192 |
| 4.6 | 10G2.0 (10–2B) | 0.133 | 0.050 | 0.91971 | 0.00173 |
| 4.6 | 10G2.0 (10–2B) | 0.150 | 0.050 | 0.92718 | 0.00192 |

The analysis shows that the array of damaged containers is subcritical.

## 5.2 Fully Reflected Single Containers

The model used for the anlaysis previously performed for an individual undamaged container when optimally moderated and fully reflected by water is essentially identical to that which would be used for the analysis including cluster separators. The hydrogen in the polyethylene of the separator holder is essentially accounted for by the hydrogen in solid water used in the single container analysis of Reference 3. Therefore, no additional calculations are required to show that the single container with assemblies using cluster separators is subcritical.

## 5.3 Arrays of Undamaged Containers

An infinite array of undamaged containers is required to be subcritical for the container to meet the requirements of a Fissile Class I package. This is demonstrated for the RA–3 container in the following.

The undamaged (RA–3) container consists of the wooden outer container and the steel inner container separated by packaging/cushioning materials. Infinite arrays of such containers are over–moderated by the wooden outer container and its packaging material. This is the case even for the Minimum Packaging Model (in which half density ethafoam is used). This is shown by the analyses in Reference 3 for the undamaged containers. The results for infinite array of containers, in contact and with no interspersed moderation in the inner container, are repeated in Table 5.5 under the heading "Original Analysis". Results are given for the 4.6% enriched fuel assemblies having ten 2% Gd rods (Gd rod configuration 10–2B) and 3.0% enriched fuel assemblies with no gadolinia, since these are the most reactive assembly configurations in the accident condition. As for the accident array, the new model has a slightly higher neutron multiplication for the cases with no cluster separator in the normal condition case. The over–moderation condition of the array of undamaged containers is also shown by comparison of the $k_\infty$ results given in Table 5.5 for arrays of containers with and without cluster separators around the assemblies. The decrease in $k_\infty$ is expected, since it has previously been shown that the addition of moderator outside the assembly results in a decrease in multiplication for the array of undamaged containers. In this respect, the separator holder is no different than other moderators and a decrease in $k_\infty$ from its inclusion in the container is anticipated just as has been shown previously.

**TABLE 5.5**
**Normal Condition (Infinite) Array**
**Comparison of Original and New Model**

| Lattice Enrichment (%) | Gad Configuration | Inter–spersed Water | $K_\infty$ ($\pm\sigma$) | | |
|---|---|---|---|---|---|
| | | | Original Analysis | New Model No Cluster | New Model With Cluster |
| 4.6 | 10G2.0 (10–2B) | 0.000 | 0.8723 (0.0031) | 0.88289 (.00110) | 0.80088 (.00143) |
| 3.0 | none | 0.000 | 0.8723 (0.0038) | 0.88060 (.00121) | 0.80552 (.00144) |

As shown in Table 5.5, the model for the limiting case with cluster separators results in a $k_\infty + 2\sigma -$ bias of 0.8114, which is well below subcritical.

## 6.0 Conclusion

The criticality safety requirements for classification as a Fissile Class I shipping container have been applied to the RA–3 container with generic BWR 9 x 9 fuel assemblies both with and without cluster separators. These have included requirements for the subcriticality of single undamaged containers, infinite arrays of undamaged containers, and arrays of at least 250 damaged containers. In this analysis it has been shown that all of the applicable requirements are met provided that the fuel assemblies comply with defined generic requirements on enrichment and Gadolinium content provided in Section 6.1.

For an array of damaged containers, it has been shown that when optimally moderated by water, the system of such packages is subcritical with each of the generic 9 x 9 fuel assembly types. These accident arrays were also shown to have higher multiplication factors than any of the undamaged container arrays or the single container and hence for the RA–3 are the limiting cases in the criticality safety analysis. The maximum $k_\infty + 2\sigma -$ bias for any of the accident cases is less than 0.94.

### 6.1 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:

| | | |
|---|---|---|
| Fuel Assembly Type: | 9 X 9 | |
| Number of Water Rods: | | * |
| Number of Fuel Rods: | | * |
| Maximum No. of Partial Rods: | | * |
| Fuel Rod OD: | | * |
| Cladding Type: | Zirconium | |
| Cladding Thickness: | | * |
| Maximum Active Fuel Length: | | * |
| Nominal Fuel Rod Pitch: | | * |
| Maximum U–235 Pellet Enricment: | | * |

In addition, the fuel assemblies must meet the U–235 enrichment and Gd rod requirements specified for generic 9 X 9 lattices. These requirements have not changed as a result of this analysis. These are summarized in Table 6.1.

**TABLE 6.1**
**ENRICHMENT AND Gd ROD REQUIREMENTS FOR GENERIC 9 x 9 FUEL ASSEMBLIES WITH OR WITHOUT CLUSTER SEPARATORS**

| | | | Required Gadolinia Number and Type* | | | | |
|---|---|---|---|---|---|---|---|
| Lattice Type† | Lattice Average Enrichment Range† | Maximum Pellet Enrichment (%) | No. of Gd Rods | Minimum Gadolinia Concentration in each Gd Rod | Minimum No. in Each Quadrant | Min. No. of Gd Rods in Outermost 2 Rings of Rod Positions | |
| A.1 | | | | | | | * |
| A.2 | | | | | | | * |
| B | | | | | | | * |
| C Group I | | | | | | | * |
| C Group II | | | | | | | * |
| C Group III | | | | | | | * |

† See Section 1.3

* Required Gd Rods Must be Distributed Symmetrically About the Major Diagonal

## 7.0 References

1. Title 10, Code of Federal Regulations, Part 71, United States of America.
2. "GEMER.4 User's Manual", GE Nuclear Energy, November 1989.
3. "Criticality Safety Analysis for the RA–3 Shipping Container with Generic 9 x 9 Fuel Assemblies", April 16, 1992. (Also included as Attachment 3 of Reference 4).
4. Submittal, TP Winslow to CE MacDonald, 4/16/92.